County-level Food Insecurity and COVID-19 Mortality in the United States: A Spatial Analysis with R-INLA

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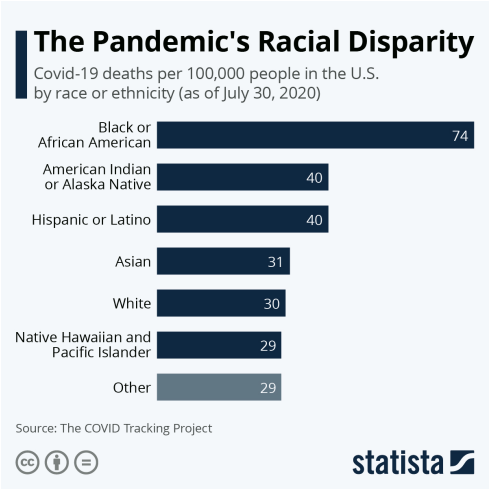

Disparities in COVID-19 mortality during the early pandemic[1]

[1] N. McCarthy. "The Pandemic's Racial Disparity". In: *Statista* (2020).

Defining Food Insecurity

According to the United States Dept. of Agriculture (USDA) **food insecurity** (FI) is defined as: *a lack of consistent to enough food for every person in a household to live an active, healthy life.*

FI in the United States

- 13.8 million FI households across the U.S. (10.5%) in 2020[2]
  - Low-income[3] households: 31.2% prevalence in 2021[4]
- Racism and housing inequality
  - Housing/redlining and supermarket redlining[5]
- Government welfare programs mitigate FI[6]
  - The Supplemental Nutrition Assistance Program (SNAP)
  - Women, Infants, and Children (WIC)
  - The National School Lunch Program

[2] A. Coleman-Jensen. *U.S. Department of Agriculture, Economic Research Service* (2020).

[3] Household income below 130% of the poverty line

[4] A. Coleman-Jensen et al., eds. AP-105. 2022. DOI: 10.22004/ag.econ.329071.

[5] Y. Shaker et al. *Agriculture and Human Values* (2022). DOI: 10.1007/s10460-022-10340-3.

[6] C. A. Swann. *Food Policy* (2017). DOI: 10.1016/j.foodpol.2017.08.006.

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FI and Health Outcomes

- FI is associated with deleterious health outcomes[7,8]
  - Hypertension
  - Hyperlipidemia
  - Depression and suicidal ideation
  - Diabetes mellitus
  - Iron deficiency anemia
- Posited mechanisms
  - Cortisol
  - Diet quality, inflammation
  - Competing demands and trade-offs

[7] C. Gundersen and J. P. Ziliak. *Health Affairs* (2015). DOI: 10.1377/hlthaff.2015.0645.

[8] H. K. Seligman and D. Schillinger. *New England Journal of Medicine* (2010). DOI: 10.1056/NEJMp1000072.

Research Question: *Is county-level food insecurity associated with COVID-19 mortality during the first 1.5 years of the COVID-19 pandemic?*

Hypothesis: We hypothesize that county-level food insecurity, given its association with other health outcomes, will adversely predict county-level COVID-19 deaths.

Analysis Plan

- Variables
  - *Dependent variable*: **County-level COVID-19 death count**
    - *Source #1*: John Hopkins University Coronavirus Resource Center (age-standardized via *indirect standardization*)
    - *Source #2*: Provisional CDC restricted access case-level data (age-standardized via *direct standardization*)
    - *Time window*: 03/25/2020-12/25/2021
  - *Independent variable*: **County-level food insecurity prevalence (%) (2020)** (*source*: Feeding America's Map the Meal Gap)

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Covariates

Table 1. Covariates and their data sources.

Covariate[a]	Source
▪ Population Density ▪ Females (%) ▪ Black (%) ▪ Native-American (%) ▪ Hispanic (%) ▪ Asian-American (%) ▪ Non-Hispanic white (%) ▪ Unemployment Rate (%) ▪ Poverty Rate (%) ▪ No Access to Vehicle (%) ▪ Disability (%) ▪ No Health Insurance (%) ▪ Gini Index ▪ Median Age	*American Community Survey, United States Census Bureau, 2020* (10,11)
▪ Average Household Size, 2015-2019 (Persons) ▪ Persons with a 4-year college degree or more, adults 25 and over, 2015-2019 (%) ▪ Persons with no high school diploma or GED, adults 25 and over, 2015-2019 (%) ▪ Civilian labor force 16 and over employed in wholesale and retail trade, 2015-19 (%) ▪ Civilian labor force 16 and over employed in transportation, warehousing and utilities, 2015-2019 (%)	*Atlas of Rural and Small Town America, Economic Resource Service, United States Department of Agriculture (USDA)* (12)
▪ Obesity Prevalence[b], 2017 (%) ▪ Diabetes Prevalence[b], 2013 (%)	*USDA Food Environment Atlas* (13)
▪ Ratio of Total County Non-Federal Emergency Physicians (MD & DO) to County Population, 2019	*American Medical Association Physician Masterfile* (14)
▪ Cardiovascular Disease Mortality Rate[b], 2014 ▪ Cancer Mortality Rate[b], 2014 ▪ Respiratory Disease Mortality Rate[b], 2014	*The University of Washington Institute for Health Metrics and Evaluation* (15)
▪ Smoking Prevalence[b], 2019 (%)	*Behavioral Risk Factor Surveillance System* (16)
▪ COVID-19 Case Incidence Count, March 17, 2020-December 17, 2021 (Expressed as a standardized incidence ratio (SIR) using the national or region-specific mean incidence rate to compute the expected case count) [†]	*The Johns Hopkins Centers for Civic Impact for the Coronavirus Resource Center* (3–5,17), *Centers for Disease Control and Prevention (CDC)*
▪ COVID-19 Vaccination Percentage, as of December 25, 2021 [†] (%)	*CDC* [c] (18)
▪ 2020 General Election Vote Differential[d] [†] (%)	*The Guardian, townhall.com, Fox News, Politico, and the New York Times (19)*
▪ Urban-Rural Classification Scheme, 2013 (Metropolitan—*large central metropolitan, large fringe metropolitan, medium metropolitan, and small metropolitan*— and Non-Metropolitan—*micropolitan and noncore*)	*The National Center for Health Statistics* (20)

[a] All variables were measured at the county level unless otherwise noted (see footnote below).
[†] A state-level aggregated version of this variable was also computed and included in the analysis.
[b] Variable used in a principal components analysis to generate a health index risk score (see the footnotes in Table 2 for further details) (8).
[c] Vaccination data from the state of Hawaii were not available, resulting in omission of its counties from the analysis.
[d] Included as a surrogate measure of county-level social-distancing policies and vaccine hesitancy, which were demonstrably correlated with party affiliation across political jurisdictions (21–23).

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A Model for the Standardized Mortality Ratio (SMR)

Spatial features: county polygons

- A model for areal data
- Intrinsic Conditional Autoregressive Model (iCAR)[9]

Model Specified

$$\ln(\mu_i) = \alpha + \mathbf{x}_i^T \boldsymbol{\gamma} + \ln(E_i) + \upsilon_i + u_{j(i)} + e_i$$

E_i is the expected death count of the i^{th} county

υ_i is a spatially structured random effect: $\upsilon_i | \upsilon_k \sim N(\frac{\sum_{k=1}^{n} w_{ik}\upsilon_k}{\sum_{k=1}^{n} w_{ik}}, \frac{\tau^2}{\sum_{k=1}^{n} w_{ik}})$

where n are the no. of counties, τ^2 is the spatial variance,
w_{ik} is the i, k-th entry, $\in \{0, 1\}$, in the $n \times n$ adjacency matrix $\mathbf{W}$, and $i \neq k$

$u_{j(i)}$ is an unstructured state-level random effect: $u_{j(i)} \sim N(0, \sigma_u^2)$

e_i is an unstructured county-level random effect: $e_i \sim N(0, \sigma_e^2)$

[9] J. Besag. *Journal of the Royal Statistical Society: Series B (Methodological)* (1974). DOI: 10.1111/j.2517-6161.1974.tb00999.x.

Additional Analytical Considerations

- Stratify per Census region
- Sequential Adjustment:
  - **Null Model**: no fixed effects, only random effs. + offset term
  - **Basic Model**: further adjust for county health index, median age, COVID-19 standardized incidence ratio (SIR)
  - **Basic + State Model**: further adjust for state-level means of health index, median age, COVID-19 SIR, 2020 general election vote differential (%)
  - **Final Model**: further adjust for FI and other covariates selected via forward selection w/ Watanabe-Aikake Information Criterion (WAIC)
- Sensitivity Analyses
  - Deviance Information Criterion for selection
  - Removal of states with suspiciously low mortality rates
  - Priors
  - No selection

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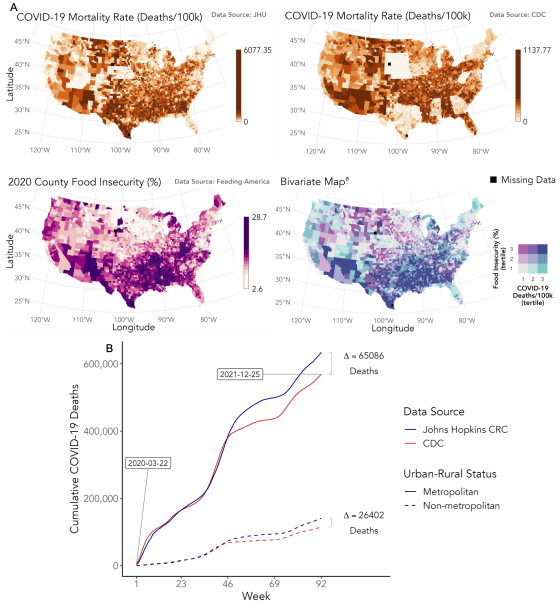


Figure 1. *Panel A*: Spatial distributions of the age-standardized dependent variables (from both the Johns Hopkins University Coronavirus Resource Center (JHU) and Centers for Disease Control and Prevention (CDC) data sources) and independent variable (food insecurity prevalence from Feeding America's Map the Meal Gap).

Panel B: A time series depiction of the cumulative crude (not age- standardized) COVID-19 mortality counts, within the analytic time window, from both sources (mapped to the line colors) and further stratified on urban-rural status (mapped to the line-type). The starting and end dates plotted are based on the beginning and end dates of the first and last MMWR week for the analytic time window.

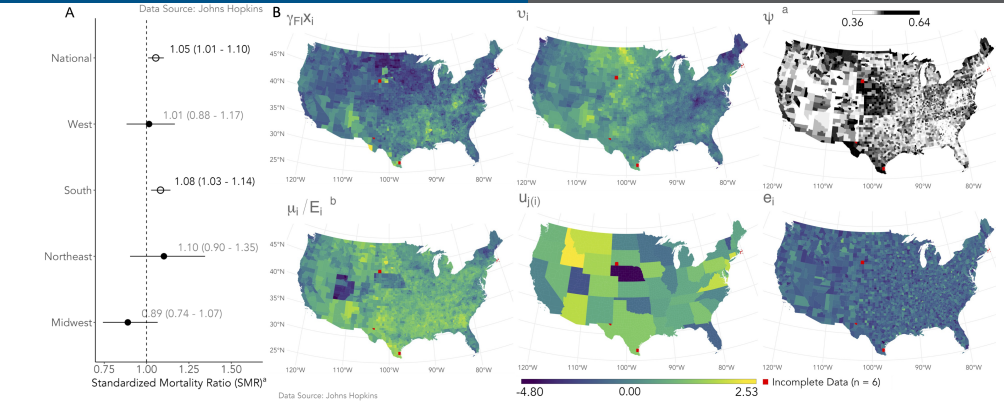


Figure 2. *Panel A*: Means and their 95% credible intervals (CrIs) for posterior distributions of the *exp*(*parameter*) for the food insecurity (FI) fixed effect for the *final model* (reflecting a standard deviation–4%– increase). A model was fit to the entire dataset (i.e., the National model–$n = 3102$) and a stratified analysis was conducted per Census region. Open circles denote posterior means with 95% CrIs whose bounds are completely above or below the reference value of 1 (dashed line). Results are shown for the analysis performed only on the age-standardized Johns Hopkins (JHU) COVID-19 mortality data.

Panel B: Map decomposition for the final model using national JHU data.

[a] $\psi = \frac{SD(v)}{SD(v)+SD(u)+SD(e)}$; [b] The overall risk, or standardized mortality ratio (SMR) in the log scale, from the final model.

The final model adjusted for county-level median age, health index score, and the standardized incidence ratio (SIR, state-level means of the health index score, the SIR, percent vaccinated, and the 2020 general election margin, percent female inhabitants and percent Hispanic inhabitants. Additional covariates in the final model were selected by forward selection with the Watanabe-Aikake Information Criterion (WAIC).

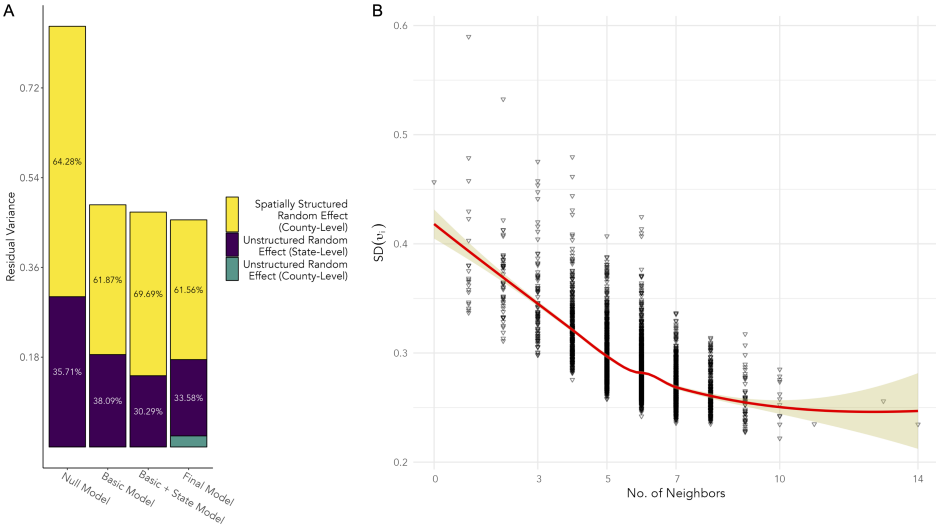
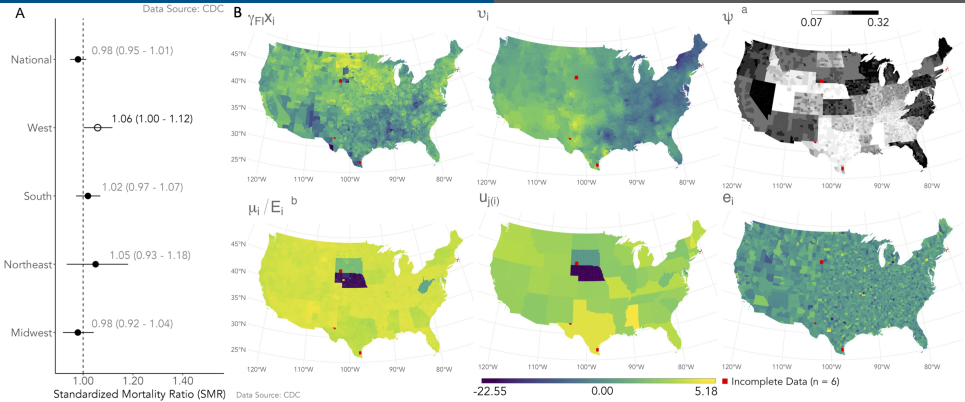


Figure 3. *Panel A*: Residual variance, computed as the sum of the variances of the random effects, across all models using national JHU data.
Panel B: Standard deviation of the spatially structured random effect (in the final model using national JHU data) mapped to the number of neighbors. The LOESS smoother is shown.



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Panel B: Map decomposition for the final model using national CDC data.

[a] $\psi = \frac{SD(\upsilon)}{SD(\upsilon)+SD(u)+SD(e)}$; [b] The overall risk, or standardized mortality ratio (SMR) in the log scale, from the final model.

The final model adjusted for county-level median age, health index score, and the standardized incidence ratio (SIR, state-level means of the health index score, the SIR, percent vaccinated, and the 2020 general election margin, percent non-Hispanic White inhabitants. Additional covariates in the final model were selected by forward selection with the Watanabe-Aikake Information Criterion (WAIC).

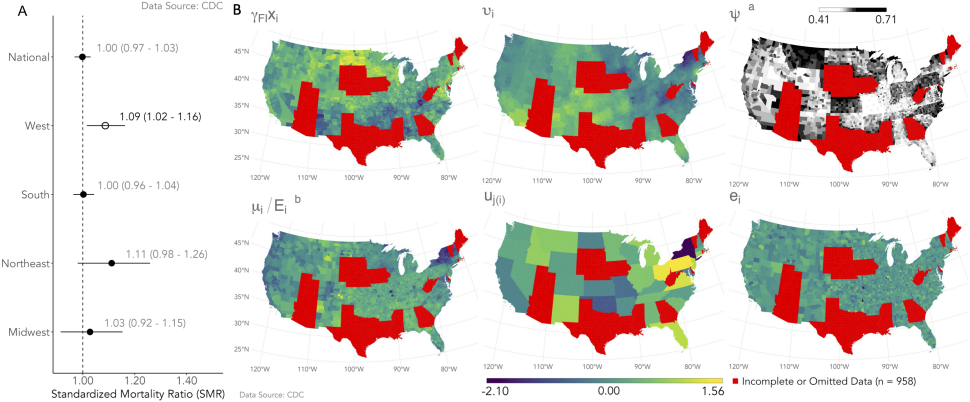
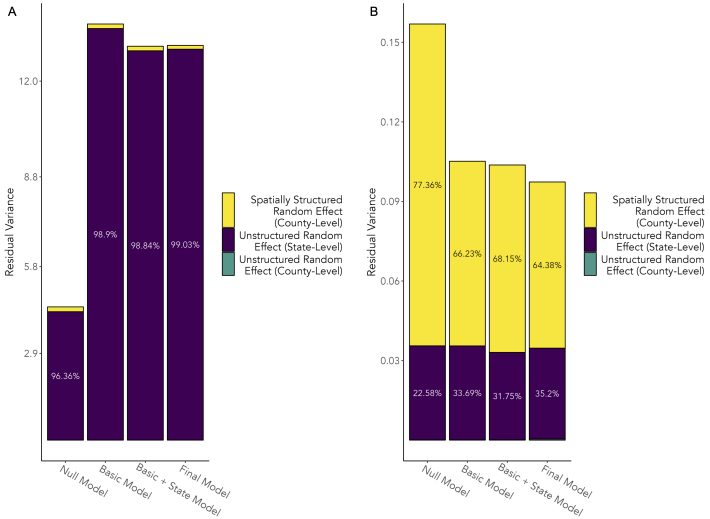


Figure S5. *Panel A*: Means and their 95% credible intervals (CrIs) for posterior distributions of the *exp*(*parameter*) for the food insecurity (FI) fixed effect for the *final model* (reflecting a standard deviation–4%– increase). A model was fit to the entire dataset (i.e., the National model) and a stratified analysis was conducted per Census region. Open circles denote posterior means with 95% CrIs whose bounds are completely above or below the reference value of 1 (dashed line). Results are shown for the analysis performed only on the age-standardized CDC COVID-19 mortality data.

Panel B: Map decomposition for the final model using national CDC data.

[a] $\psi = \frac{SD(\upsilon)}{SD(\upsilon)+SD(u)+SD(e)}$; [b] The overall risk, or standardized mortality ratio (SMR) in the log scale, from the final model.

The final model adjusted for county-level median age, health index score, and the standardized incidence ratio (SIR, state-level means of the health index score, the SIR, percent vaccinated, and the 2020 general election margin, percent non-Hispanic White inhabitants. Additional covariates in the final model were selected by forward selection with the Watanabe-Aikake Information Criterion (WAIC).



Panel A: Total residual variance and relative composition from the main analysis using the CDC data (*final model*).
Panel B: Total residual variance and relative composition from the state sensitivity analysis using the CDC data (*final model*).

Conclusions

Conclusions and Strengths:

- *County-level food insecurity was positively associated with COVID-19 mortality*
  - Spatial autocorrelation
  - Multivariable adjustment, age-standardization
  - Regional specificity
  - Robustness
- *Gaps in COVID-19 mortality data?*
  - CDC vs. JHU

Limitations:

- Unmeasured confounding, causality
- Spatial resolution
- Aggregate data; ecological fallacy

Acknowledgements

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- May A. Beydoun (*LEPS, NIH/NIA*)
- Anna E. Arthur (*Dept. of Nutrition and Dietetics, Univ. of Kansas Medical Center*)
- Francesca Gany (*Memorial Sloan Kettering Cancer Center*)

GitHub Repository (R Code and Data)
github.com/cmainov/covid-fi-mortality-mirror

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Data

- *CDC*
- *JHU CRC*
- *2023 County Health Rankings–RWJF and Univ. of Wisconsin*

github.com/cmainov