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

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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).

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

- Numerous scientific studies have linked PM$_{2.5}$ 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

Previous Epidemiological Evidence

- 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.

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

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
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<tbody>
<tr>
<td>COVID-19 Deaths and Cases</td>
<td>Johns Hopkins University CSSE Coronavirus Resource Center</td>
</tr>
<tr>
<td>Long-Term Average PM$_{2.5}$ Concentrations (2000-2016)</td>
<td>Atmospheric Composition Analysis Group, Dalhousie University</td>
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<td># of Hospital Beds</td>
<td>Homeland Infrastructure Foundation</td>
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<td>Temperature, Relative Humidity</td>
<td>GRIDMET via Google Earth Engine</td>
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<td>Time of issuances of public policy interventions</td>
<td>COVID-19 United States state policy database</td>
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<td>Time since first reported COVID-19 case</td>
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<td>COVID-like symptoms map, mobility measures</td>
<td>Facebook Data for Good</td>
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<tr>
<td>Longitude and Latitude of each county</td>
<td>Johns Hopkins University CSSE Coronavirus Resource Center</td>
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</tbody>
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Outcome

Exposure

Potential Confounders
On June 18\textsuperscript{th}, we found that an increase of 1 \( \mu g/m^3 \) 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.
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 for 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. The correlation of aggregate quantities (or ecological correlation) is not equal to the correlation of individual quantities.

- Cannot adjust for individual risk factors such as age, gender, and race
- Results are sensitive to the assumptions of the statistical model
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 disproportionately affected by air pollution, further exacerbating health disparities