The Hidden Toll of Airborne Lead: Infant Mortality Impacts of Industrial Lead Pollution

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Motivation

- Air emissions of lead continue to impact millions in the US and globally
  - Evidence suggests that industrial emissions remain high globally
  - UNICEF report: 1 in 3 children worldwide have blood lead levels above 5 μg/DL

Motivation

- While the literature on lead and health is large, we know surprisingly little about air lead and infant mortality
  - No studies that show a causal relationship between air lead and infant mortality
  - Key challenges: avoidance behavior and measurement error (timing of exposure)

This Paper

- This paper provides IV estimates of the effects of air lead concentration on infant mortality in the United States over the period 1988-2018
  - Start year dictated by the creation of the Toxic Release Inventory (TRI)
  - By 1988, nearly all of the decline in lead in gasoline has occurred

Data

- We draw on data from
  - TRI on plant level emissions of lead and other chemicals
    - Stack (predictable) and
    - Fugitive (unintended and intermittent)
  - Infant mortality, birth outcomes, and maternal characteristics, wind, weather, socioeconomic
  - Child blood lead levels (NHANES)

Background - TRI

- Fugitive emissions: “all releases that are *NOT* released through confined vents, ducts, pipes, or other confined air stream.” Examples:
    - emissions from handling and processing operations, furnaces, hot metal transfer and processing, and casting leaks from operating machinery
    - air emissions as the result of spills
    - emissions from the handling of ash

Data

- IV sample 127 counties
  - In 1990, 26% of the US population lived in these counties
  - The sample accounts for 21% of lead emissions

Figure A.4: Geographic Distribution of Counties in the IV Sample

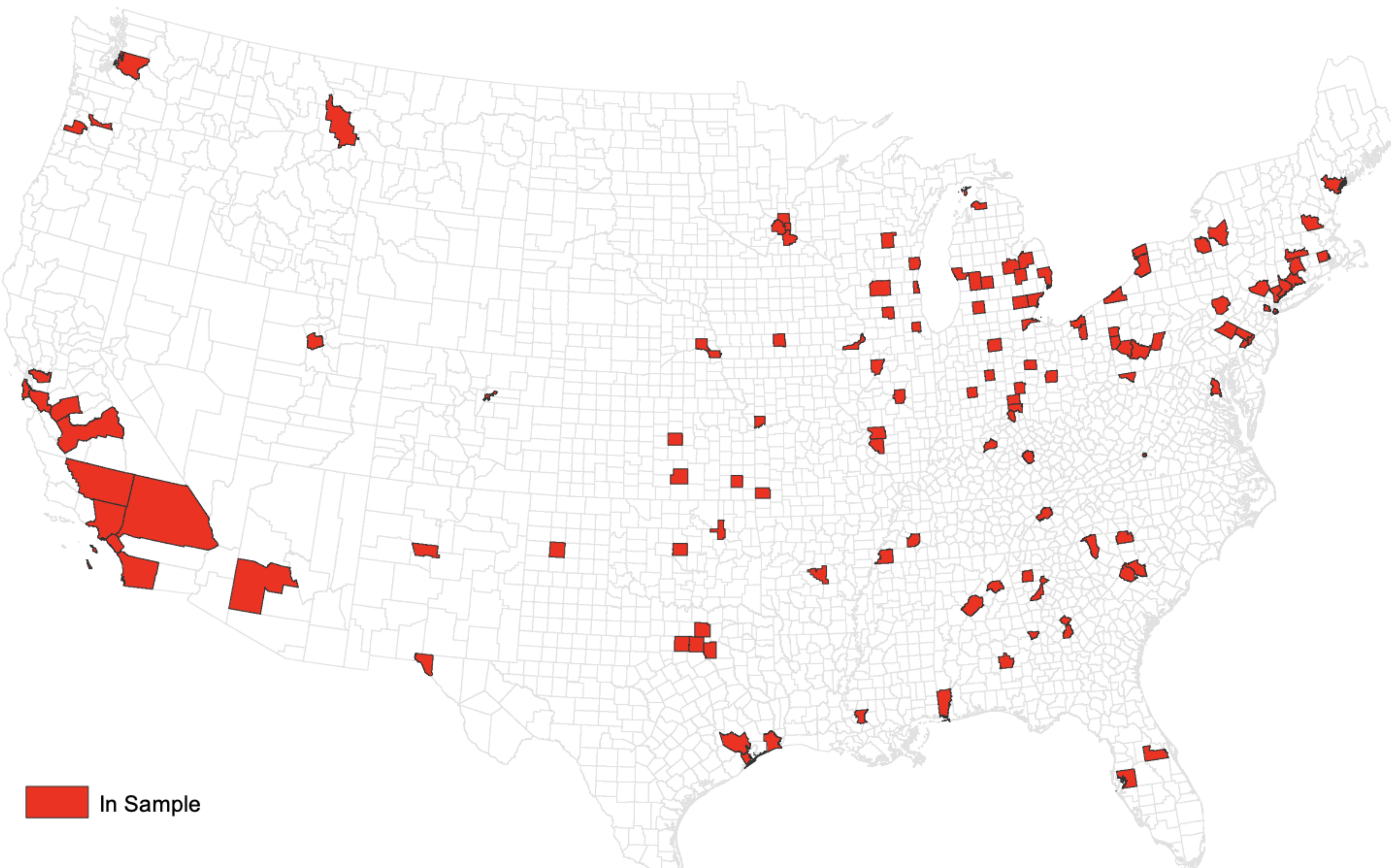
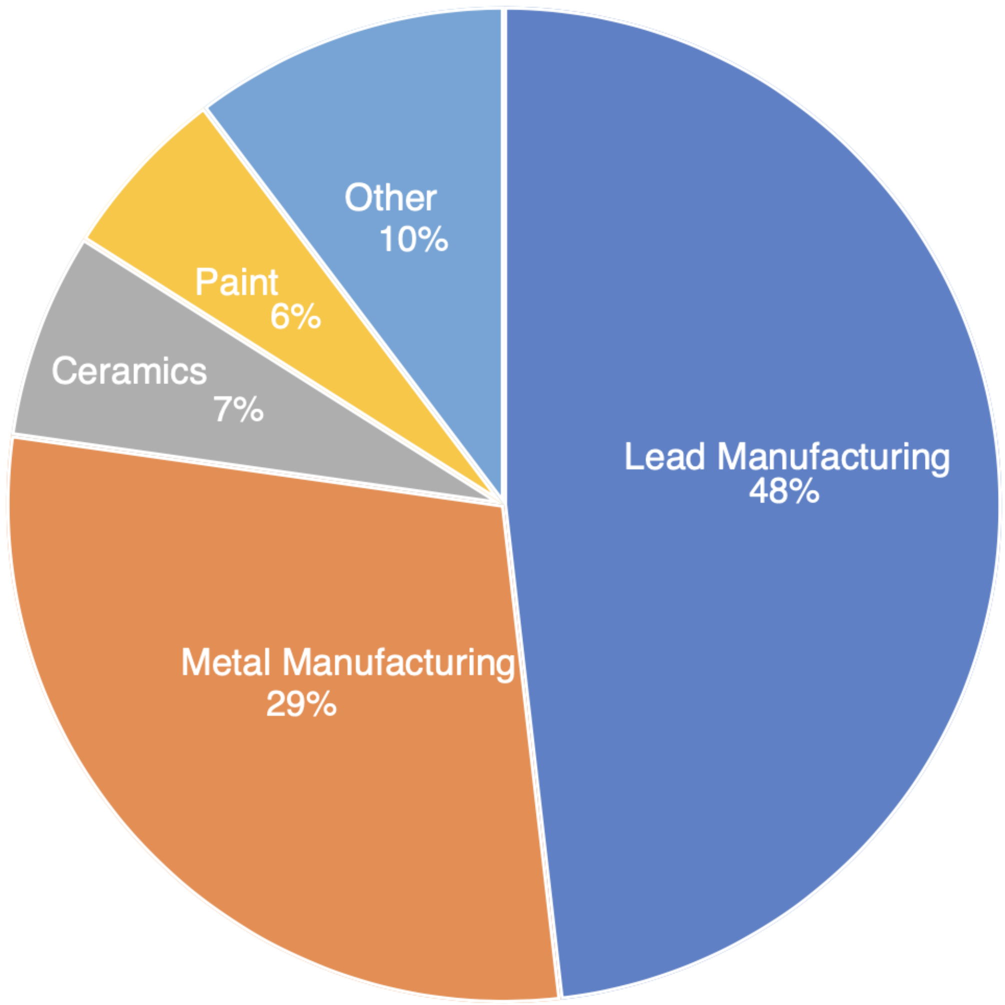
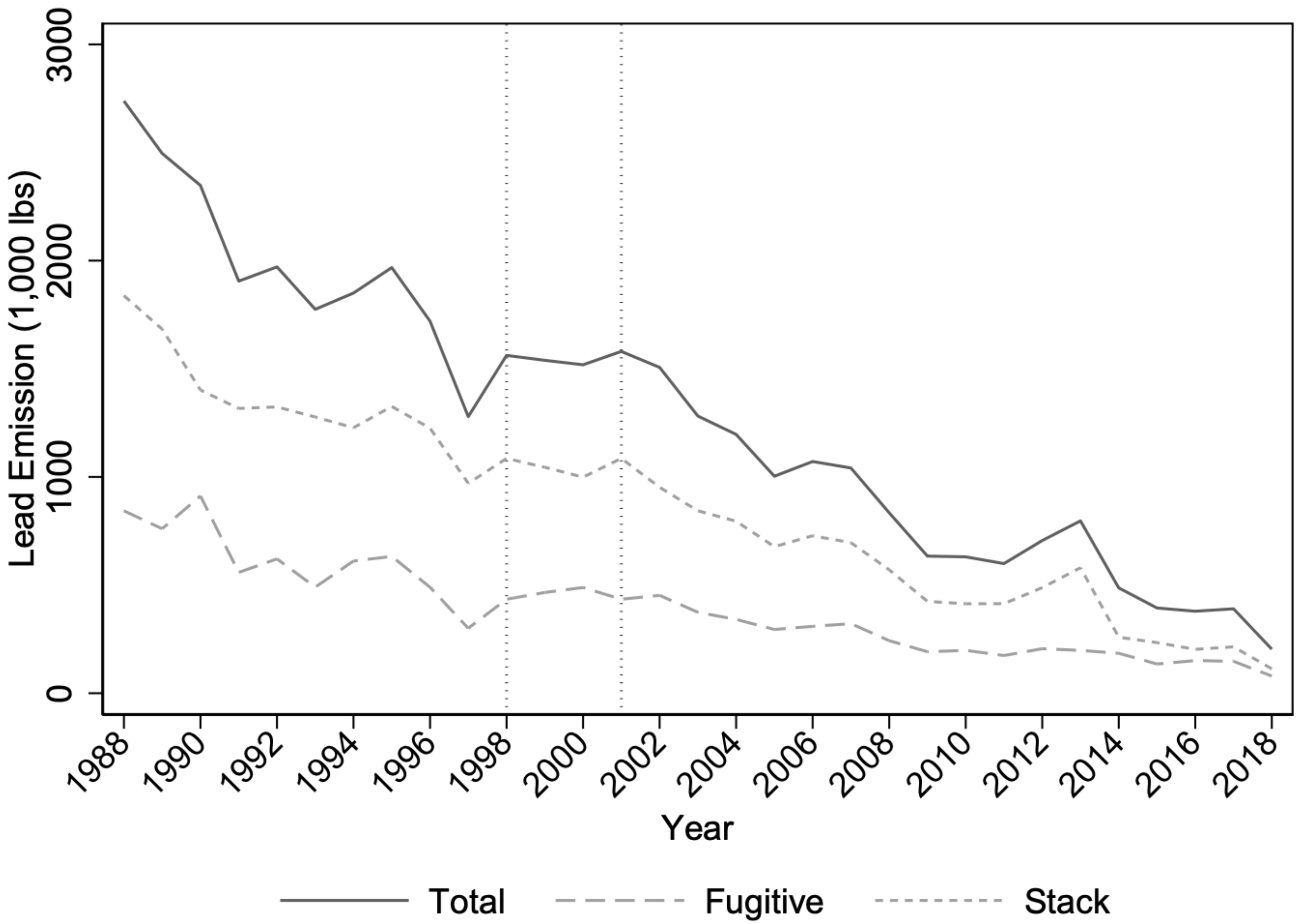


Figure A.1: Industry Distribution of Air Lead Emissions of Facilities



Notes: This pie-chart shows the industry distribution of airborne lead emissions (sum over time) by the sampling industrial facilities. The emissions include both fugitive and stack lead emissions. Calculates are weighted by the number of births in a county.

Figure 1: Trends in Fugitive and Stack Emissions



Notes: This figure shows the trend of fugitive, stack, and total air lead emissions reported by TRI plants during 1988 to 2018. The vertical lines mark year 1998 when seven additional industries were added to TRI and year 2001 when the threshold for lead reporting was significantly lowered. Appendix Figure A.3 shows the number of reporting plants and changes that their inclusion have on reported totals. Appendix Figure A.2 shows trends in airborne, waterborne, landborne, and recycled lead.

Table 1: Child Blood Lead Level and Industrial Lead Emission

	Pct Elevated BLL			
	(1)	(2)	(3)	(4)
Air Fugitive Lead	0.763**	0.837*	0.898*	0.805**
	(0.363)	(0.485)	(0.521)	(0.399)
Air Stack Lead	0.057	0.049	0.049	0.048
	(0.062)	(0.044)	(0.047)	(0.050)
Adjusted R^2	0.989	0.989	0.989	0.991
Dep Var Mean	6.572			
Fug Mean[S.D.]	0.520[1.094]			
CountyYear	365	365	365	365
Counties	57	57	57	57
County,Region-Year FE	Y	Y	Y	Y
Other Chem	Y	Y	Y	Y
Base IMR		Y	Y	Y
Socioeconomic,Mother		Y	Y	Y
Climate Var			Y	Y
Water,Land Lead				Y

Empirical Strategy

- Instrumental Variables
  - Instrument EPA air lead concentration with TRI fugitive lead emissions interacted with wind speed near the plants
    - Fugitive lead emissions are unintended and intermittent
    - Wind speed variation is plausibly exogenous
  - Rich set of controls
    - Including stack lead and other TRI chemicals interacted with wind speed

First Stage

$$AirLead_{ct} = \delta^F F_{ct} + Wind_{ct}\delta_w + (Wind_{ct} \times F_{ct})\delta_w^F$$
$$+ \delta^S S_{ct} + (Wind_{ct} \times S_{ct})\delta_w^S + Chem_{ct}\delta_c + (Wind_{ct} \times Chem_{ct})\delta_{wc}$$
$$+ \eta_c + \lambda_{rt} + Media_{ct}\psi + Z_{ct}\pi + \omega_{ct} \qquad (1)$$

where $AirLead_{ct}$ is air lead concentration in county c in year t, measured as the average across all monitors within two miles from any industrial plants with air lead emissions.[15], [16] The key explanatory variables are F_{ct}, denoting the aggregated fugitive lead emissions from plants in county c in year t, and its interaction with $Wind_{ct}$, a fourth order polynomial for wind speed.[17] We control for the stack lead emissions (S_{ct}), fugitive and stack emissions of other TRI-reported chemicals ($Chem_{ct}$), and their interactions with wind [18]. The regression includes county fixed effects (η_c) and region-by-year fixed effects (λ_{rt}) to control for time-invariant determinants of and region-specific trends in infant mortality over time. We also control for waterborne and landborne lead emissions ($Media_{ct}$).[19]

Figure A.7: Plume Patterns

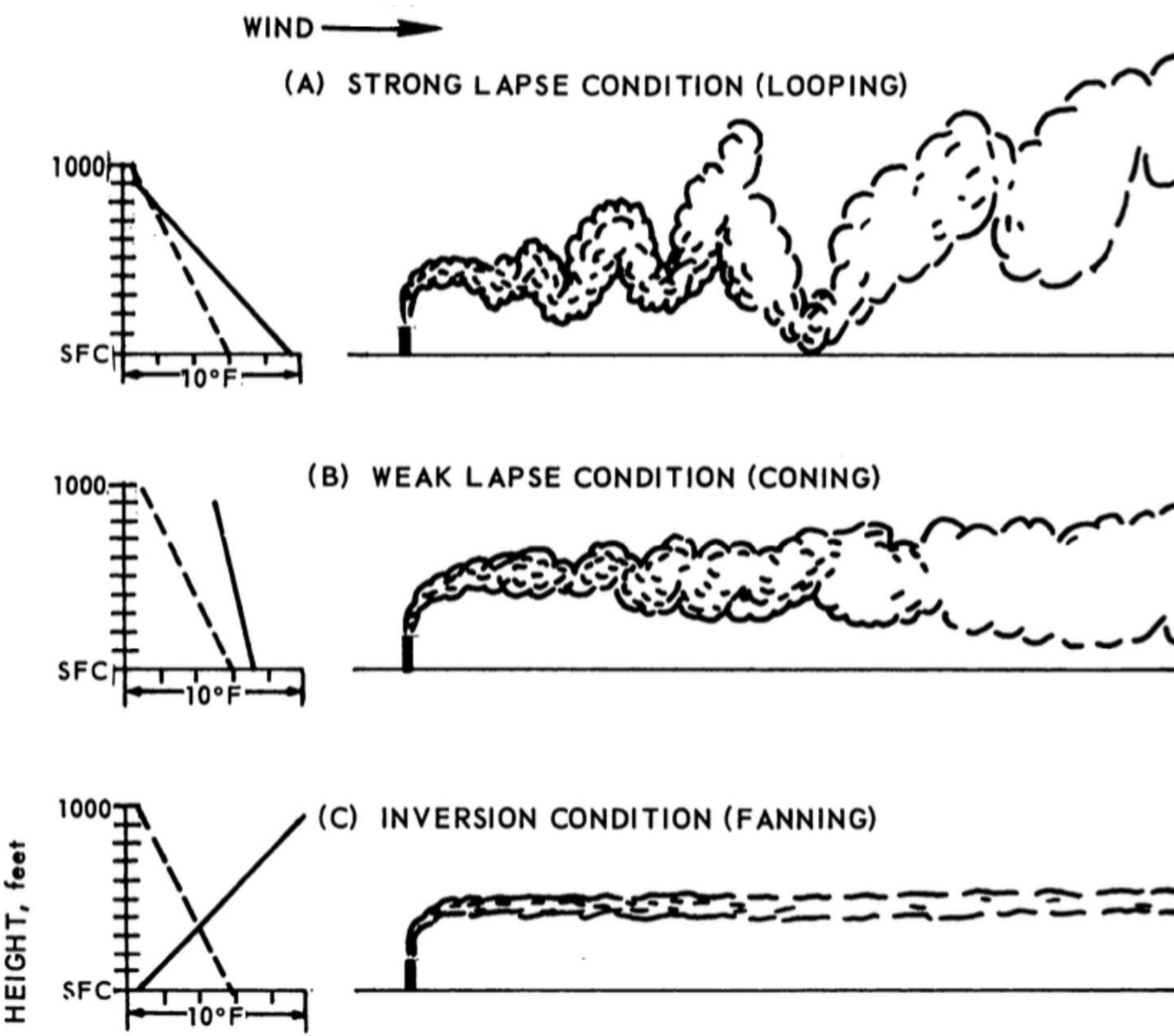
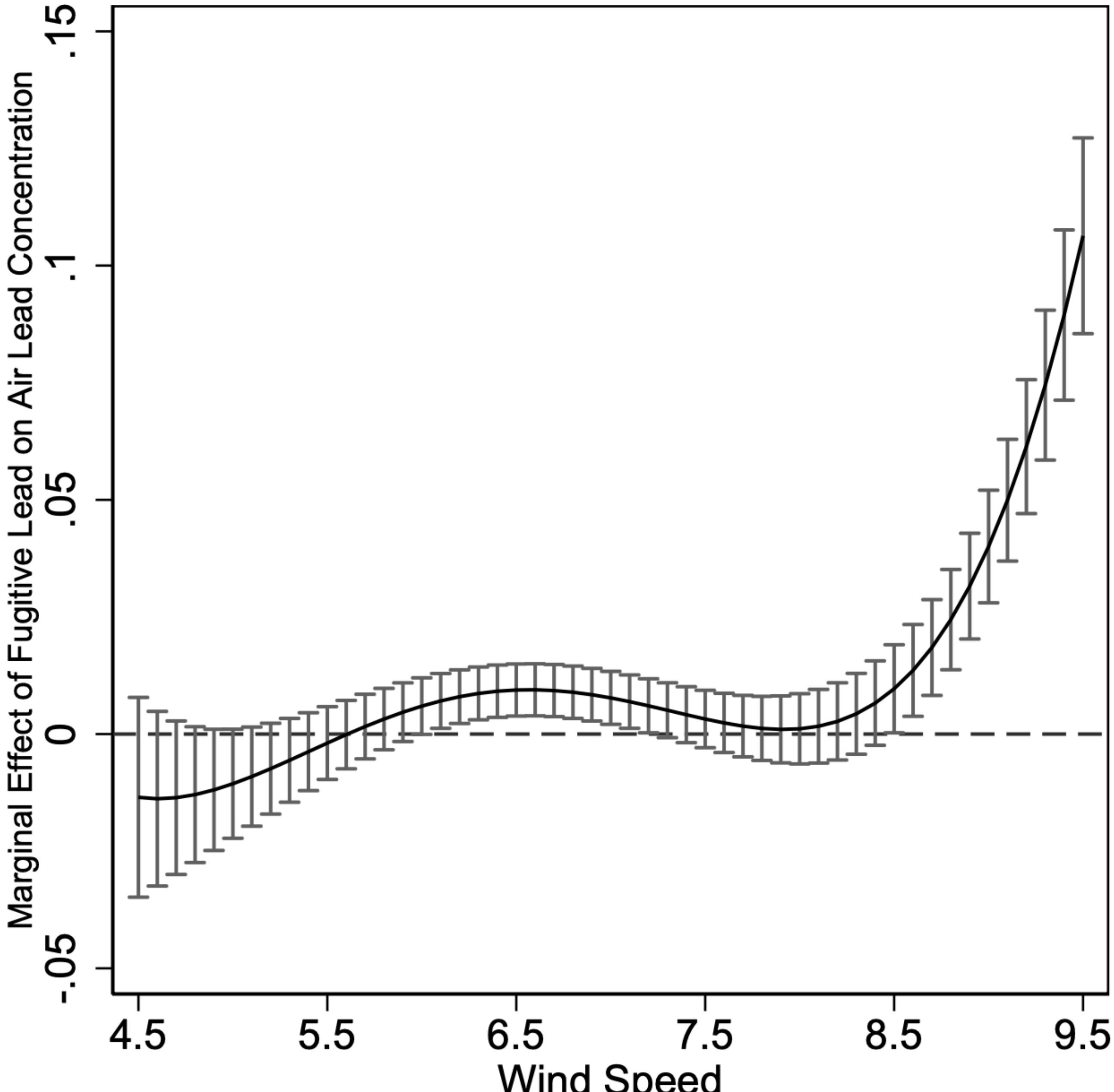


Figure 2: Air Fugitive Lead and Air Lead Concentration with Controls



Main Results

- Two main findings
  - Higher air lead concentration causes higher infant mortality in the first month and in the first year
    - Point estimates by race suggest larger effects on nonwhite infants, but might be proportional due to higher IMR for nonwhites

Table 3: IV Estimates of Air Lead Concentration and Infant Mortality

	(1) IMR	(2) IMR	(3) IMR	(4) IMR	(5) IMR
Air Lead Concentration	1.998***	1.753***	1.717***	1.685***	1.676***
	(0.429)	(0.453)	(0.447)	(0.395)	(0.435)
KPFstat	41.983	40.252	38.029	45.036	41.232
DepMean	7.718	7.718	7.718	7.718	7.718
County-Year	1553	1553	1553	1553	1553
Counties	127	127	127	127	127
County,Region-by-Year FE	Y	Y	Y	Y	Y
Base IMR		Y	Y	Y	Y
Socioeconomic,Mother		Y	Y	Y	Y
Climate Var			Y	Y	Y
Water,Land Lead				Y	Y
Other Chem					Y

- Decline in fugitive emissions reduce infant deaths by 59 deaths/year (241 if we consider all airborne lead reductions)
- Using VSL, $667 million/year ($2.7 billion)

Table 4: IV Estimates By Age at Death and Timing of Birth

	(1) IMR 1m	(2) IMR 1y	(3) IMR AD1m	(4) IMR AD1y	(5) IMR JD1m	(6) IMR JD1y
Air Lead Concentration	0.728**	1.676***	1.155***	2.128***	1.143***	2.660***
	(0.323)	(0.435)	(0.336)	(0.430)	(0.387)	(0.530)
KPFstat	41.232	41.232	40.884	40.884	40.337	40.337
DepMean	5.104	7.718	5.09	7.565	4.988	7.453
County-Year	1553	1553	1553	1553	1553	1553
Counties	127	127	127	127	127	127
All Controls	Y	Y	Y	Y	Y	Y

Table 7: IV Estimates By Race of Mother

	(1) IMR1yrnwh	(2) IMR1yrwh	(3) IMR1mnwh	(4) IMR1mwh
Air Lead Concentration	3.068**	1.415***	1.977**	0.478*
	(1.212)	(0.361)	(0.998)	(0.256)
KPFstat	39.646	41.711	39.646	41.711
DepMean	11.778	6.067	8.346	4.044
CountyYear	1552	1552	1552	1552
Counties	127	127	127	127
AllControls	Y	Y	Y	Y

Main Results

- Two main findings
  - Higher air lead concentration increases deaths from
    - low birthweight
    - sudden unexplained infant death (SUID)
    - respiratory and nervous system causes

Table 5: IV Estimates By Cause

	(1) LowBw	(2) SUID	(3) Resp.	(4) Nerv.	(5) Cong.	(6) Peri.	(7) Others
Panel A. IMR in the first year							
Air Lead	0.349**	0.407*	0.419***	0.121**	0.110	-0.238	0.544***
	(0.163)	(0.208)	(0.149)	(0.051)	(0.144)	(0.281)	(0.120)
Dep Mean	1.172	1.113	0.890	0.112	1.541	1.880	0.834
Panel B. IMR in the first month							
Air Lead	0.363**	0.020	0.242**	0.059**	0.080	-0.225	0.262***
	(0.162)	(0.034)	(0.117)	(0.023)	(0.136)	(0.295)	(0.065)
Dep Mean	1.152	0.109	0.624	0.017	1.098	1.782	0.366
KP F-Stat	41.069	41.069	41.069	41.069	41.069	41.069	41.069
County-Year	1548	1548	1548	1548	1548	1548	1548
Counties	126	126	126	126	126	126	126
All Controls	Y	Y	Y	Y	Y	Y	Y

Mechanisms

- SUID (Sudden Unexpected Infant Death)
  - Speculation on lead and SIDs
    - Erickson et al (1983), Lyngbye et al (1985)
  - Neuroinflammation, sleep disruption in rats
    - Chibowska 2020, Hsu et al 2021
- Nervous system
  - Neuroinflammation, sleep disruption in rats
    - Chibowska 2020, Hsu et al 2021

Contributions: (1) Lead and Infant Health

- Previous studies have focused on:
  - Air/water lead effects on intensive margin outcomes (e.g., birth weight, prematurity) (Bui et al., 2022; Dave & Yang, 2022; Tanaka et al., 2022; Wang et al., 2022).
  - Historical (1900-1920) water lead exposure and infant mortality (Troesken, 2008; Clay et al., 2014).
- This paper: first causal estimates of airborne lead's effects on infant mortality in a modern setting with contemporary medical care and exposure levels.

Contributions: (2) Lead Effects – Mechanisms

- Underexplored topic in economics
  - Medical and animal studies suggest:
    - Sudden unexplained infant death (SUID) (Erickson et al., 1983; Lyngbye et al., 1985; Kato et al., 2003; Liu et al., 2015; Jansen et al., 2019; Chibowska et al., 2020; Hsu et al., 2021)
    - Lead weakens immune system, potentially increasing vulnerability to respiratory mortality (Thind & Yusuf Khan, 1978; Dyatlov & Lawrence, 2002; Metryka et al., 2018)
- This paper: first causal evidence linking lead exposure to specific causes of infant death
  - SUID, respiratory/nervous system, low birthweight

Concluding Remarks

- These new estimates can inform investments in reductions in air lead emissions
  - In the U.S., industrial firms and the aviation industry still emit hundreds of thousands of pounds of lead into the air
  - In other countries air lead emissions appear to be significant
    - e.g., China and Mexico
    - UNICEF report: 1 in 3 children worldwide had blood lead levels above 5 µg/DL

Thank You!

- Questions? Comments?
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