Air pollution and COVID-19 mortality in the United States: strengths and limitations of an ecological regression design

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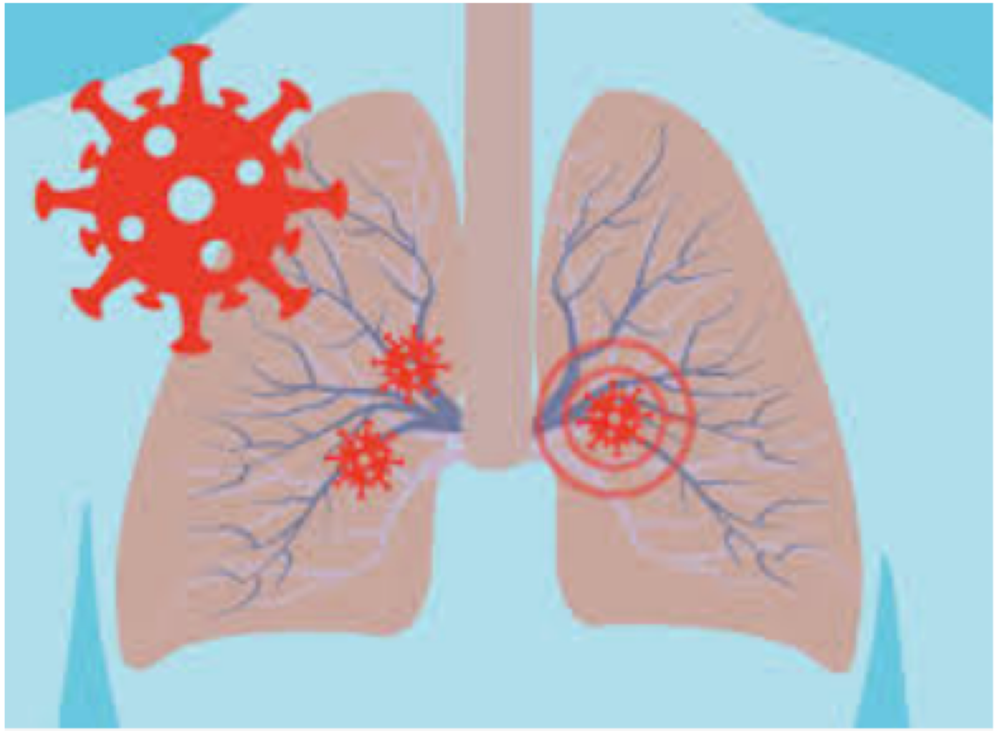
Background

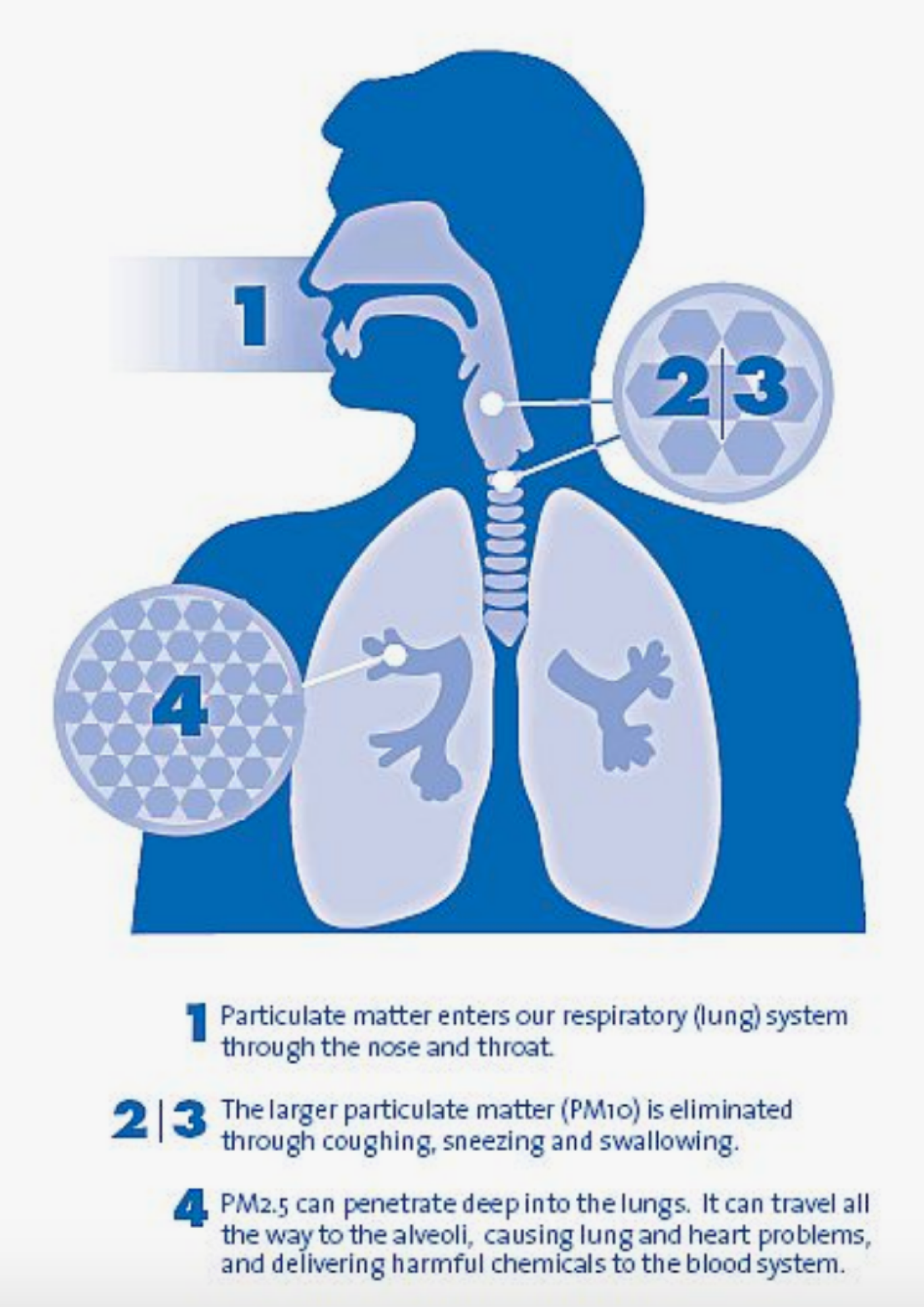
- COVID-19 is an unmatched public health emergency
- Important to identify key environmental factors (such as air pollution) that may contribute to the severity of health among individuals with COVID-19
  - Guide policies and behaviors to minimize fatality related to the pandemic.
  - Provide a strong scientific argument towards the revision of the US national $PM_{2.5}$ standards amid a pandemic.
- Caveat: We are not presenting conclusive studies yet but hope to stimulate discussions in this rapidly evolving area of research.

Health Effects of COVID-19

- COVID-19 can cause viral pneumonia and acute respiratory distress syndrome (ARDS) which has a mortality rate of 27% to 45%.
- COVID-19 can cause severe inflammation to the heart and circulatory system
- Majority of deaths in individuals 65+.
- Certain comorbidities lead to an increase in mortality (especially hypertension, diabetes, cardiovascular disease, cerebrovascular disease).



1. Wang D, Hu B, Hu C, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. JAMA 2020.
2. Xu Z, Shi L, Wang Y, et al. Pathological findings of COVID-19 associated with acute respiratory distress syndrome. Lancet Respir Med 2020;8(4):420-22.
3. Shi S, Qin M, Shen B, et al. Association of cardiac injury with mortality in hospitalized patients with COVID-19 in Wuhan, China. JAMA Cardiol 2020.



Health Effects of long-term exposure to $PM_{2.5}$

- Numerous scientific studies have linked PM2.5 to a variety of adverse health events including mortality
- Strong evidence of an association between long term exposure to $PM_{2.5}$ and heart and lung disease, brain diseases, irregular heartbeats, aggravated asthma, decreased lung function

1. Brook RD, Franklin B, Cascio W, et al. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circulation 2004;109(21):2655-71.
2. Ciencewicki J, Jaspers I. Air pollution and respiratory viral infection. Inhal Toxicol 2007;19(14):1135-46.
3. Dominici F, Peng RD, Bell ML, et al. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. JAMA 2006;295(10):1127-34.
4. Puett RC, Hart JE, Yanosky JD, et al. Chronic fine and coarse particulate exposure, mortality, and coronary heart disease in the Nurses' Health Study. Environ Health Perspect 2009;117(11):1697-701.

Previous Epidemiological Evidence

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Evaluating the impact of long-term exposure to fine particulate matter on mortality among the elderly

X. Wu[1,*], D. Braun[1,2,*], J. Schwartz[3], M. A. Kioumourtzoglou[4] and F. Dominici[1,†]

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- Leveraging 16 years of data—68.5 million Medicare enrollees—we provide strong evidence of the causal link between long-term PM2.5 exposure and mortality.
- Lowering the air quality standard to 10 micrograms per cubic meter would save 143,257 lives (95% confidence interval, 115,581 to 170,645) in one decade.

ENVIRONMENT

Strongest Evidence Yet Shows Air Pollution Kills

The finding comes as the Trump administration has been rolling back clean air regulations

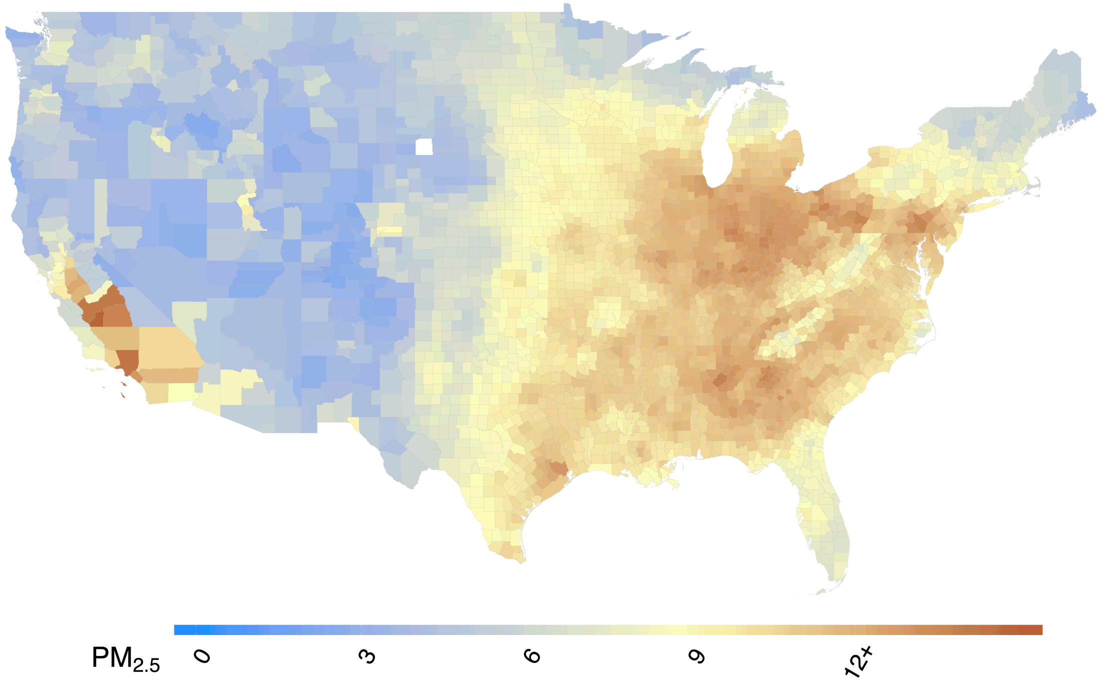
By Susan Cosier on July 29, 2020

1. Wu, X., Braun, D., Schwartz, J., Kioumourtzoglou, M.A. and Dominici, F., 2020. Evaluating the impact of long-term exposure to fine particulate matter on mortality among the elderly. Science Advances, 6(29), p.eaba5692.

Why investigate effects of $PM_{2.5}$ on COVID-19 deaths?

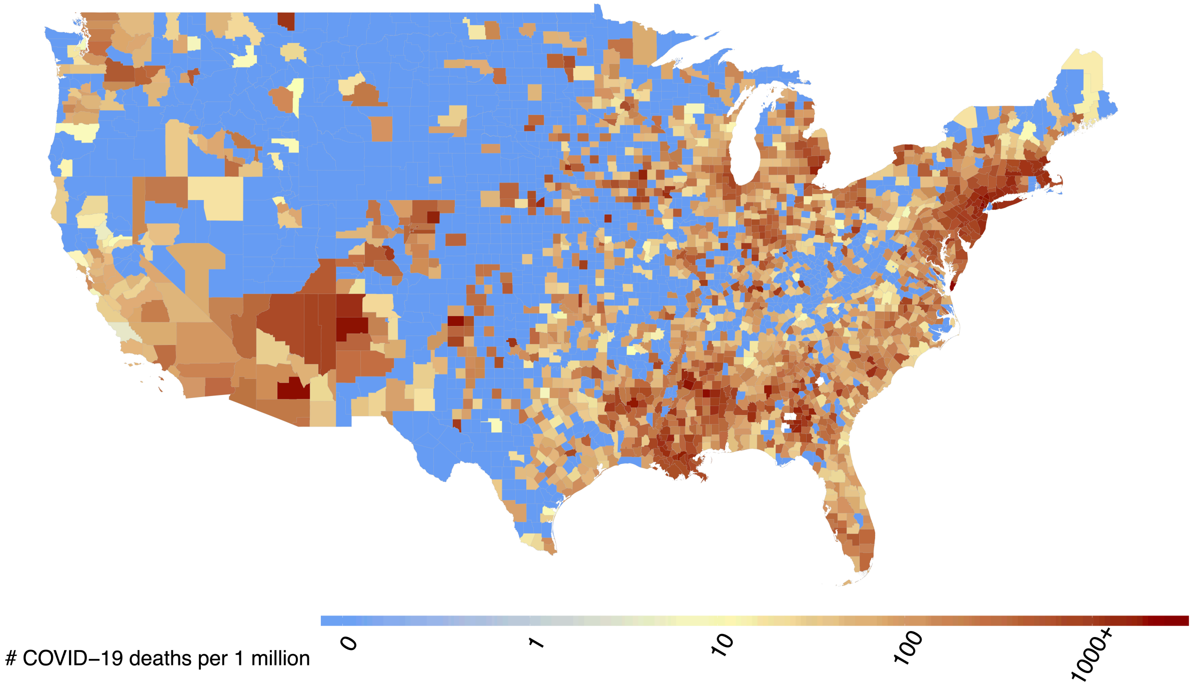
- Although the epidemiology of COVID-19 is evolving, we have determined that there is a large overlap between causes of death of COVID-19 patients and the diseases that are affected by long-term exposure to fine particulate matter ($PM_{2.5}$)
- We hypothesize that because long-term exposure to $PM_{2.5}$ adversely affects the respiratory and cardiovascular system; it can also exacerbate the severity of the COVID-19 infection symptoms and may increase the risk of death in COVID-19 patients
- We conduct one of the first preliminary investigations of this question in the US

Historical exposure to $PM_{2.5}$ and COVID 19 death rates in 3000+ US counties



County-level 17-year long-term average of $PM_{2.5}$ concentrations (2000–2016) in the US

County-level number of COVID-19 deaths per 1 million population in the US up to and including June 18, 2020.

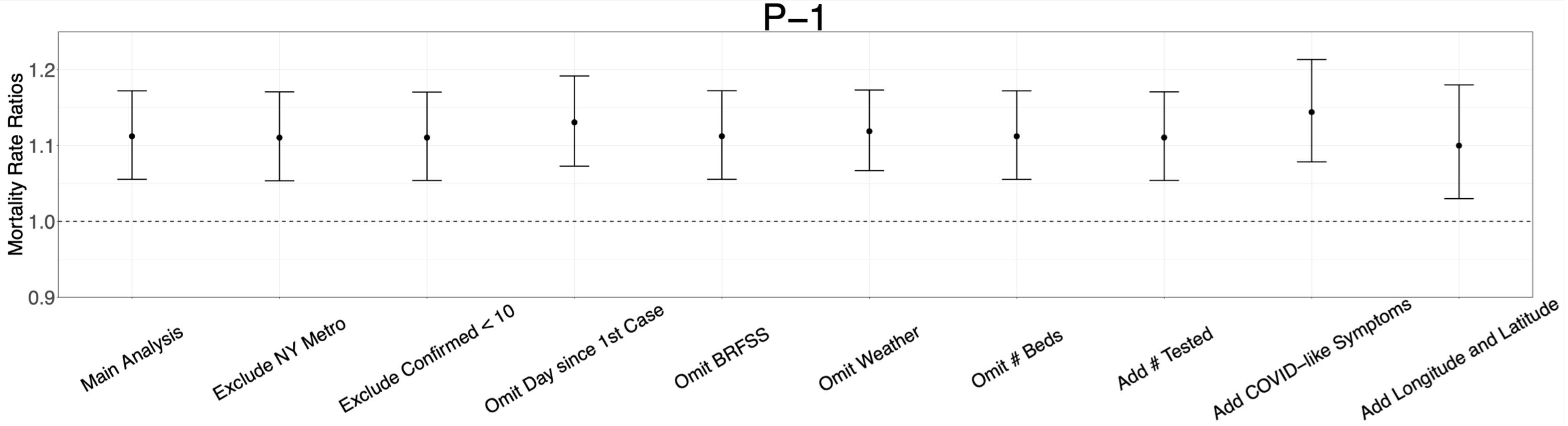


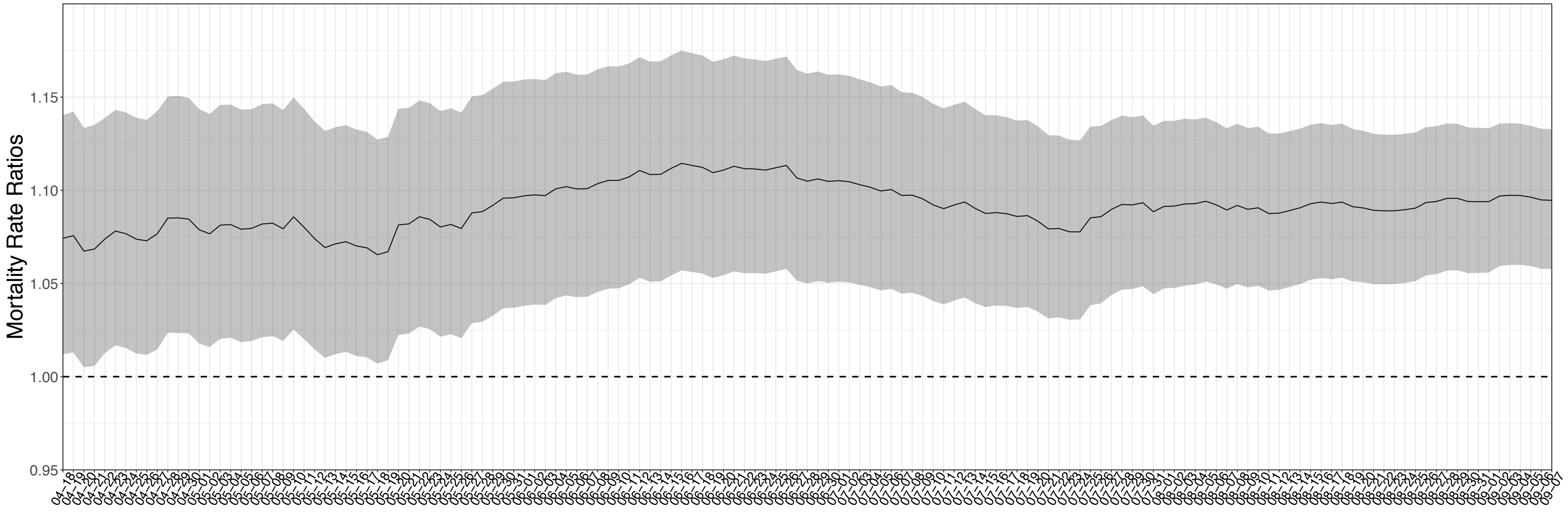
Account for systematic differences between counties

	Data	Source
Outcome	COVID-19 Deaths and Cases	Johns Hopkins University CSSE Coronavirus Resource Center
Exposure	Long-Term Average $PM_{2.5}$ Concentrations (2000-2016)	Atmospheric Composition Analysis Group, Dalhousie University
Potential Confounders	# of Hospital Beds	Homeland Infrastructure Foundation
	Population, Population Density, Age Demographics, Racial Demographics, Education, Income, Wealth, Poverty, and Home Ownership	US Census + American Community Survey
	Current Smoker Population, Obesity Population	Robert Wood Johnson Foundation
	Temperature, Relative Humidity	GRIDMET via Google Earth Engine
	Time of issuances of public policy interventions Time since first reported COVID-19 case	COVID-19 United States state policy database
	COVID-like symptoms map, mobility measures	Facebook Data for Good
	Longitude and Latitude of each county	Johns Hopkins University CSSE Coronavirus Resource Center

On June 18th, we found that an increase of 1 μg/m^3 in $PM_{2.5}$ is associated with an 11% increase in the county-level COVID-19 mortality rate (95% confidence interval [CI]: 6%, 17%). The association is very consistent throughout the time period.

Sensitivity Analyses on June 18th





We also found a 49% (38%, 61%) increase in COVID- 19 mortality rate associated with a 1-standard deviation (per 14.1%) increase in percent Black residents of the county.

Table 1: Mortality rate ratios (MRR), 95% confidence intervals (CI), and P-values
variables in the main analysis. Details of the statistical models are available in Secti

	MRR	95% CI	P-value
$PM_{2.5}$	1.11	(1.06, 1.17)	0.00
Population density (Q2)	0.91	(0.71, 1.15)	0.42
Population density (Q3)	0.91	(0.71, 1.16)	0.45
Population density (Q4)	0.74	(0.57, 0.95)	0.02
Population density (Q5)	0.92	(0.69, 1.23)	0.56
% In poverty	1.04	(0.96, 1.12)	0.31
log(Median house value)	1.13	(0.99, 1.29)	0.07
log(Median household income)	1.19	(1.04, 1.35)	0.01
% Owner-occupied housing	1.12	(1.04, 1.20)	0.00
% Less than high school education	1.20	(1.10, 1.32)	0.00
% Black	1.49	(1.38, 1.61)	0.00
% Hispanic	1.06	(0.97, 1.16)	0.23
% 65 years of age	1.04	(0.93, 1.17)	0.46
% 45-64 years of age	0.77	(0.67, 0.90)	0.00
% 15-44 years of age	0.76	(0.68, 0.85)	0.00

Strength and Limitations: Ecological Regression

Strengths

- Feasible, timely, and cost-effective
- Data are representative of the entire US population
- Allows inference at the area-level, which can be useful for policy making
- Computationally efficient and can be conducted daily to allow for the dynamic nature of the data and observe temporal trends
- Facilitates comparison of results across countries

Limitations

- Cannot be used to make inference about individual-level associations, doing so leads to ecological fallacy[1]
- Cannot adjust for individual risk factors such as age, gender, and race
- Results are sensitive to the assumptions of the statistical model

1. The correlation of aggregate quantities (or ecological correlation) is not equal to the correlation of individual quantities.

Other Challenges

Outcome

- Potential outcome misclassification, particularly differential misclassification over time and space, which could bias results

Exposures

- Aggregation assumes that everyone in a county experiences the same exposures, leading to exposure misclassification, especially for the largest counties
- Can be used to assess historical exposures to air pollution but not real-time exposures

Confounders

- County average features may not represent the features of COVID-19 patients, leading to inadequate adjustment
- Difficult to formalize the notion of “epidemic stage,” which may be an important confounder
- The threat of unmeasured confounding bias still present
- Sensitive to the form of the statistical model specified (i.e., assumptions of linearity and no effect modification)

Future Research

- Augment county-level data with individual-level data to correct for ecological bias
- Conduct individual-level studies on air pollution and important fatal COVID-19 outcome (e.g., ARDS) using traditional regression and causal inference methods
- Conduct studies on short-term air pollution and COVID-19 and important fatal comorbidities, e.g., Whether wildfire smoke may increase the risk of COVID-19
- Mount an emergency response team to gather quality COVID-19 data. Access to representative, individual-level data on COVID-19 health outcomes will require consideration of many privacy, legal, and ethical trade-offs

Public Health Implications

- Prioritize counties that historically are more polluted
- Stress importance of continued regulation of $PM_{2.5}$ and air pollution
- People of color and poor people disproportionally affected by air pollution, further exacerbating health disparities

Exposure to air pollution and COVID-19 mortality in the United States
X Wu, RC Nethery, BM Sabath, D Braun, F Dominici
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Covid-19 death rate rises in counties with high air pollution, study says

By Sandee LaMotte, CNN
Updated 7:36 PM ET, Tue April 7, 2020

New Research Links Air Pollution to Higher Coronavirus Death Rates

HARVARD UNIVERSITY HARVARD.EDU

COVID-19 PM2.5

A national study on long-term exposure to air pollution and COVID-19 mortality in the United States

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All code and data used are publicly available on GitHub:
https://github.com/wxwx1993/PM_COVID
Our website: https://projects.iq.harvard.edu/covid-pm