Supplemental Materials: Predictive Spatial Modeling of Sociodemographic Risk for COVID-19 Mortality

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Contents

Appendix Overview

Summary

Below are supplemental materials associated with the submitted manuscript.

Part 1: Study Area and Regionalization

Regionalization is based on United States(US) Health and Human Services (HHS) health regions.

- Region 1 and 2 (combined): NorthEast: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, New York and New Jersey
- Region 3: MidEast: Pennsylvania, West Virginia, Maryland, Delaware, Virginia and the District of Columbia
- Region 4: SouthEast: Florida, Georgia, South Carolina, and North Carolina, Alabama, Mississippi, Tennessee, and Kentucky
- Region 5: Midwest: Ohio, Indiana, Illinois, Michigan, Wisconsin, and Minnesota
- Region 6: MidSouth: Texas, Louisiana, Arkansas, and New Mexico, Oklahoma
- Region 7: Middle West: Iowa, Missouri, Nebraska, and Kansas
- Region 8: MidNorth: Montana, Wyoming, Utah, Colorado, North Dakota, and South Dakota
- Region 9: West: California, Nevada, and Arizona
- Region 10: Pacific Northwest: Idaho, Oregon, and Washington

Part 2: Datasets and Modeling Framework

Part 2 of our analysis documents the datasets and modeling methodology employed as part of this effort.

Part 3: Exploratory Data Analysis and Regression Modeling

Our regional analysis examines COVID-19 parameters for the entire United States, as well as for each of the nine (9) regions listed above.

- The first plot (1) shows fatality rates vs. logarithmic population density, categorized by voting ideology summarized by the 2020 Presidential Election. 100-75% vote for Biden = very liberal, 75-50% for Biden = moderately liberal, 100-75% for Trump = very conservative, and 75-50% for Trump = moderately conservative. Each observation represents one county.
- The second plot (2) shows cumulative cases, adjusted for population, vs. cumulative deaths, adjusted for population, categorized by voting ideology - as noted above.
- The third (3) and fourth (4) plots show the relationship of the four ideology groupings across the specified region, over time - examining deaths for a rolling window, as well as cumulative deaths. These plots provide a summary view of the change in ideological and regional associations with cases and deaths.

For each region, we have outputs for three linear linear models, with population adjusted deaths (by county) as the dependent variable - for each of the three time windows (alpha, delta, and omicron variant). In addition, we have standardized coefficients graphs, that indicates the effect for each variable, for each model.

Part 4: Spatial Autocorrelation

The second portion of this analysis evaluates the spatial autocorrelation of population adjusted county deaths, for all three time periods examined.

Part 5: Geographically Weighted Random Forest (GWRF) Modeling

The third portion of this analysis attempts to model spatial variation for the entire United States, using geographically weighted random forest modeling (GWRF). Our model incorporates the same independent variables that are used as part of our regionalized linear models.

Geographical Weighted Random Forest (GWRF) is a spatial analysis method using a local version of the Random Forest Regression Model. It allows for the investigation of spatial non-stationarity, and the relationship between a dependent and a set of independent variables. The latter is possible by fitting a sub-model for each observation in space, taking into account the neighboring observations. This technique adopts the idea of the Geographically Weighted Regression Kalogirou (2003). The main difference between a tradition (linear) GWR and GRF is that we can model non-stationarity coupled with a flexible non-linear model which is very hard to overfit due to its bootstrapping nature, thus relaxing the assumptions of traditional Gaussian statistics. Essentially it was designed to be a bridge between machine learning and geographical models, combining inferential and explanatory power. Additionally, it is suited for datasets with numerous predictors, due to the robust nature of the random forest algorithm with regards to high dimensionality.

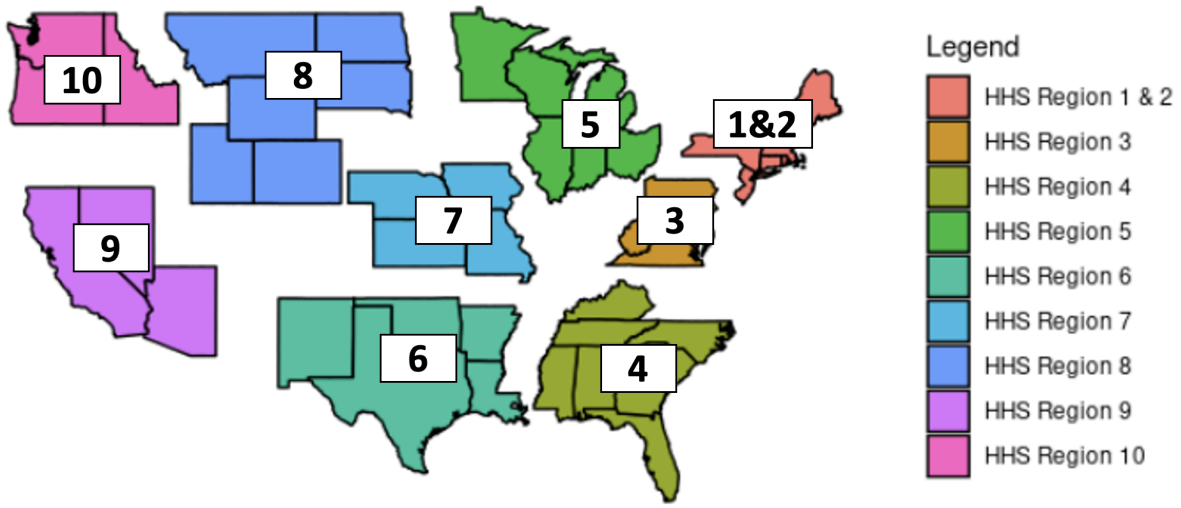
For this analysis, We generate GWRF localized model fits and feature importances (IncMSE). The feature importance algorithmic process is:

1. Compute model MSE
2. For each variable in the model:
    a. Permute variable
    b. Calculate new model MSE according to variable permutation
    c. Take the difference between model MSE and new model MSE
3. Collect the results in a list

Part 1: Study Area and Regionalization

For the initial portion of our analysis, we examine COVID-19 cases and deaths for the entire United States, as well as by U.S. Human Health Services (HHS) regions, as noted in Figure S1 below.

Figure S1: Study Area



Part 2: Datasets and Modeling Framework

We utilize fifteen (15) independent variables and one (1) dependent variable for our analysis.

Table T1: Variable Descriptions

Table 1: Table T1: Variable Descriptions. * = dependent variable

Variables	Description	Data Source
Socioeconomic Status	Index which represents income, poverty, employment, and education.	Social Vulnerability Indices (SVI) taken from the US Census agency for toxic substances and disease registry (ATSDR)
Household Composition and Disability	Index with represents age, single parenting, and disability.	
Minority Status	Index which represents race and ethnicity.	
Housing Type and Transportation	Index which represents housing structure, crowding and vehicle access.	
Obesity	Number of people who are obese, at a county level.	University of Wisconsin's Population Health Institute
Unemployment	Number of unemployed adults per county.	
Uninsured Adults	Number of uninsured adults per county.	
Social Associations	Number of people who are members of a social organization (churches, clubs, etc).	
Diabetes	Number of people with diabetes at a county level.	
Food Insecurity	Index indicating the relative level of food insecurity in a county.	
Broadband Access	Number of people without broadband access.	
Population Density	Population density at a county level.	2020 US Census
Population Age 65+	Number of people age 65 or older in a county.	
Democratic Voting Percentage	Represents voting outcomes from the 2020 presidential general election.	Massachusettes Institute of Technology's (MIT) Election Lab
Vaccination Rate	CDC data for two dose vaccination rates at a county level, ending in April 1, 2022.	US Centers for Disease Control (CDC)
Population adjusted COVID-19 deaths*	Population-adjusted COVID-19 deaths per county.	

Using this framework, we constructed three (3) temporal model time frames:

1. Alpha variant time window (deaths calculated from December 1, 2019 to May 1, 2021)
2. Delta variant time window (deaths calculated from May 1, 2021, to December 1, 2021)
3. Omicron variant time window (deaths calculated from December 1, 2021 to April 1, 2022)

Figure S2: Model Framework

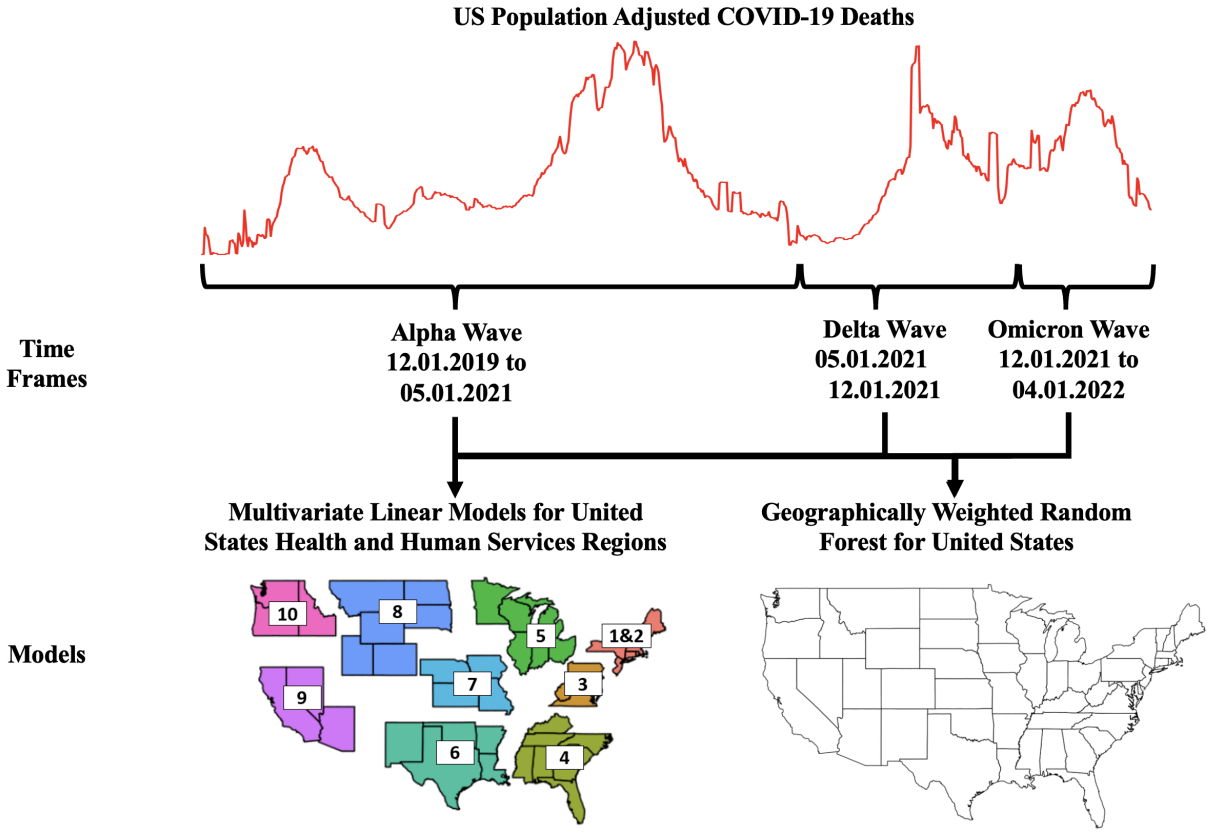
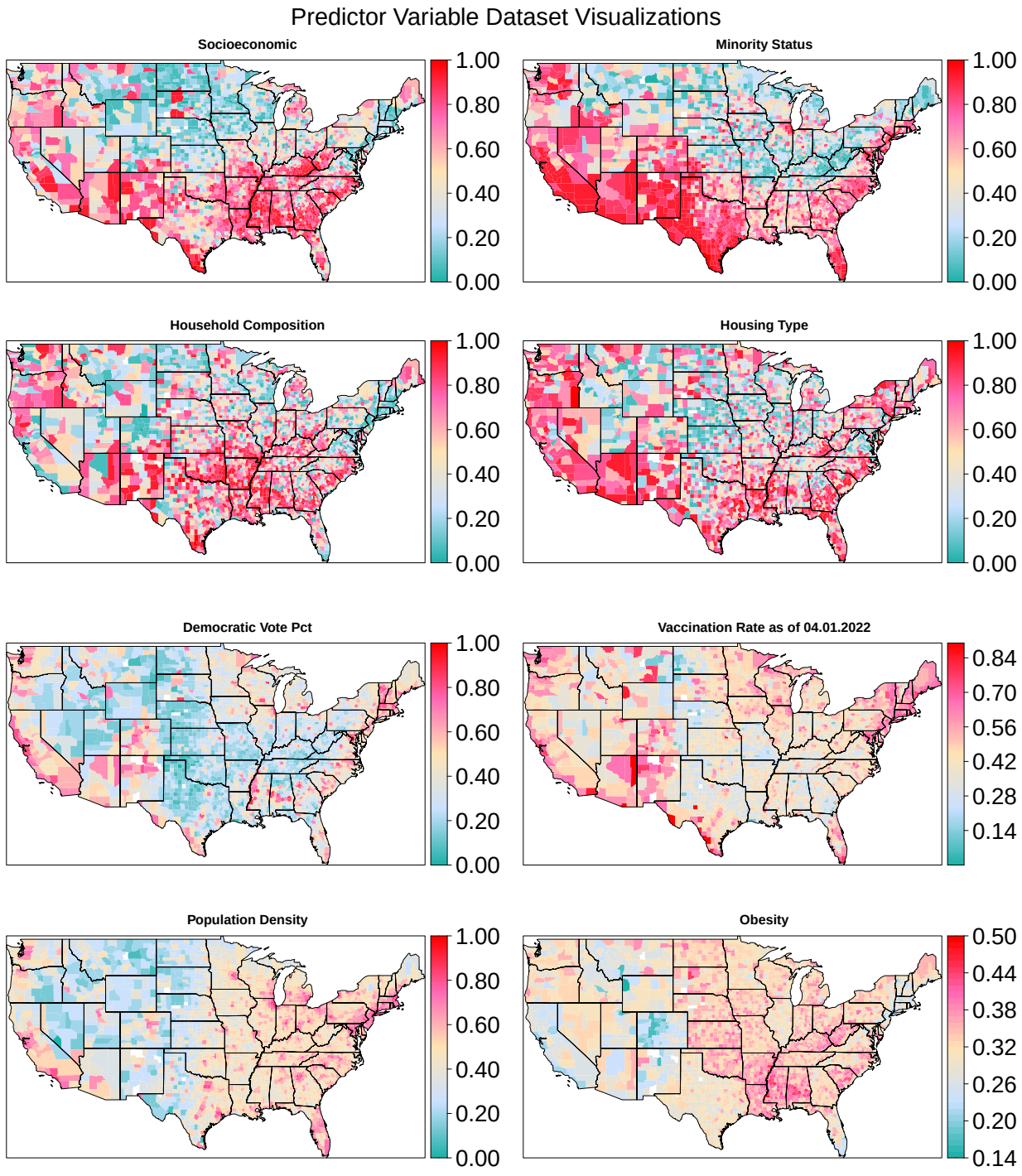
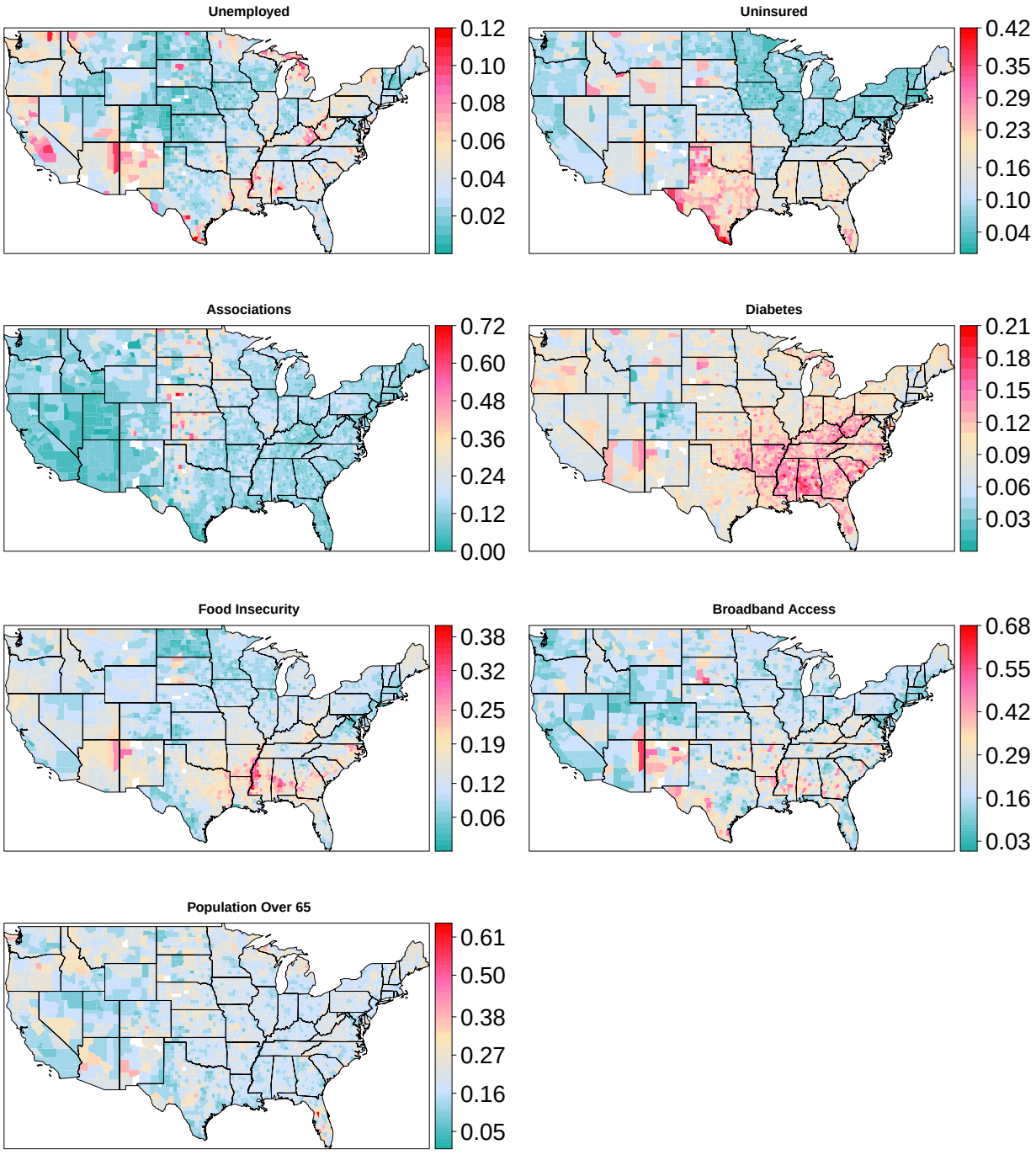


Figure S3: Dataset Visualizations




Unemployed
0.12
0.10
0.08
0.06
0.04
0.02
Uninsured
0.42
0.35
0.29
0.23
0.16
0.10
0.04
Associations
0.72
0.60
0.48
0.36
0.24
0.12
0.00
Diabetes
0.21
0.18
0.15
0.12
0.09
0.06
0.03
Food Insecurity
0.38
0.32
0.25
0.19
0.12
0.06
Broadband Access
0.68
0.55
0.42
0.29
0.16
0.03
Population Over 65
0.61
0.50
0.38
0.27
0.16
0.05

Response Variable Dataset Visualizations

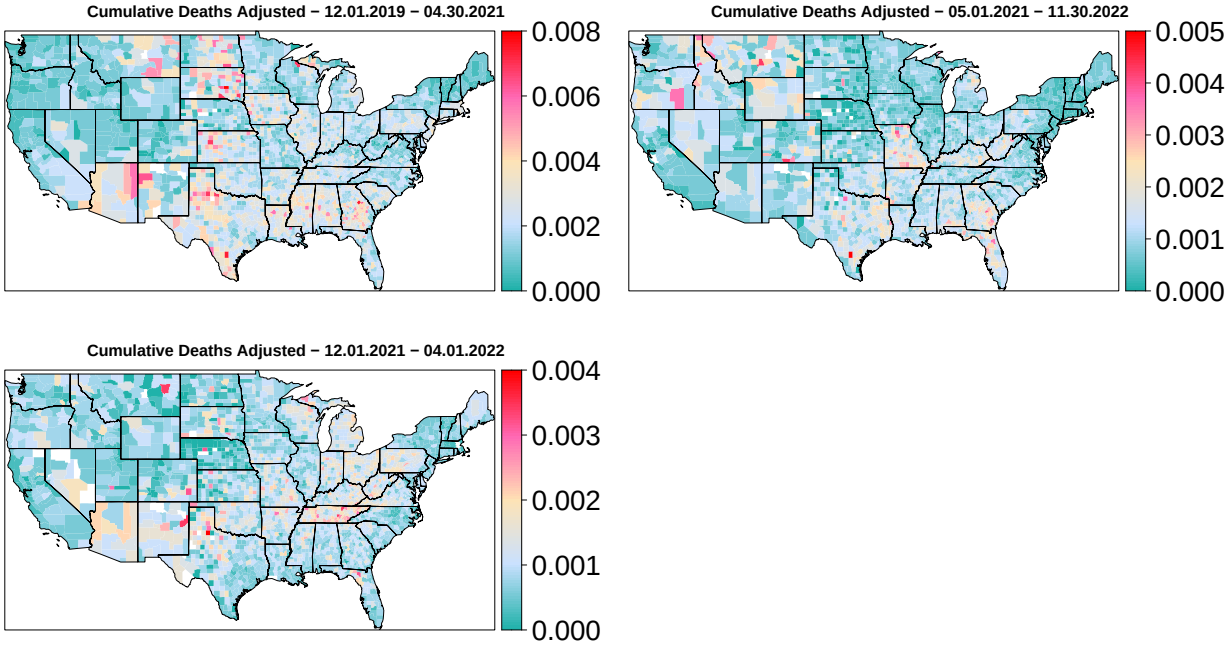
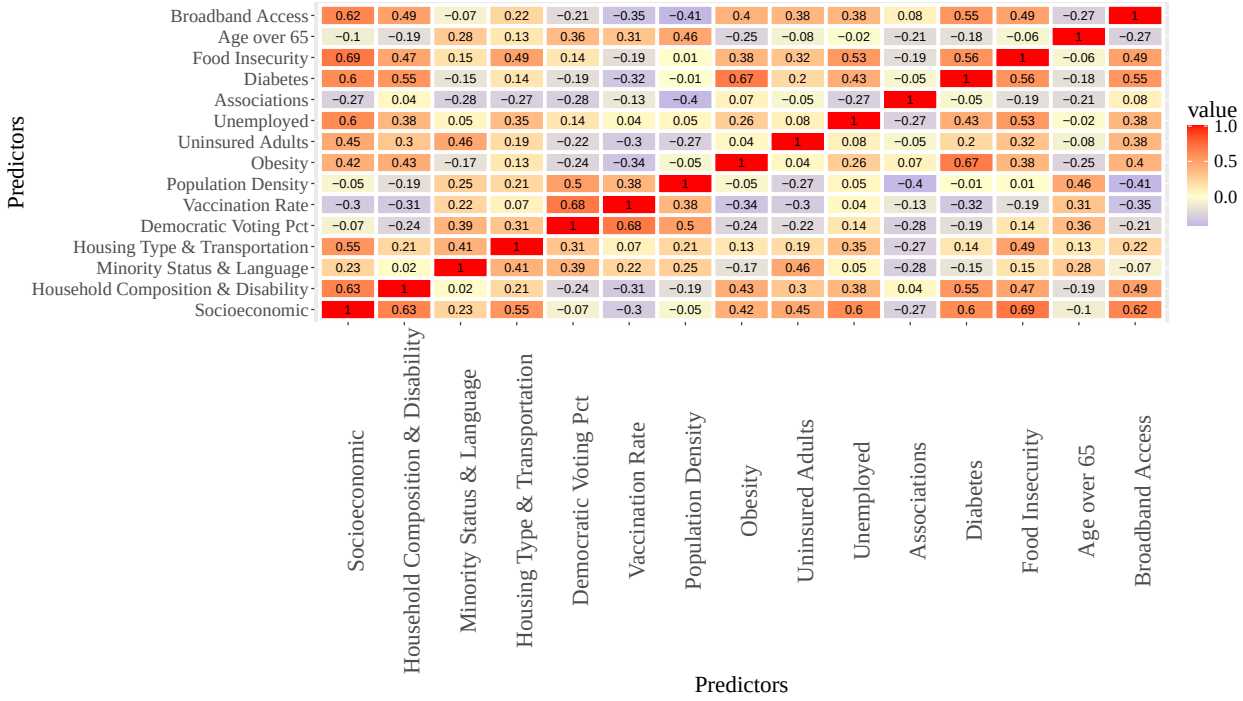


Figure S4: Correlation HeatMap



Part 3: Data Analysis and Regression: United States

Figure S5: Fatality Rate vs. Population Density

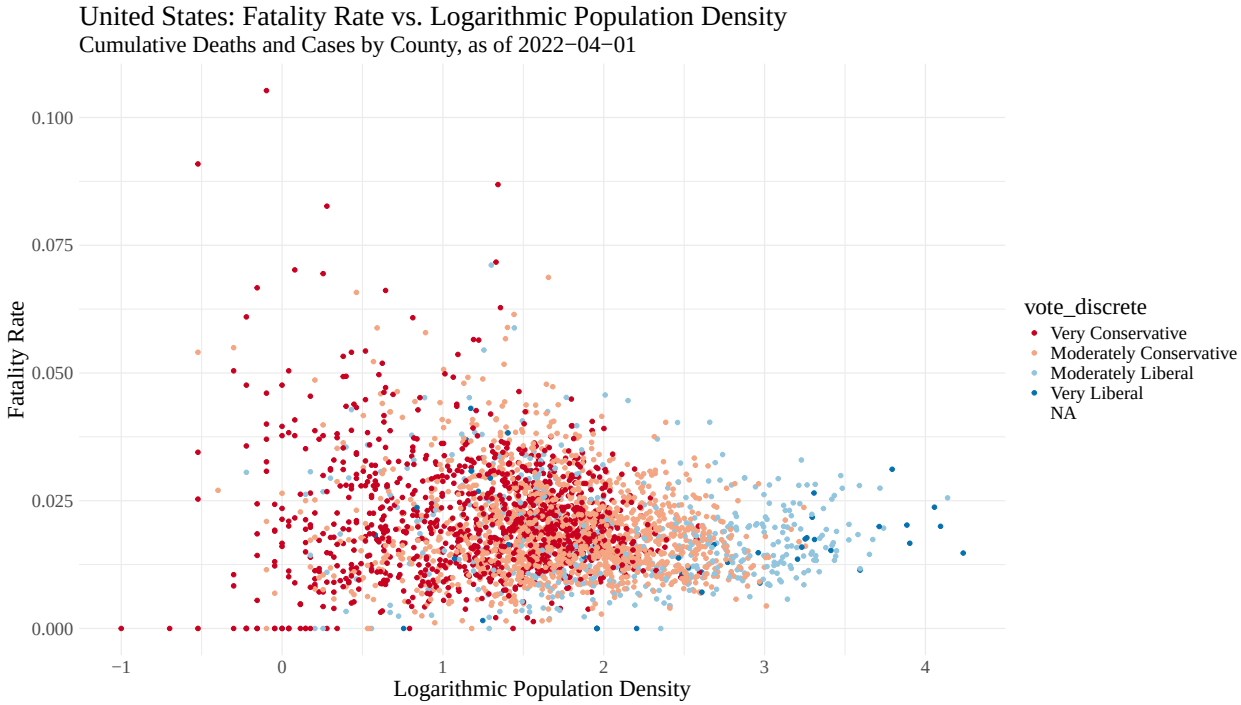


Figure S6: County Level Cumulative Cases vs. Cumulative Deaths

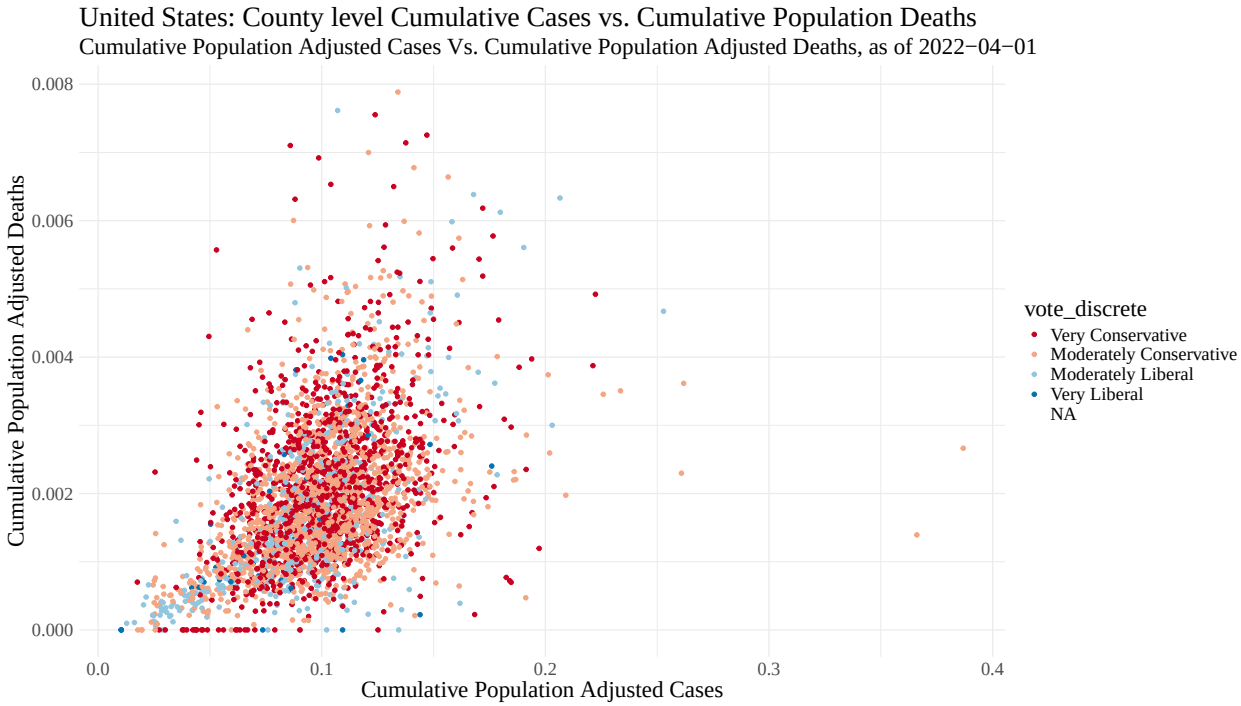


Figure S7: Population Adjusted Cumulative Deaths vs Ideology over time

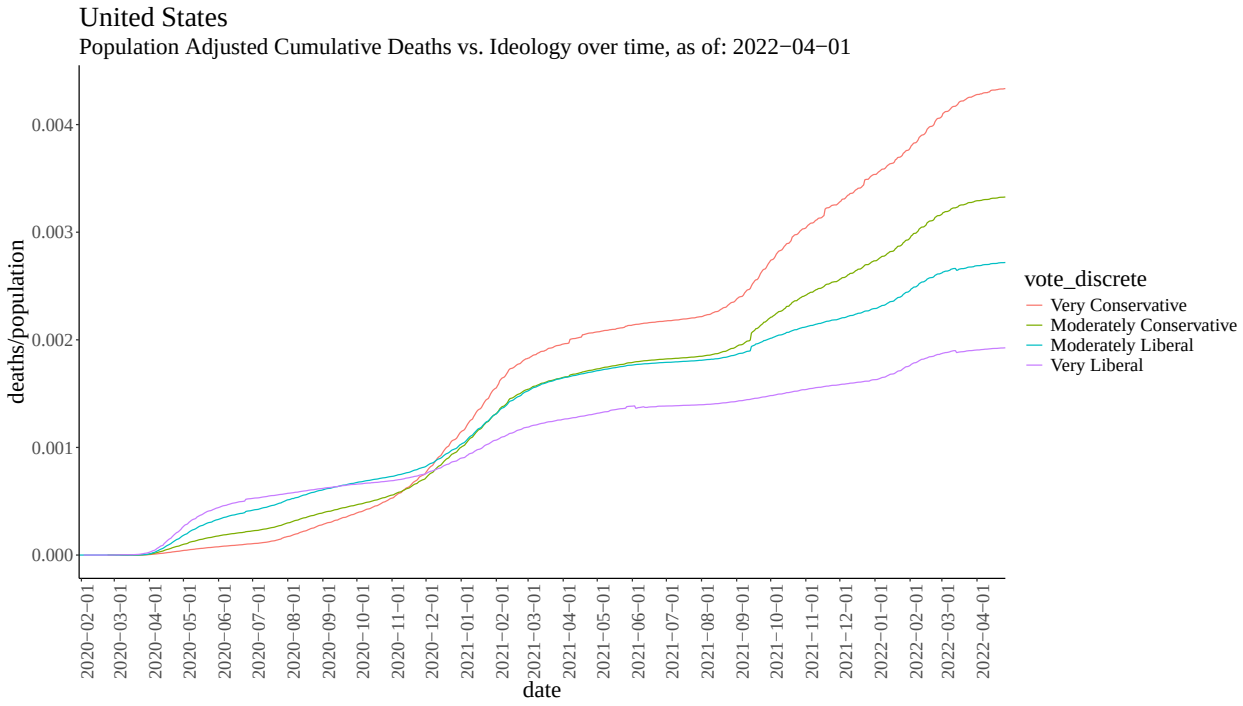


Table T2: United States: Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-7.73313	**0**	-7.05210	**0**	-7.49889	**0**
Socioeconomic	0.04435	1	-0.03913	1	0.05413	1
Household Composition & Disability	0.26958	**2.84e-07**	0.28751	**3.83e-09**	0.36952	**1.7e-14**
Housing Type & Transportation	0.11719	0.57	0.20256	**5.18e-05**	-0.09546	1
Unemployed	0.86481	**5.59e-13**	-0.06978	1	0.33055	1
Food Insecurity	-1.22957	**6.24e-47**	1.02947	**1.21e-31**	0.04276	1
Broadband Access	2.87818	**2.49e-60**	-0.99263	**3.65e-06**	1.17898	**2.31e-08**
Diabetes	0.71078	**2.65e-13**	1.30850	**4.96e-48**	0.49088	**1.89e-05**
Obesity	-0.22955	1	-0.49613	**2.47e-06**	0.27717	0.381
Population Density	0.09549	**6.62e-42**	-0.01686	1	0.05980	**8.87e-14**
Associations	1.46995	**2.52e-18**	-0.94949	**6.9e-07**	0.23206	1
Age over 65	0.00000	**1.03e-18**	0.00000	1	0.00000	**7.46e-13**
Democratic Voting Pct	-0.62271	**1.3e-11**	-1.41023	**1.77e-59**	-0.98851	**5.87e-27**
Vaccination Rate	-0.08105	1	-0.29546	1	-0.35674	0.368
Minority Status and Language	0.44996	**1.88e-19**	-0.32104	**4.78e-10**	-0.24493	**4.06e-05**
Uninsured Adults	-0.10371	1	1.25487	**3.2e-89**	-0.56820	**1.15e-15**

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.416	0.675	0.505

Part 3: Data Analysis and Regression: Regions 1 and 2 (Northeast)

Figure S8: Population Adjusted Cumulative Deaths vs Ideology over time

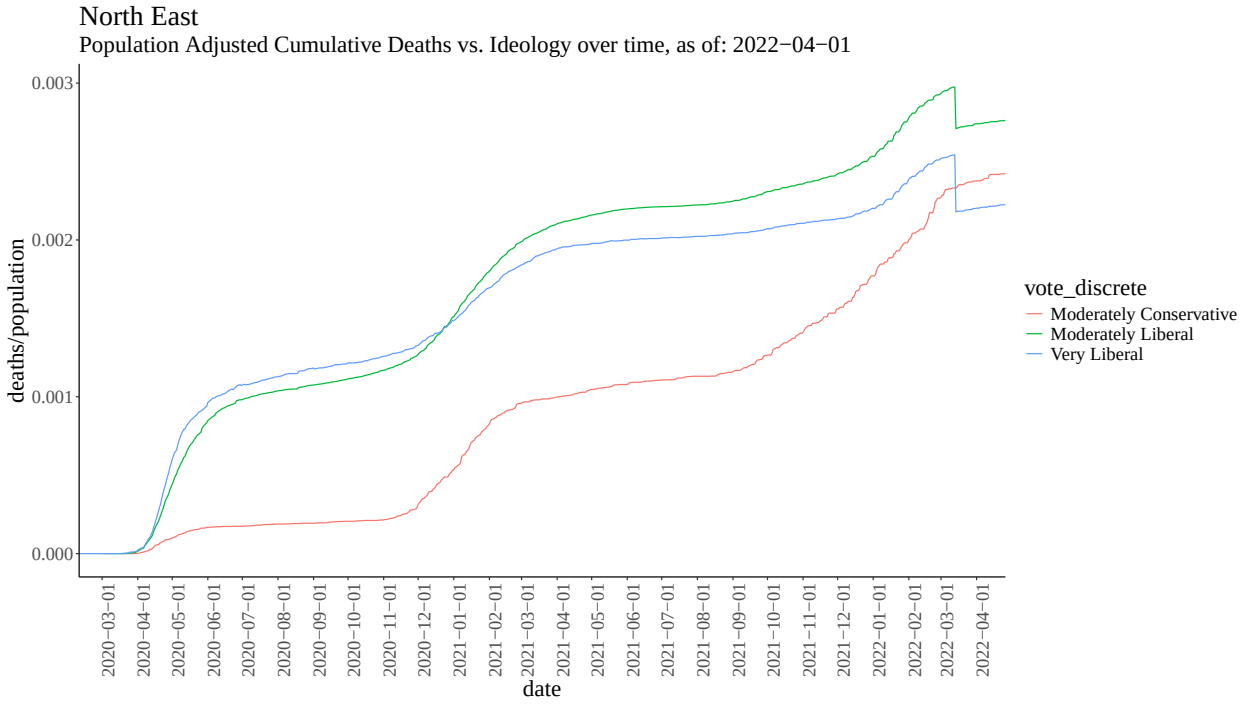


Table T3: Region 1 & 2 (Northeast): Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-6.86873	**1.35e-23**	-7.74156	**1.48e-28**	-7.96547	**1.66e-22**
Socioeconomic	-0.26708	1	0.04714	1	-1.02173	1
Household Composition & Disability	0.52020	1	0.57848	1	0.09737	1
Housing Type & Transportation	-0.19817	1	-0.25663	1	-0.34620	1
Unemployed	1.20729	1	-0.18706	1	0.04937	1
Food Insecurity	-0.65298	1	0.74533	1	2.96898	**0.00599**
Broadband Access	-0.35437	1	-1.19573	1	1.13081	1
Diabetes	0.75029	1	1.59200	0.487	-0.67270	1
Obesity	-0.39090	1	0.60732	1	1.15140	1
Population Density	0.13353	0.26	-0.01360	1	0.02968	1
Associations	-1.29308	1	-1.18799	1	0.24632	1
Age over 65	0.00000	1	0.00000	1	0.00000	1
Democratic Voting Pct	0.39742	1	-0.04418	1	-2.46815	**0.000359**
Vaccination Rate	-1.73077	**0.0322**	-1.32625	0.32	0.36338	1
Minority Status and Language	1.25563	**7.79e-05**	-0.02484	1	0.47390	1
Uninsured Adults	-0.24291	1	0.52166	1	2.32747	**5.13e-07**

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.746	0.687	0.579

Part 3: Data Analysis and Regression: Region 3 (Mideast)

Figure S9: Population Adjusted Cumulative Deaths vs Ideology over time

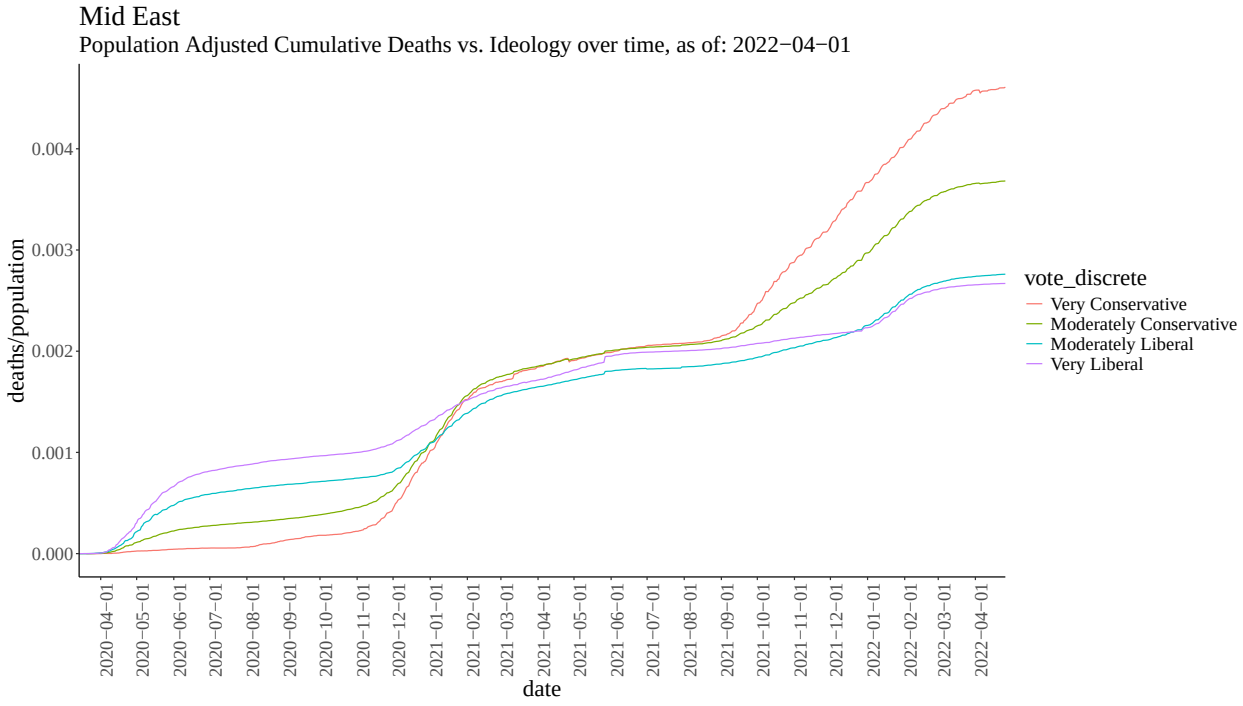


Table T4: Region 3 (Mideast): Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-8.19564	**1.69e-19**	-6.35088	**1.15e-16**	-7.13452	**2.03e-19**
Socioeconomic	-0.48507	1	-0.03362	1	0.00117	1
Household Composition & Disability	0.10017	1	0.18438	1	0.14994	1
Housing Type & Transportation	0.25276	1	0.18837	1	0.15533	1
Unemployed	1.10955	1	-0.50541	1	-0.44242	1
Food Insecurity	-0.99300	1	1.50070	1	0.17215	1
Broadband Access	1.22363	1	0.30970	1	1.43765	1
Diabetes	1.53415	1	0.46753	1	0.53123	1
Obesity	-0.13497	1	0.22203	1	0.56479	1
Population Density	0.12248	1	-0.09856	1	0.04430	1
Associations	2.53055	0.572	1.61776	1	0.84714	1
Age over 65	0.00000	1	0.00000	1	0.00000	1
Democratic Voting Pct	-0.81226	1	-1.05361	1	-1.56177	0.308
Vaccination Rate	-0.69419	1	-1.43693	1	-1.23740	1
Minority Status and Language	0.56628	1	0.03903	1	0.49975	1
Uninsured Adults	0.89883	1	-1.44345	1	-1.52570	1

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.601	0.902	0.846

Part 3: Data Analysis and Regression: Region 4 (Southeast)

Figure S10: Population Adjusted Cumulative Deaths vs Ideology over time

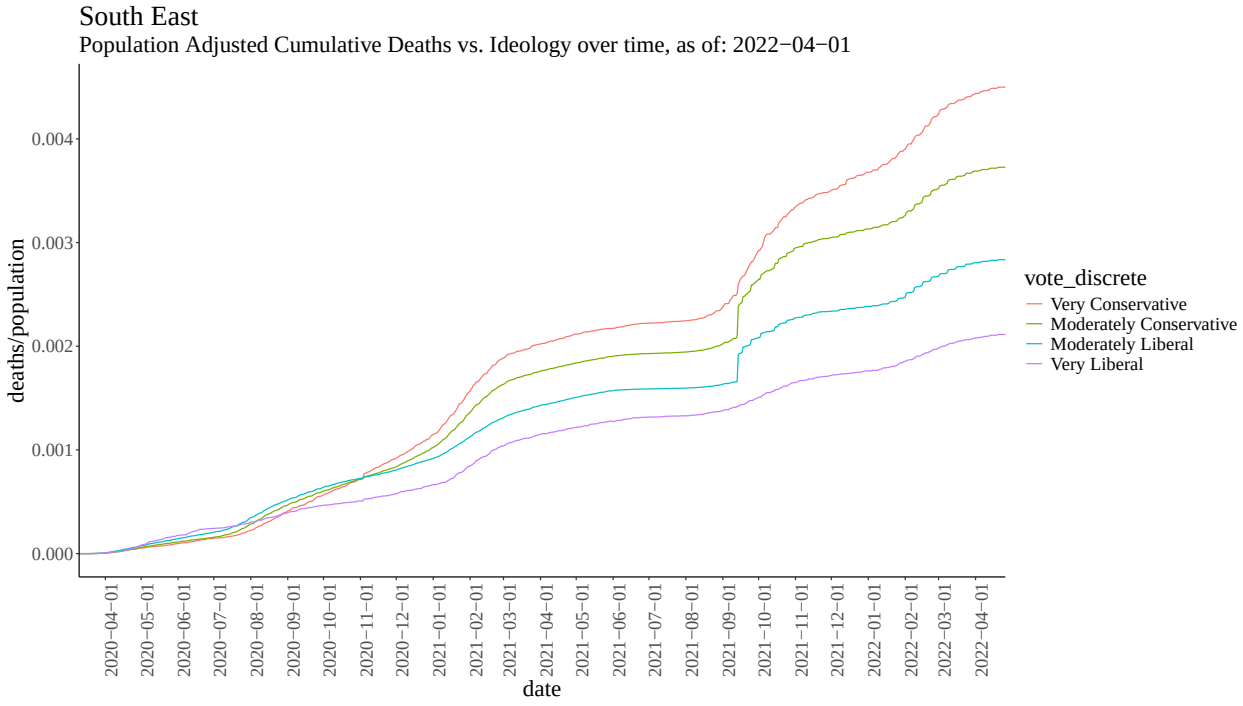


Table T5: Region 4 (Southeast): Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-6.85646	**1.7e-78**	-7.30640	**1.39e-85**	-8.12183	**2.66e-77**
Socioeconomic	0.06928	1	0.33690	1	0.48855	1
Household Composition & Disability	0.03956	1	0.06639	1	0.02512	1
Housing Type & Transportation	0.22072	1	0.11574	1	0.09814	1
Unemployed	1.52933	0.265	-0.96852	1	-0.72504	1
Food Insecurity	-0.13147	1	1.08227	**0.00374**	-0.30966	1
Broadband Access	0.49178	1	-0.44920	1	0.33004	1
Diabetes	1.22163	**6.26e-06**	1.74104	**2e-13**	1.56182	**5.01e-07**
Obesity	-0.51579	1	-0.28424	1	-0.41424	1
Population Density	0.00438	1	0.09345	0.0518	0.11829	**0.0304**
Associations	0.67955	1	-1.43454	0.39	0.32951	1
Age over 65	0.00000	**0.000176**	0.00000	0.312	0.00000	1
Democratic Voting Pct	-0.43876	1	-1.86379	**2.59e-16**	-0.90938	0.0513
Vaccination Rate	-0.85461	**0.0477**	0.22911	1	-0.41733	1
Minority Status and Language	-0.22207	1	-0.40134	1	-0.51729	1
Uninsured Adults	0.64855	1	0.85339	0.491	0.55185	1

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.584	0.667	0.51

Part 3: Data Analysis and Regression: Region 5 (Midwest)

Figure S11: Population Adjusted Cumulative Deaths vs Ideology over time

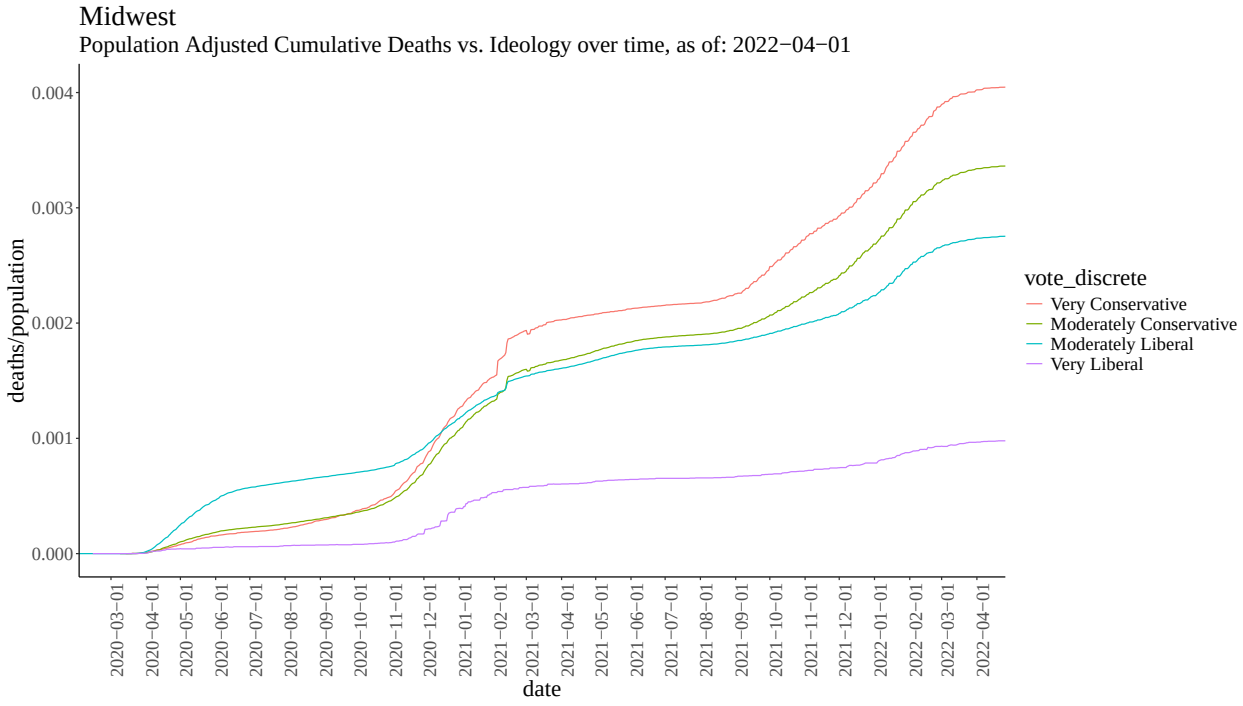


Table T6: Region 5 (Midwest): Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-6.94886	**2.88e-120**	-6.54557	**7.3e-117**	-6.90905	**3.73e-127**
Socioeconomic	0.55317	0.382	0.41446	1	0.18806	1
Household Composition & Disability	0.15342	1	0.00564	1	0.05908	1
Housing Type & Transportation	-0.33920	**0.00177**	-0.19458	1	-0.23791	0.28
Unemployed	-0.12705	1	0.16473	1	0.47176	1
Food Insecurity	-0.19024	1	0.55389	1	0.52868	1
Broadband Access	1.17890	1	-0.22728	1	-0.20504	1
Diabetes	0.19387	1	0.98215	**0.00602**	1.04838	**0.00174**
Obesity	0.11704	1	0.07098	1	0.41692	1
Population Density	0.09447	**0.00495**	-0.01116	1	0.04381	1
Associations	1.31211	**0.0295**	0.03780	1	-0.16923	1
Age over 65	0.00000	**4.37e-07**	0.00000	1	0.00000	1
Democratic Voting Pct	-1.06926	**0.0115**	-0.51710	1	-0.68378	1
Vaccination Rate	-0.25797	1	-1.83330	**3.9e-08**	-1.35636	**0.000416**
Minority Status and Language	0.24760	1	-0.21075	1	-0.01256	1
Uninsured Adults	-0.58554	1	-1.04889	0.303	-1.14056	0.0716

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.475	0.729	0.663

Part 3: Data Analysis and Regression: Region 6 (MidSouth)

Figure S12: Population Adjusted Cumulative Deaths vs Ideology over time

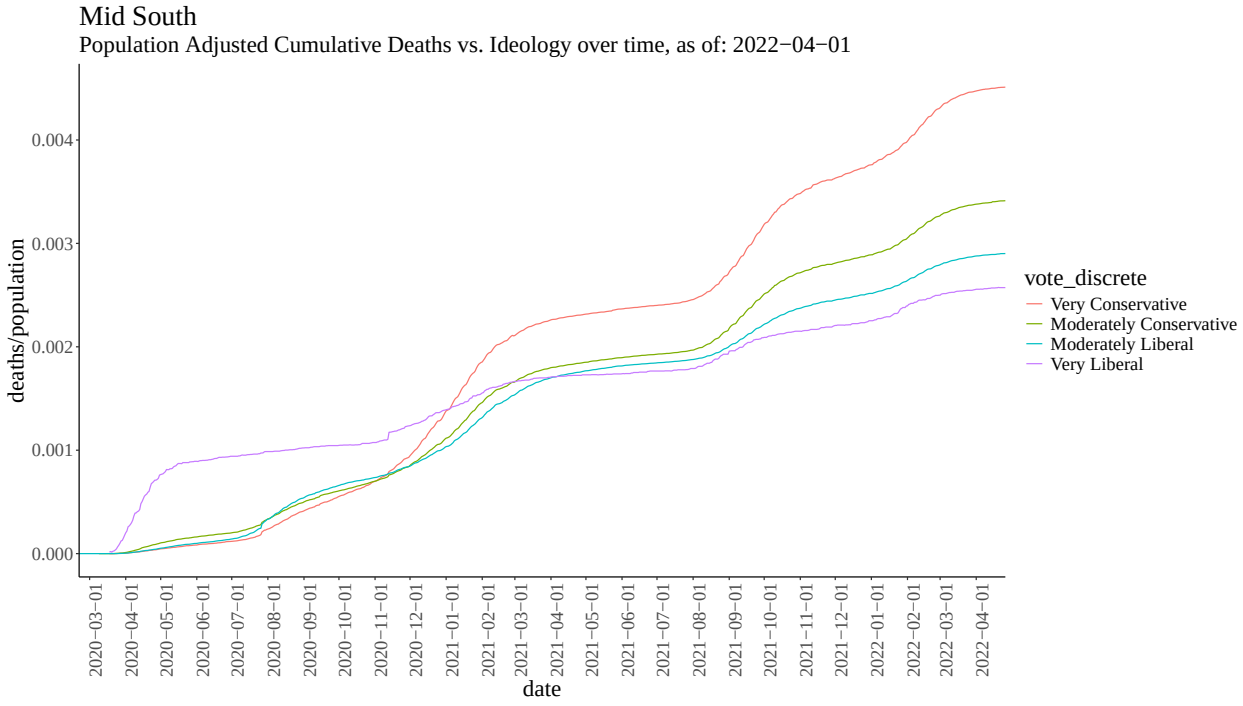


Table T7: Region 6 (Midsouth): Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-7.65733	**3.5e-151**	-6.97919	**4e-114**	-6.87554	**2.46e-84**
Socioeconomic	0.53296	**0.00621**	-0.30269	1	0.86127	**0.000984**
Household Composition & Disability	0.29521	**0.0367**	0.39013	**0.00337**	0.43952	**0.0348**
Housing Type & Transportation	-0.02747	1	0.39149	**0.00522**	-0.24974	1
Unemployed	-0.26979	1	0.71855	0.9	-0.90166	1
Food Insecurity	-0.33501	1	-0.02349	1	-0.27052	1
Broadband Access	1.42132	**2.84e-05**	-0.02865	1	0.51295	1
Diabetes	0.27870	1	0.57168	1	-0.15867	1
Obesity	0.16686	1	0.04141	1	-0.88882	0.204
Population Density	0.03436	1	0.00827	1	-0.00184	1
Associations	1.20362	0.135	0.20369	1	1.71743	0.132
Age over 65	0.00000	**0.00671**	0.00000	1	0.00000	0.653
Democratic Voting Pct	-0.43711	1	-1.07261	**5.23e-05**	-0.67672	1
Vaccination Rate	0.41396	1	-1.02493	**0.014**	-0.25775	1
Minority Status and Language	0.10192	1	0.00175	1	0.06413	1
Uninsured Adults	0.53406	**3.32e-05**	0.52512	**0.00708**	-0.63743	**0.0094**

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.735	0.646	0.543

Part 3: Data Analysis and Regression: Region 7 (Middle West)

Figure S13: Population Adjusted Cumulative Deaths vs Ideology over time

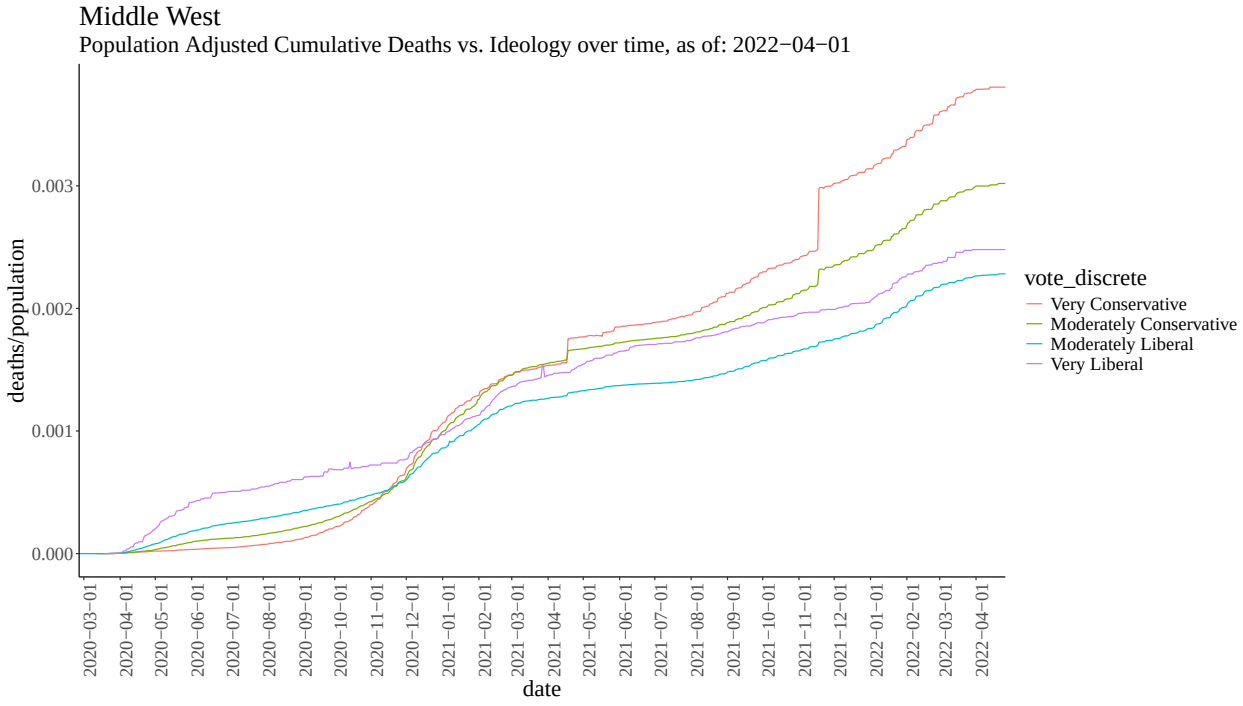


Table T8: Region 7 (Middle West): Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-7.46413	**3.53e-91**	-8.41197	**6.27e-104**	-8.15363	**6.83e-111**
Socioeconomic	0.97137	**0.00203**	0.22546	1	0.46984	1
Household Composition & Disability	-0.01422	1	-0.02338	1	0.25401	1
Housing Type & Transportation	0.12783	1	0.23982	1	0.29623	1
Unemployed	-0.78433	1	1.98276	0.433	0.75574	1
Food Insecurity	-1.62269	**0.0316**	-0.10961	1	-1.30323	0.292
Broadband Access	1.04802	1	2.05093	**0.0172**	1.34660	1
Diabetes	0.66050	1	1.02775	0.226	1.44357	**0.000162**
Obesity	0.84039	1	0.03524	1	0.09693	1
Population Density	-0.04989	1	0.17783	**6.22e-05**	0.04196	1
Associations	1.89596	**1.37e-06**	0.10615	1	-0.18211	1
Age over 65	0.00001	**6.45e-10**	0.00000	1	0.00000	0.199
Democratic Voting Pct	-0.41993	1	-2.23074	**3.24e-07**	-0.25273	1
Vaccination Rate	0.93607	1	0.24890	1	0.32851	1
Minority Status and Language	-0.03396	1	-0.83243	**4.12e-07**	-0.64657	**0.000186**
Uninsured Adults	-1.46429	**0.00165**	0.64250	1	-1.02792	0.164

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.406	0.705	0.469

Part 3: Data Analysis and Regression: Region 8 (Midnorth)

Figure S14: Population Adjusted Cumulative Deaths vs Ideology over time

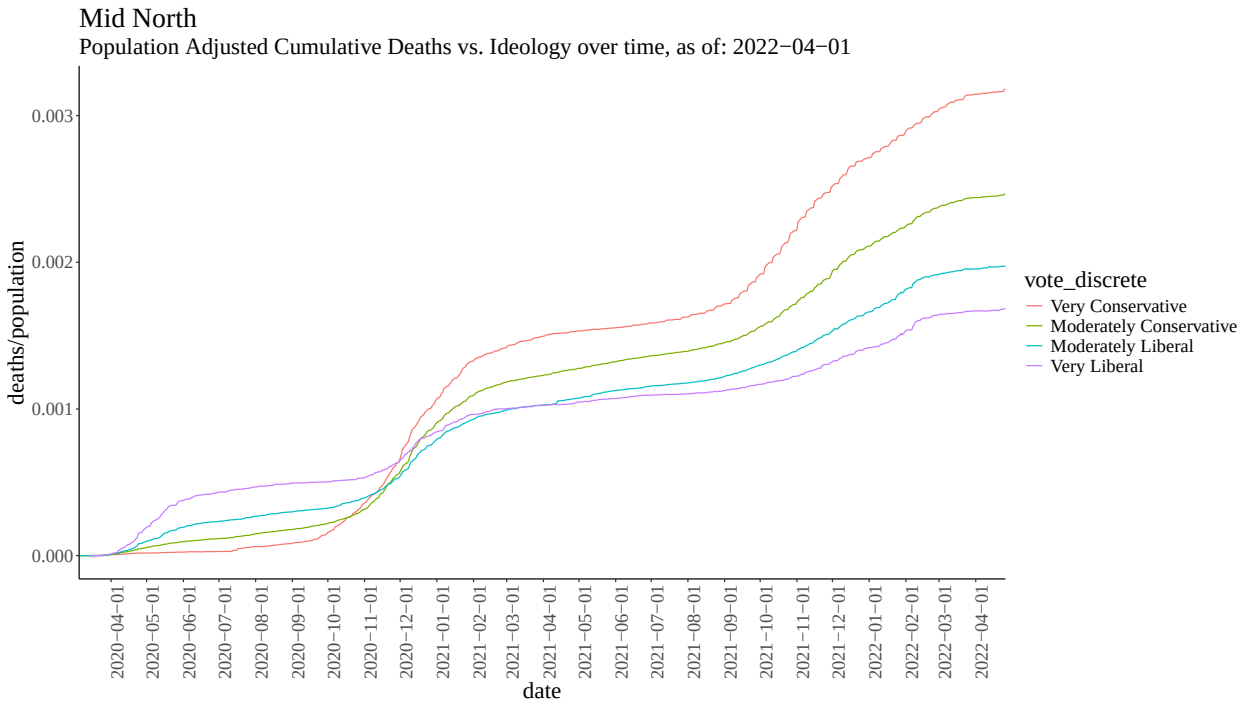


Table T9: Region 8 (Midnorth): Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-7.91859	**1.95e-97**	-5.47511	**7.93e-65**	-7.50607	**2.7e-92**
Socioeconomic	0.18120	1	0.59815	1	0.39659	1
Household Composition & Disability	0.39364	1	0.66044	**0.0016**	0.73803	**0.000143**
Housing Type & Transportation	0.30730	1	0.38971	0.521	-0.04798	1
Unemployed	0.50777	1	2.08208	**0.0201**	0.92001	1
Food Insecurity	-1.76848	**0.0275**	-1.57352	0.291	-1.61032	0.0853
Broadband Access	1.61826	1	-1.61975	1	1.17985	1
Diabetes	1.51712	1	1.19272	1	1.41921	1
Obesity	0.34548	1	-1.55514	**0.000938**	-1.09261	0.203
Population Density	0.03450	1	-0.10705	0.143	0.07310	1
Associations	2.05406	**8.48e-06**	0.05882	1	0.99016	1
Age over 65	0.00000	1	0.00001	**0.0346**	0.00000	1
Democratic Voting Pct	0.03840	1	-0.32925	1	-0.63898	1
Vaccination Rate	0.35246	1	-2.03345	**7.48e-05**	-0.94783	1
Minority Status and Language	-0.07720	1	-0.41948	1	0.13485	1
Uninsured Adults	-0.32234	1	0.15231	1	0.15209	1

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.599	0.658	0.512

Part 3: Data Analysis and Regression: Region 9 (West)

Figure S15: Population Adjusted Cumulative Deaths vs Ideology over time

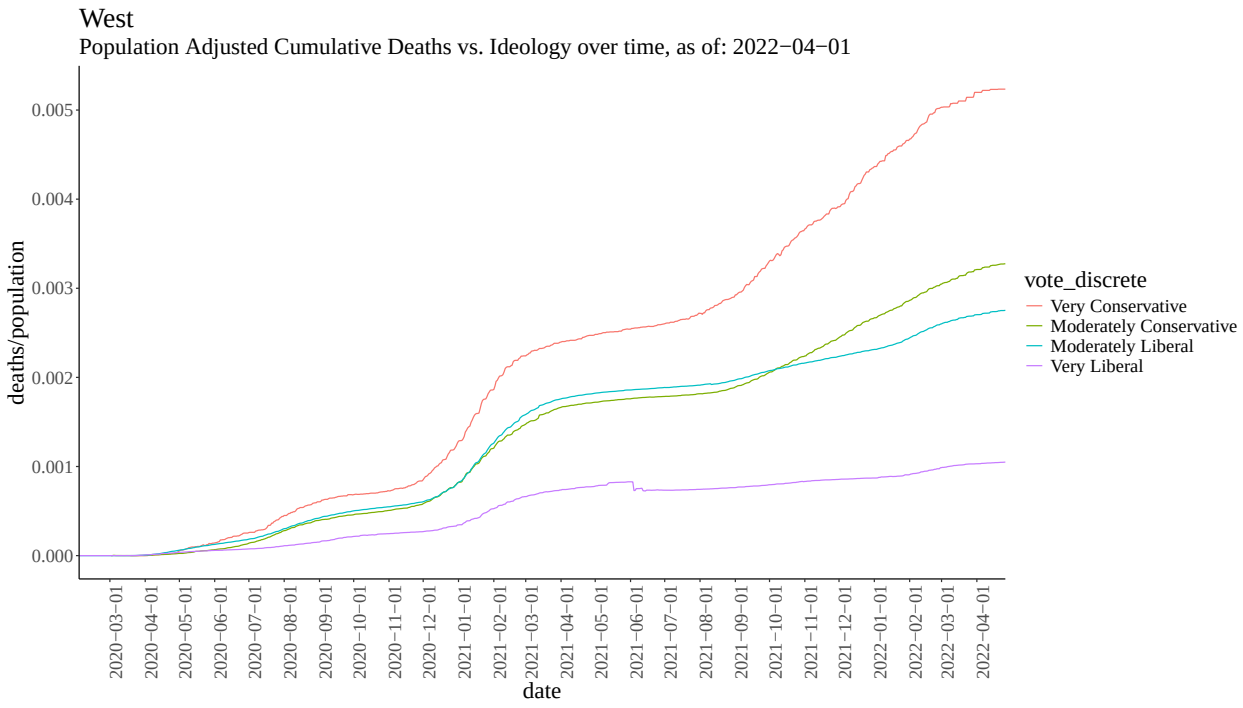


Table T10: Region 9 (West): Regression Model Results

	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-7.98148	**8.95e-20**	-6.66531	**2.1e-17**	-8.37587	**2.29e-23**
Socioeconomic	0.37314	1	-0.34068	1	-0.48551	1
Household Composition & Disability	0.64966	1	0.91646	0.53	0.96979	0.0759
Housing Type & Transportation	0.06940	1	-0.07575	1	0.10618	1
Unemployed	-0.33010	1	-0.74193	1	-0.19793	1
Food Insecurity	0.55654	1	1.33930	1	2.02330	1
Broadband Access	-1.14067	1	2.33539	1	-1.59325	1
Diabetes	0.45332	1	-0.25726	1	0.25752	1
Obesity	-0.22381	1	0.33973	1	0.43690	1
Population Density	-0.02014	1	0.01582	1	0.01915	1
Associations	-2.57495	1	0.25890	1	2.03072	1
Age over 65	0.00000	**0.000941**	0.00000	1	0.00000	0.172
Democratic Voting Pct	-1.99598	**0.00721**	0.45966	1	-1.94638	**0.0154**
Vaccination Rate	2.01693	0.309	-3.28240	**0.00398**	0.21535	1
Minority Status and Language	0.58953	1	-0.36186	1	-0.13905	1
Uninsured Adults	2.06686	0.467	1.83145	1	3.31353	**0.000356**

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.834	0.856	0.898

Part 3: Data Analysis and Regression: Region 10 (Pacific NW)

Figure S16: Population Adjusted Cumulative Deaths vs Ideology over time

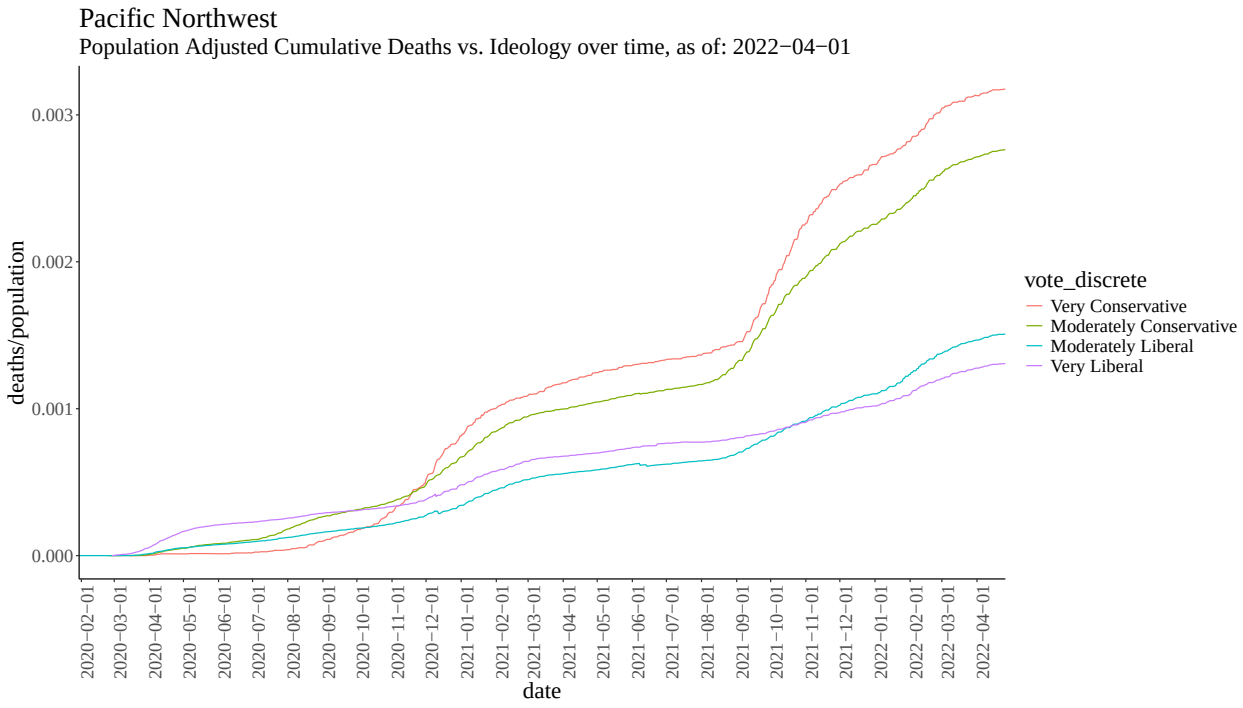


Table T11: Region 10 (Pacific Northwest): Regression Model Results

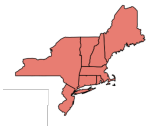
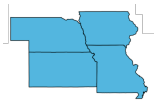
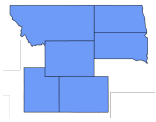
	Alpha Wave		Delta Wave		Omicron Wave	
	Estimates	Adjusted P values	Estimates	Adjusted P values	Estimates	Adjusted P values
Intercept	-6.96286	**7.27e-17**	-6.05658	**6.59e-20**	-8.34470	**1.82e-31**
Socioeconomic	-0.70491	1	0.46027	1	-0.69910	1
Household Composition & Disability	-0.00756	1	0.49524	1	0.59038	0.433
Housing Type & Transportation	0.96654	0.0576	0.19635	1	0.16829	1
Unemployed	0.58820	1	0.35461	1	1.04207	1
Food Insecurity	-0.37086	1	0.06493	1	1.27980	1
Broadband Access	1.28472	1	-1.12118	1	2.18260	1
Diabetes	0.60859	1	1.72064	0.376	1.00624	1
Obesity	-1.47614	0.824	-1.88333	**0.00139**	-0.52021	1
Population Density	0.17573	**0.0122**	0.10403	0.635	0.05367	1
Associations	1.13769	1	1.68158	1	-0.64760	1
Age over 65	0.00000	1	0.00000	1	0.00000	1
Democratic Voting Pct	-3.14551	**0.00511**	-2.12781	**0.0185**	-0.71067	1
Vaccination Rate	-1.10760	1	-1.32513	1	-0.31436	1
Minority Status and Language	0.68178	1	-0.62560	1	0.06624	1
Uninsured Adults	2.12267	0.36	0.65449	1	0.47717	1

Note:
Bold = significant value

	Alpha Wave	Delta Wave	Omicron Wave
Pseudo R2	0.63	0.853	0.674

Part 3: Regression Modeling Summarized Model Results

Table T12: Regionalized Regression Model Results: Significance Table

Regions	Alpha	AlphaR2	Delta	DeltaR2	Omicron	OmicronR2	Map
Regions 1-2	Vaccination Rate, Minority Status	0.746		0.687	Food Insecurity, Voting, Uninsured Adults	0.579	
Region 3		0.601		0.902		0.846	
Region 4	Diabetes, Age over 65+, Vaccination Rate	0.584	Food Insecurity, Diabetes, Voting	0.667	Diabetes, Population Density	0.51	
Region 5	Housing Type, Population Density, Social Associations, Age over 65+, Voting	0.475	Diabetes, Vaccination Rate	0.729	Diabetes, Vaccination Rate	0.663	
Region 6	Socioeconomics, Household Composition, Broadband Access, Age over 65+, Uninsured Adults	0.735	Household Composition, Housing Type, Voting, Vaccination Rate, Uninsured Adults	0.646	Socioeconomics, Household Composition, Uninsured Adults	0.543	
Region 7	Socioeconomics, Food Insecurity, Social Associations, Age over 65+, Uninsured Adults	0.406	Broadband Access, Population Density, Voting, Minority Status	0.705	Diabetes, Minority Status	0.469	
Region 8	Food Insecurity, Social Associations	0.599	Household Composition, Unemployment, Obesity, Age over 65+, Vaccination Rate	0.658	Household Composition	0.512	
Region 9	Age over 65+, Voting	0.834	Vaccination Rate	0.856	Voting, Uninsured Adults	0.898	
Region 10	Population Density, Voting	0.63	Obesity, Voting	0.853		0.674	

Part 4: Spatial Autocorrelation

Morans I is a test of spatial autocorrelation.

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \left(x_i - \overline{x}\right) \left(x_j - \overline{x}\right)}{\sum_{i=1}^{n} \left(x_i - \overline{x}\right)^2}$$

- N: The number of spatial units indexed by i and j
- W: The sum of all wij
- x: The variable of interest (in this instance, cumulative COVID cases, adjusted for population)
- x: The mean of x
- wij: A matrix of spatial weights

Figure S17: Morans I results: United States - Alpha Wave, Dependent Variable

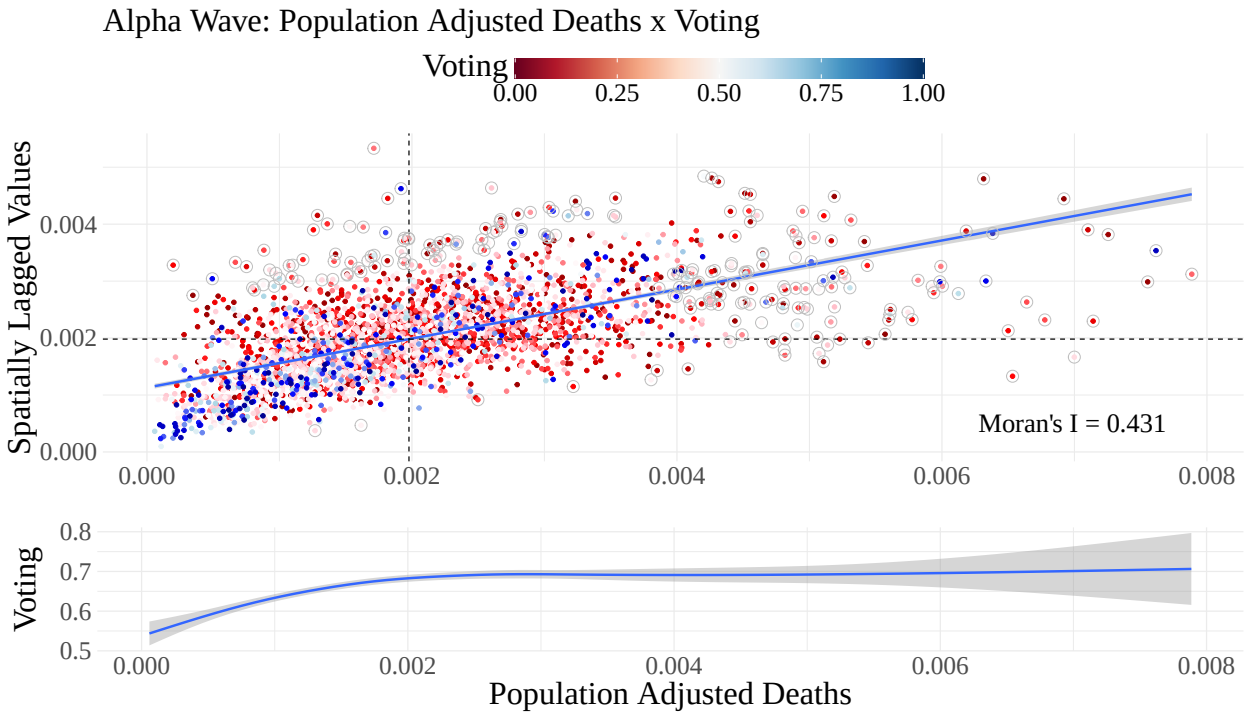
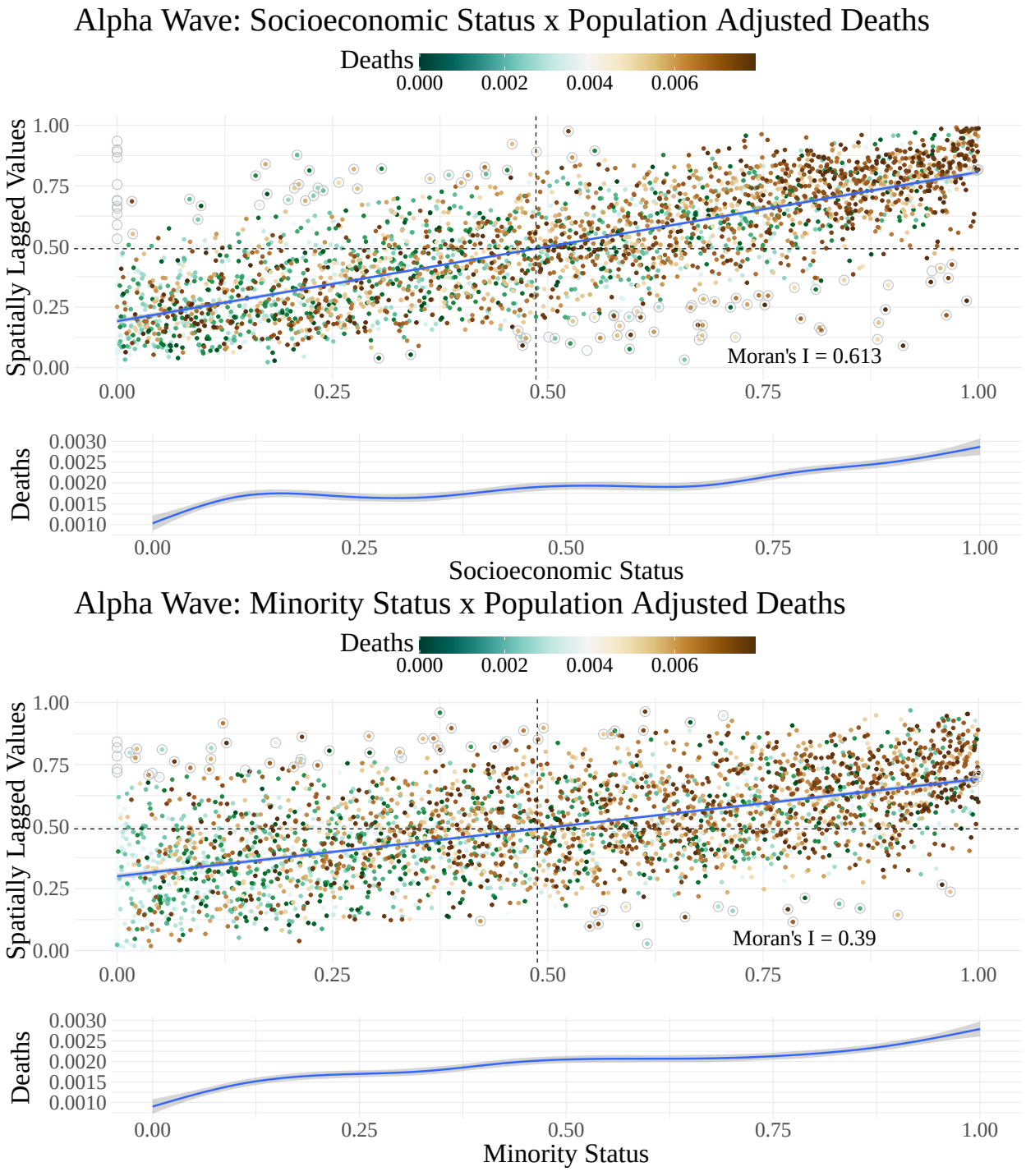
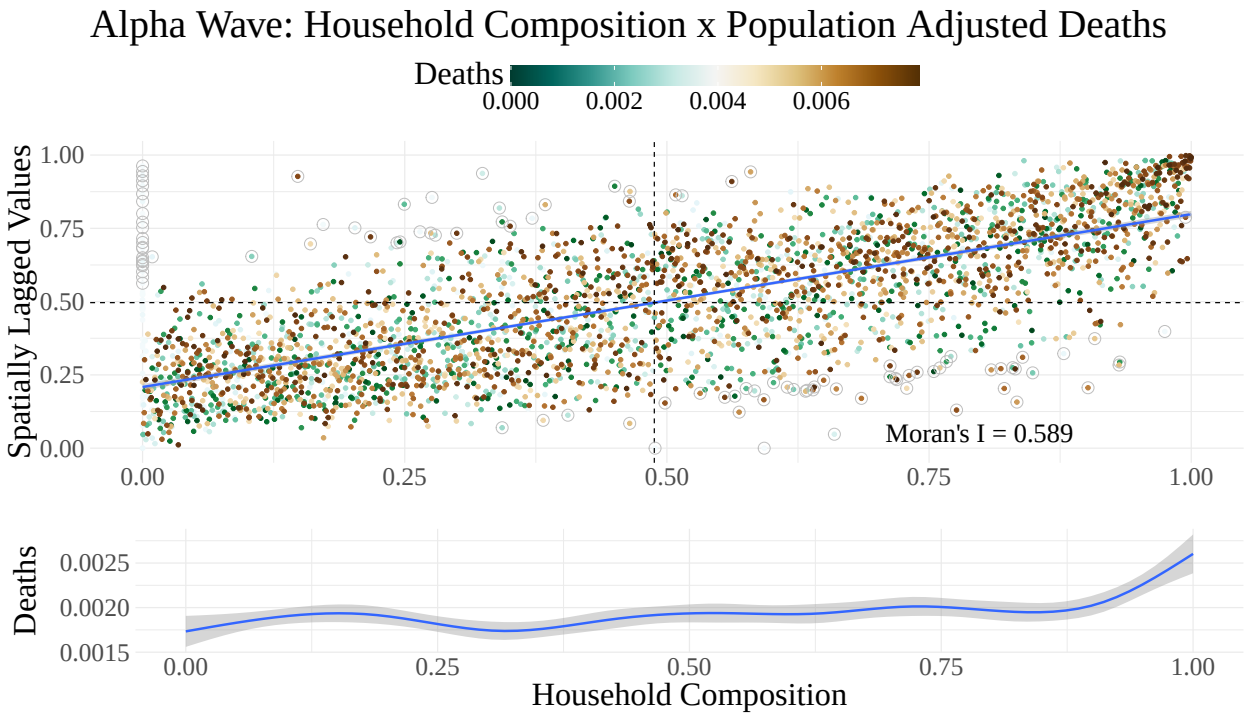
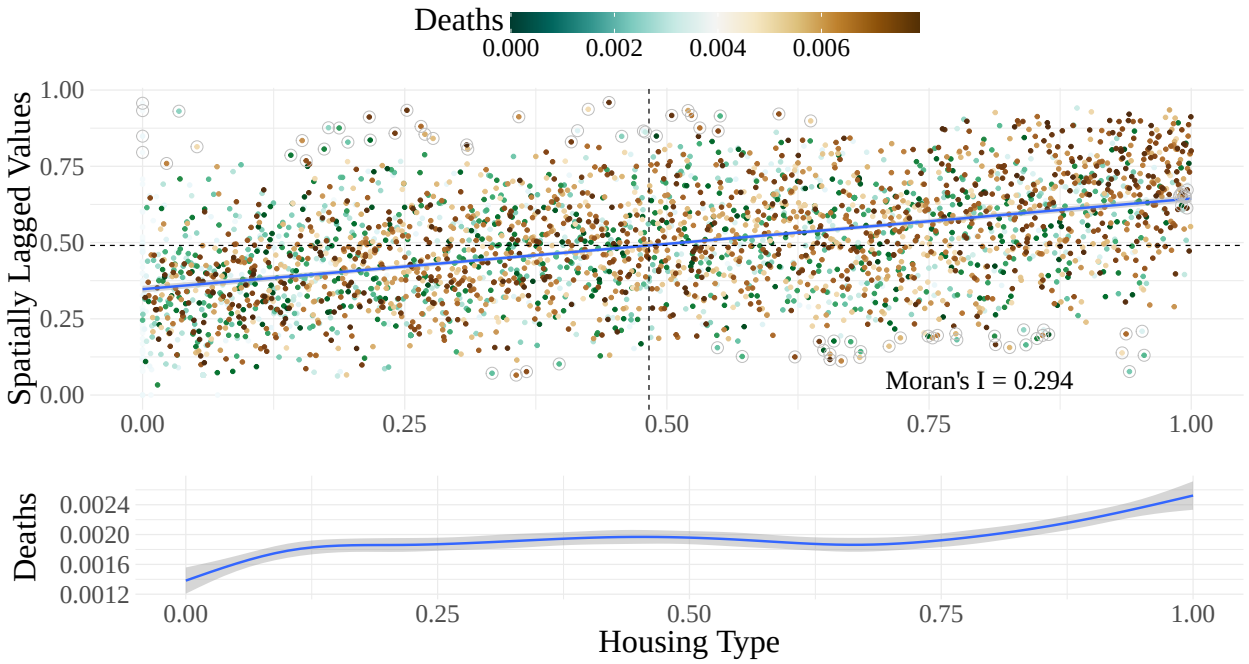
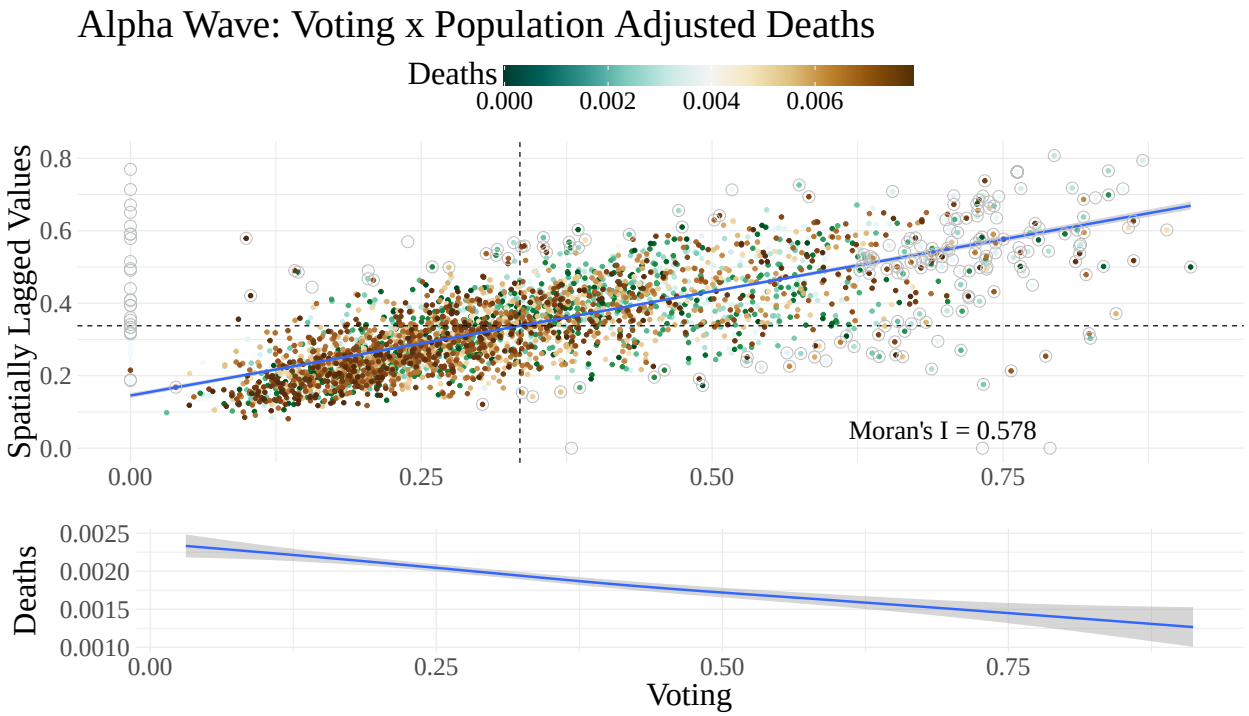


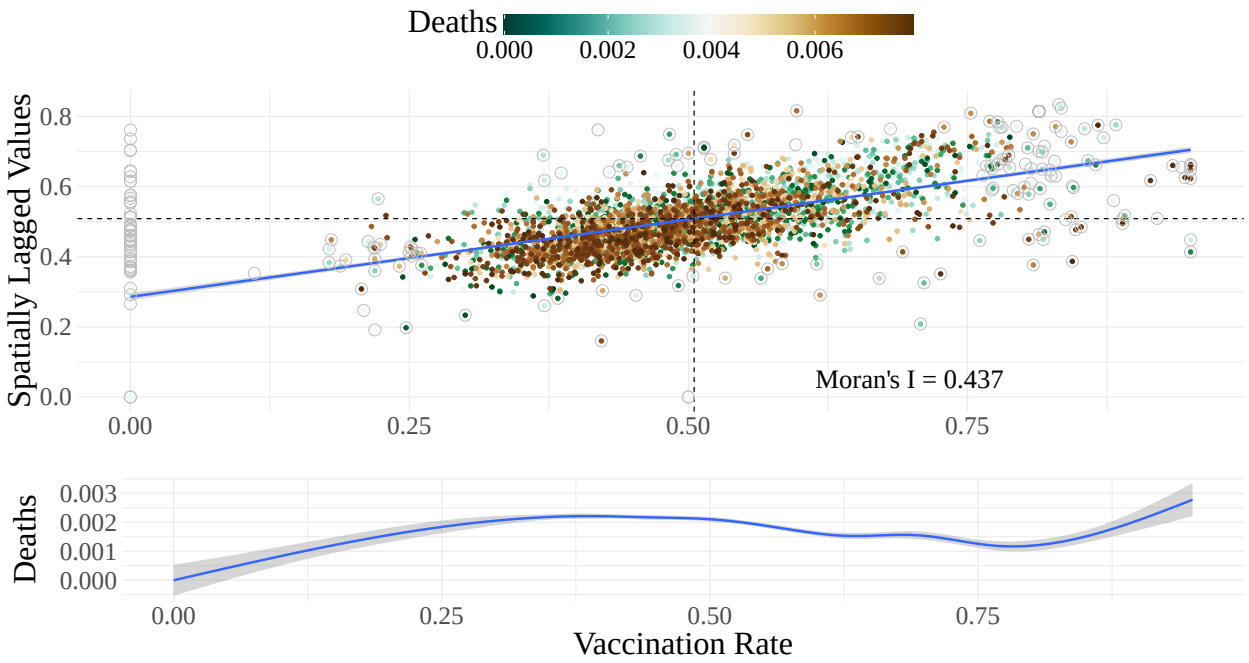
Figure S18: Morans I results: United States - Alpha Wave, Independent Variables



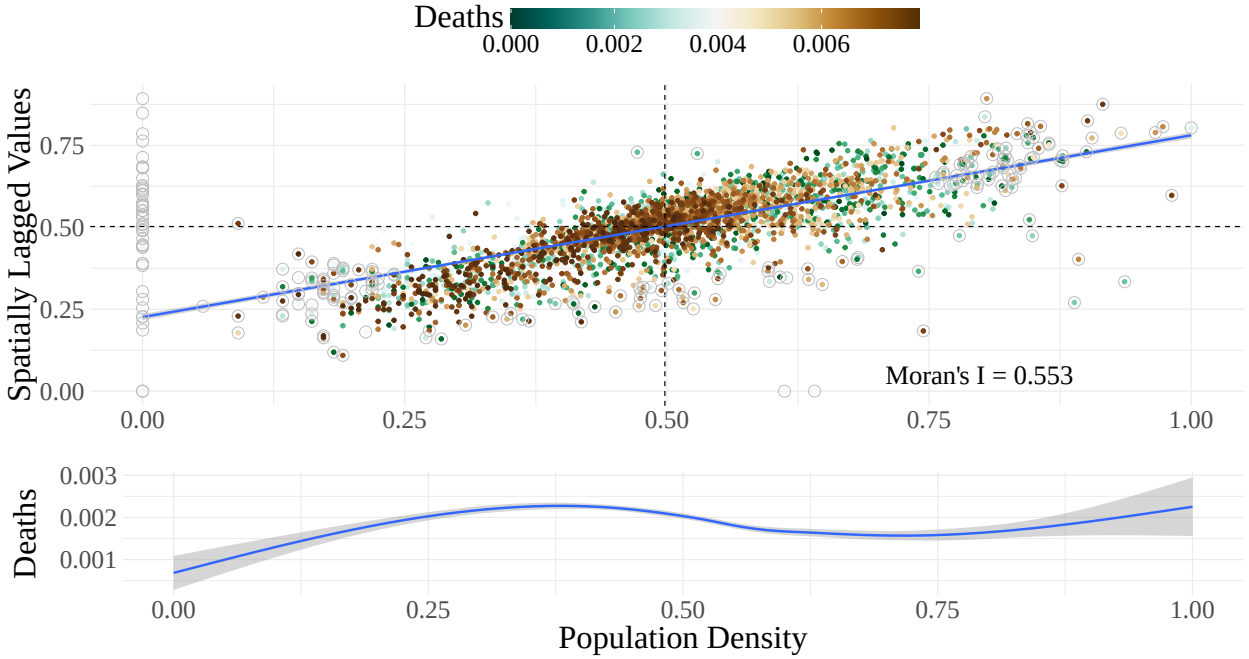

Alpha Wave: Household Composition x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
1.00
0.75
0.50
0.25
0.00
Moran's I = 0.589
0.00
0.25
0.50
0.75
1.00
Deaths
0.0025
0.0020
0.0015
Household Composition


Alpha Wave: Housing Type x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
1.00
0.75
0.50
0.25
0.00
Moran's I = 0.294
0.00
0.25
0.50
0.75
1.00
Deaths
0.0024
0.0020
0.0016
0.0012
Housing Type

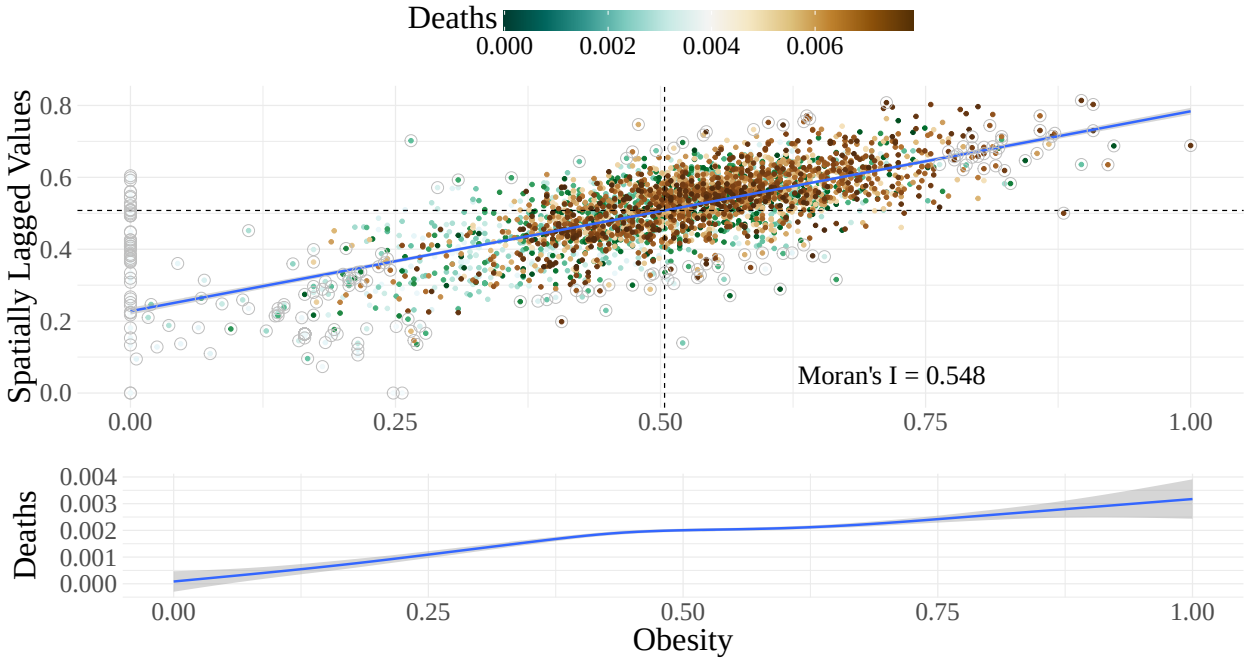

Alpha Wave: Voting x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.0
0.2
0.4
0.6
0.8
Moran's I = 0.578
0.00
0.25
0.50
0.75
Deaths
0.0010
0.0015
0.0020
0.0025
Voting

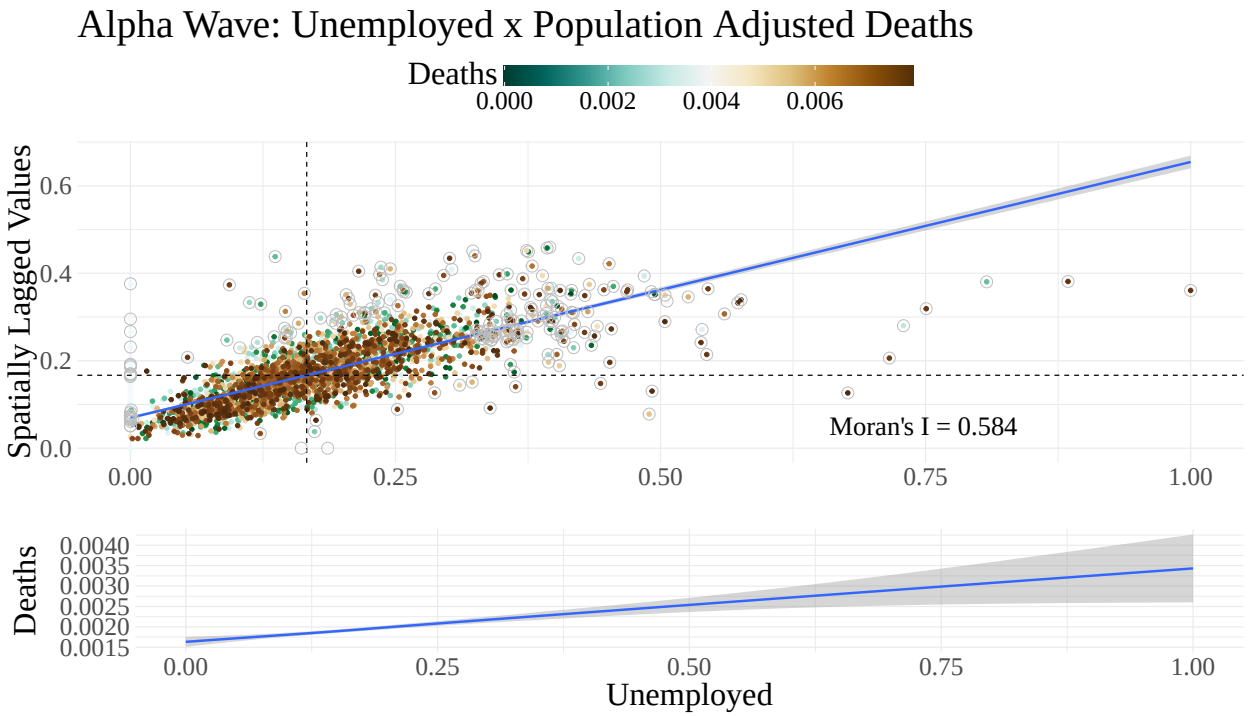

Alpha Wave: Vaccination Rate x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.0
0.2
0.4
0.6
0.8
Moran's I = 0.437
0.00
0.25
0.50
0.75
Deaths
0.000
0.001
0.002
0.003
Vaccination Rate

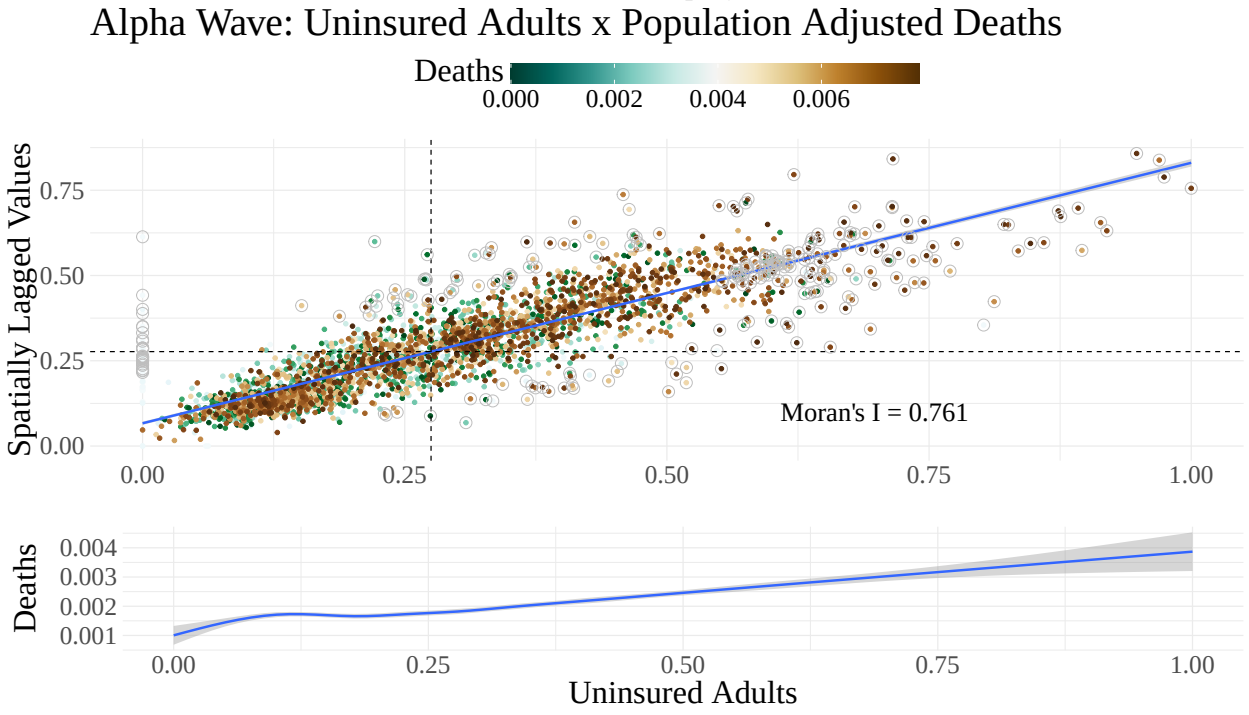
Alpha Wave: Population Density x Population Adjusted Deaths

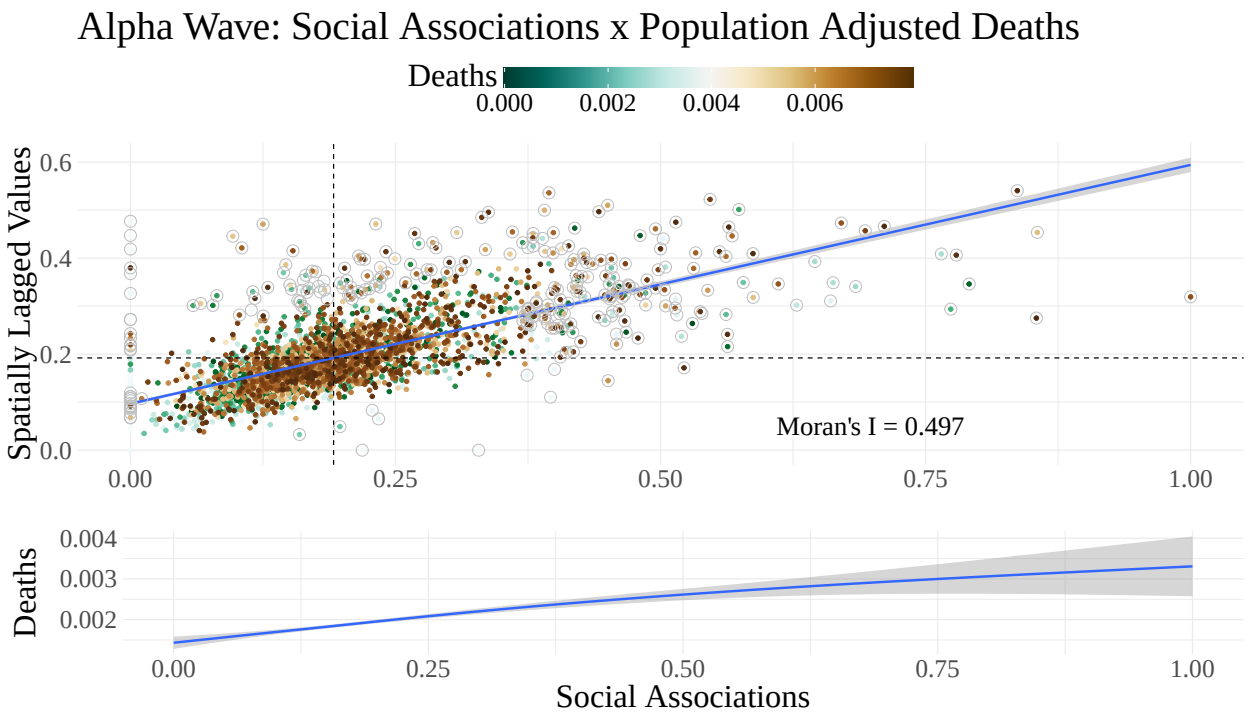


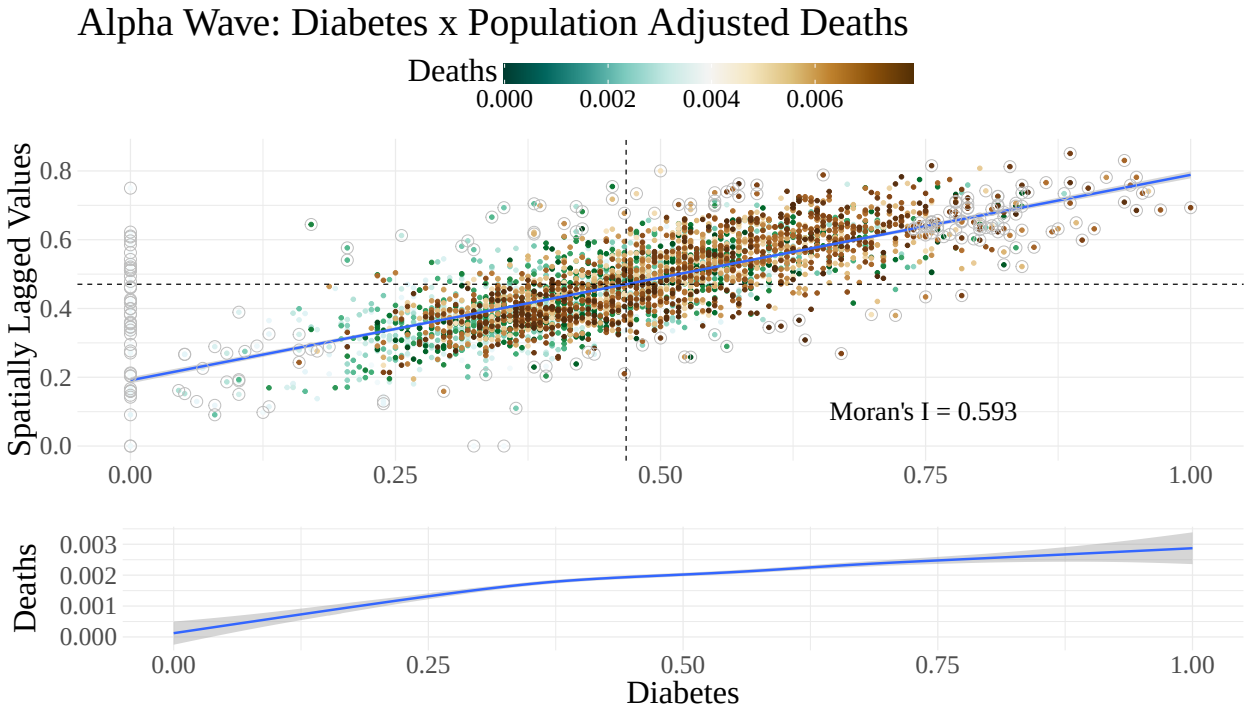
Alpha Wave: Obesity x Population Adjusted Deaths

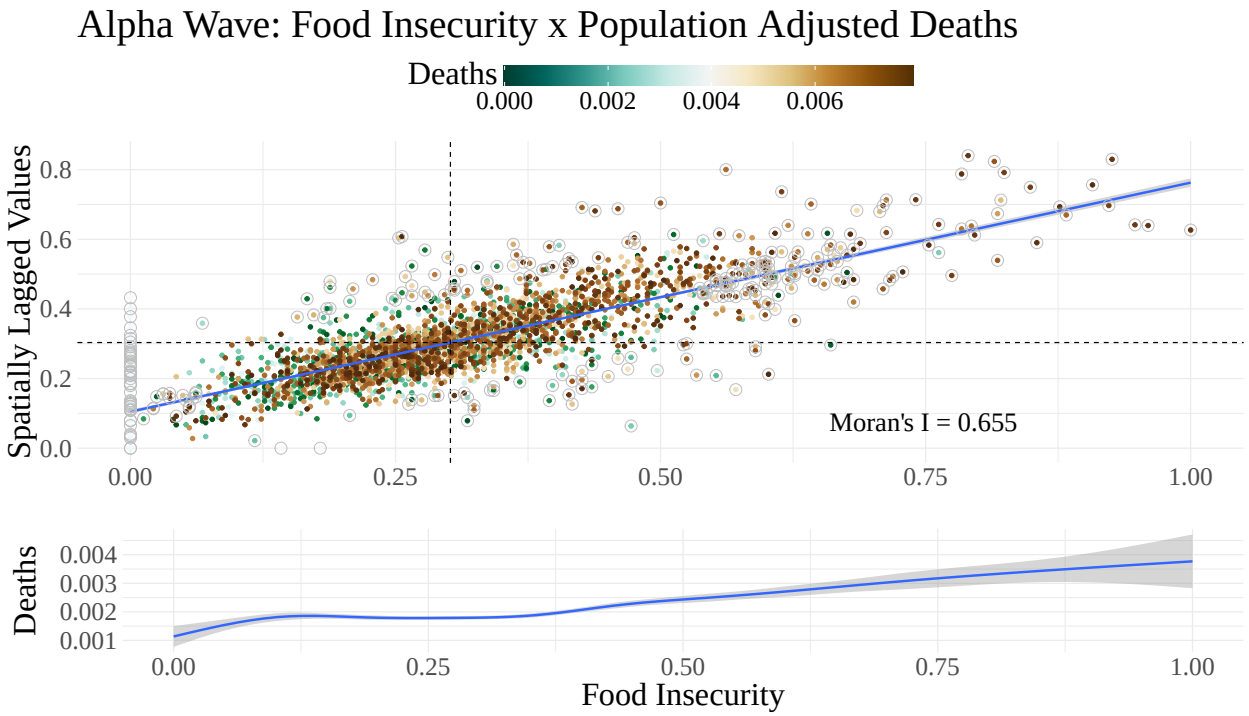


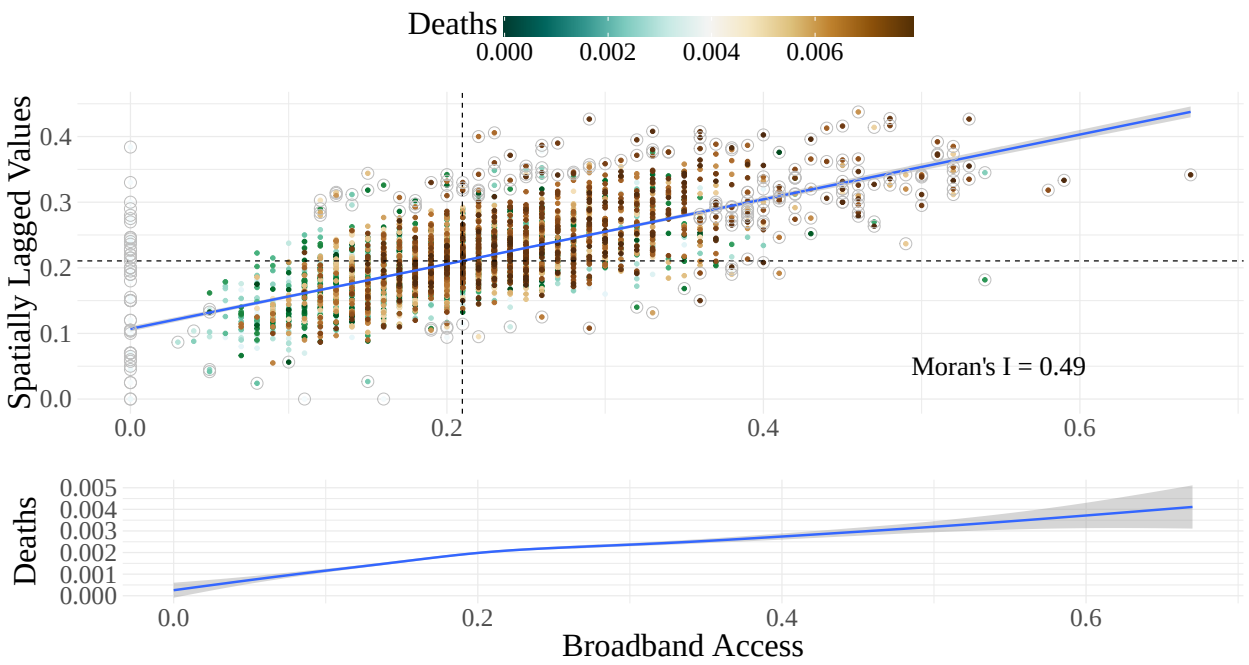

Alpha Wave: Unemployed x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.0
0.2
0.4
0.6
Moran's I = 0.584
0.00
0.25
0.50
0.75
1.00
Deaths
0.0040
0.0035
0.0030
0.0025
0.0020
0.0015
Unemployed


Alpha Wave: Uninsured Adults x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.00
0.25
0.50
0.75
Moran's I = 0.761
0.00
0.25
0.50
0.75
1.00
Deaths
0.004
0.003
0.002
0.001
Uninsured Adults


Alpha Wave: Social Associations x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.6
0.4
0.2
0.0
Moran's I = 0.497
0.00
0.25
0.50
0.75
1.00
Deaths
0.004
0.003
0.002
Social Associations


Alpha Wave: Diabetes x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.8
0.6
0.4
0.2
0.0
Moran's I = 0.593
0.00
0.25
0.50
0.75
1.00
Deaths
0.003
0.002
0.001
0.000
Diabetes


Alpha Wave: Food Insecurity x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.0
0.2
0.4
0.6
0.8
Moran's I = 0.655
0.00
0.25
0.50
0.75
1.00
Deaths
0.001
0.002
0.003
0.004
Food Insecurity


Alpha Wave: Broadband Access x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.0
0.1
0.2
0.3
0.4
Moran's I = 0.49
0.0
0.2
0.4
0.6
Deaths
0.000
0.001
0.002
0.003
0.004
0.005
Broadband Access

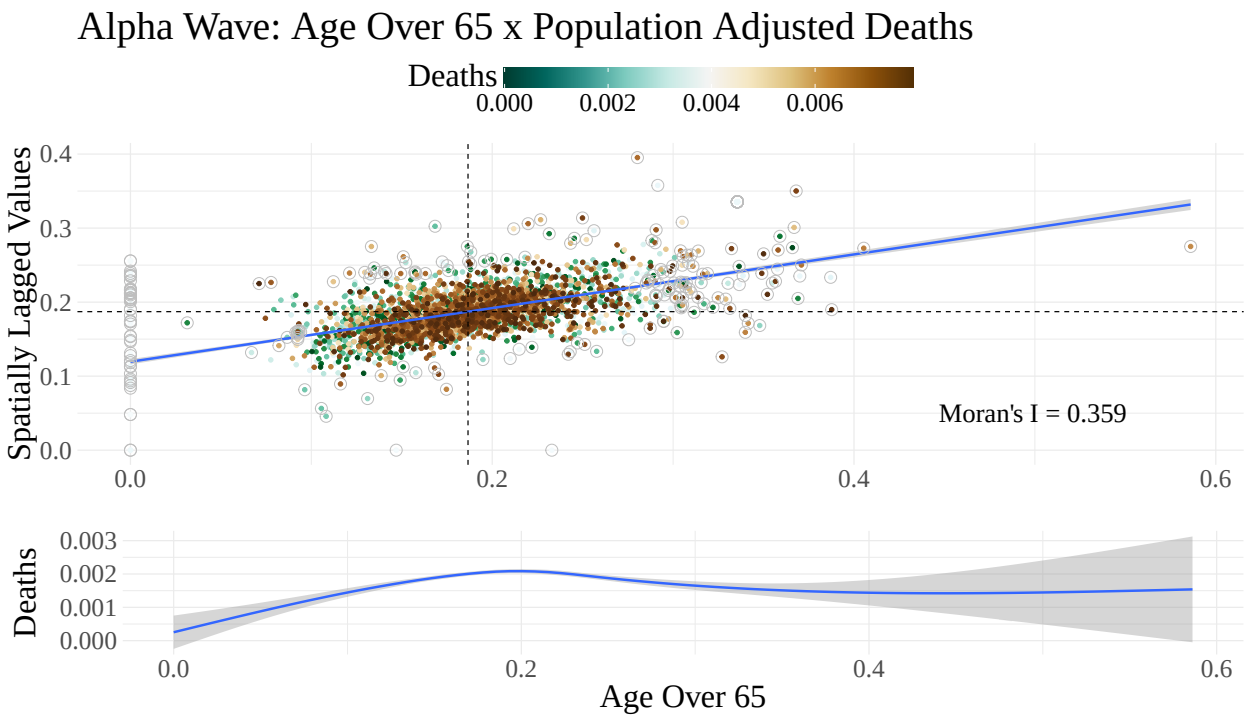

Alpha Wave: Age Over 65 x Population Adjusted Deaths
Deaths
0.000
0.002
0.004
0.006
Spatially Lagged Values
0.4
0.3
0.2
0.1
0.0
Moran's I = 0.359
0.0
0.2
0.4
0.6
Deaths
0.003
0.002
0.001
0.000
0.0
0.2
0.4
0.6
Age Over 65

Figure S19: Morans I results: United States - Delta Wave, Dependent Variable

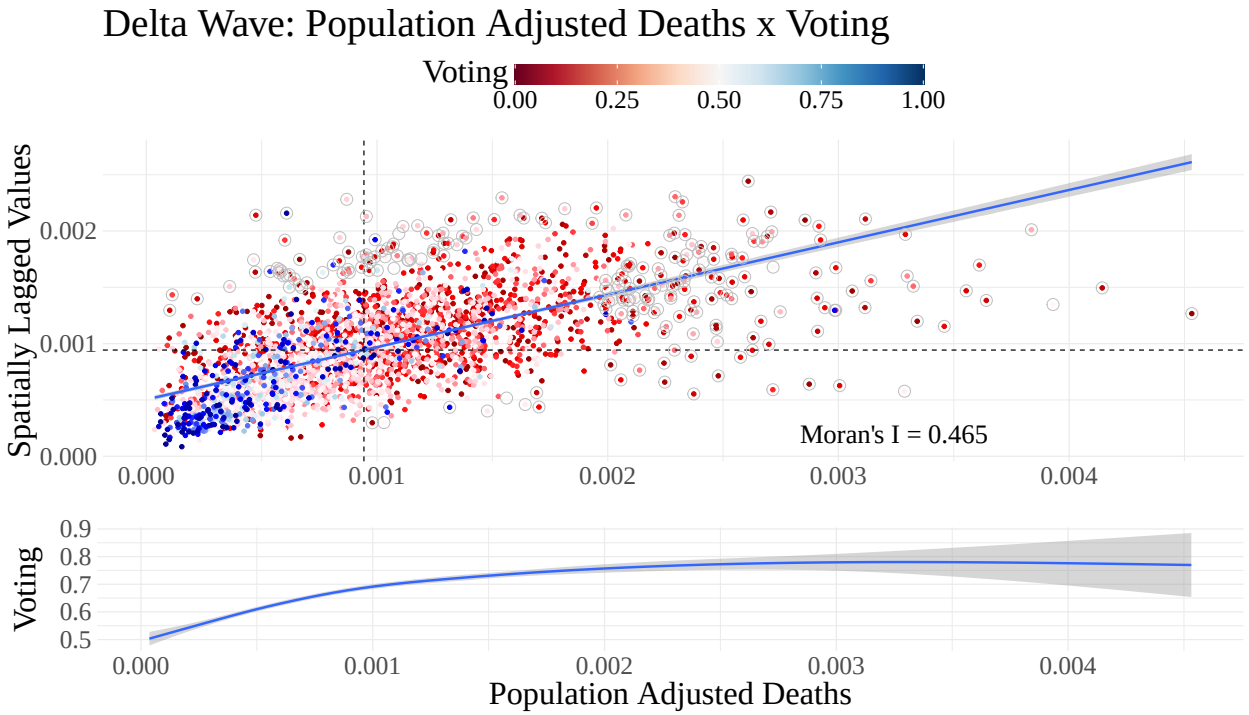
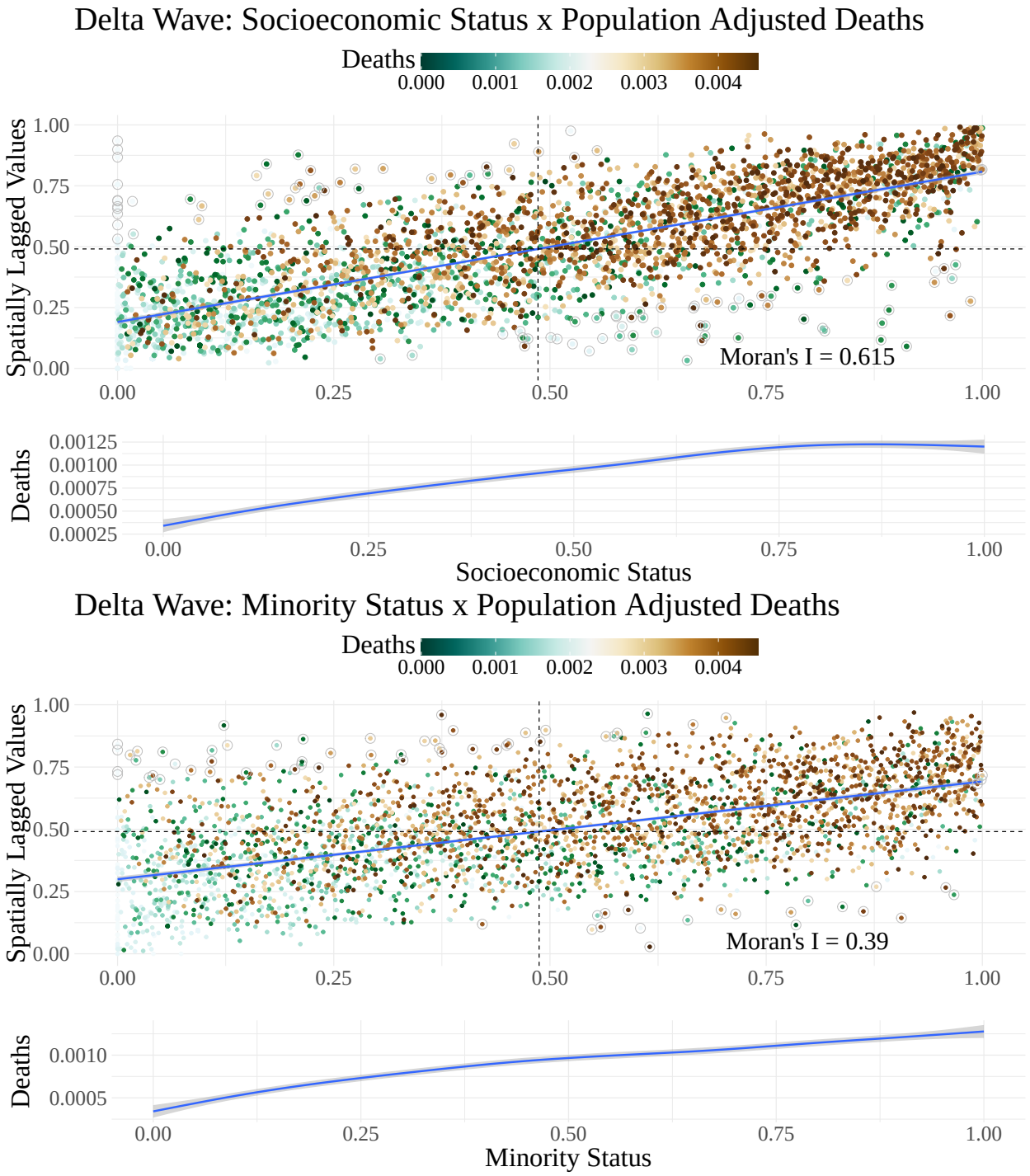
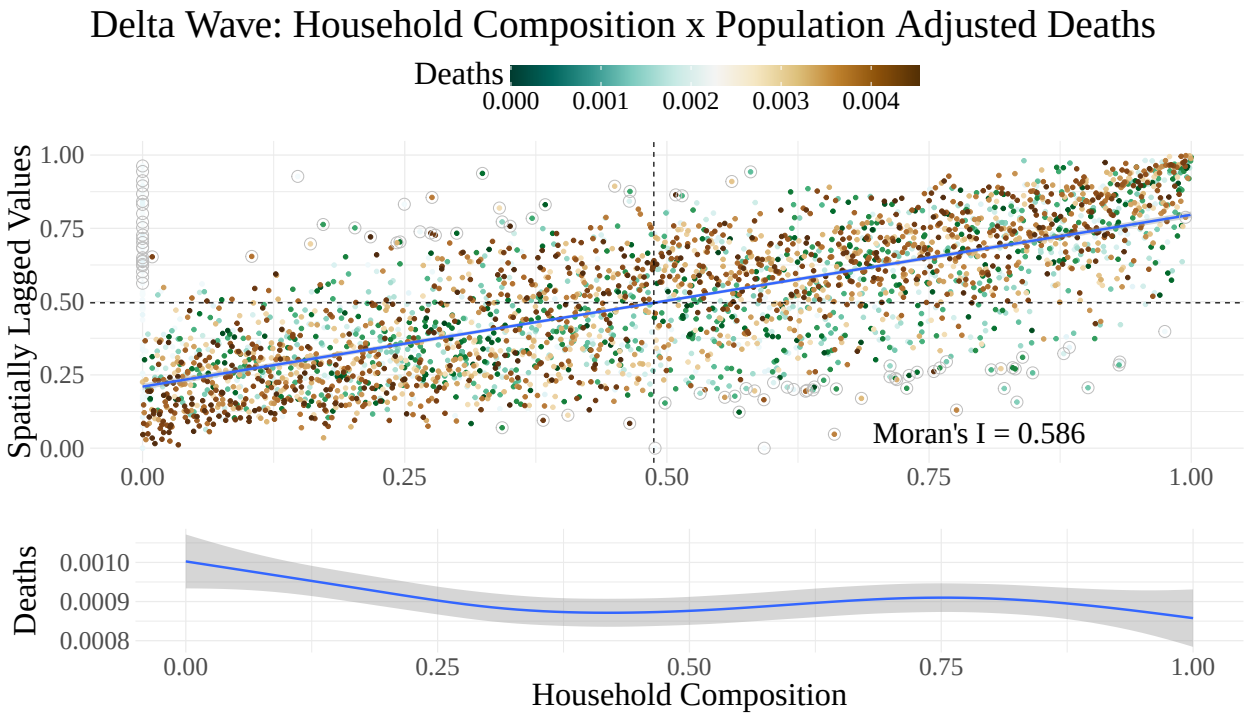
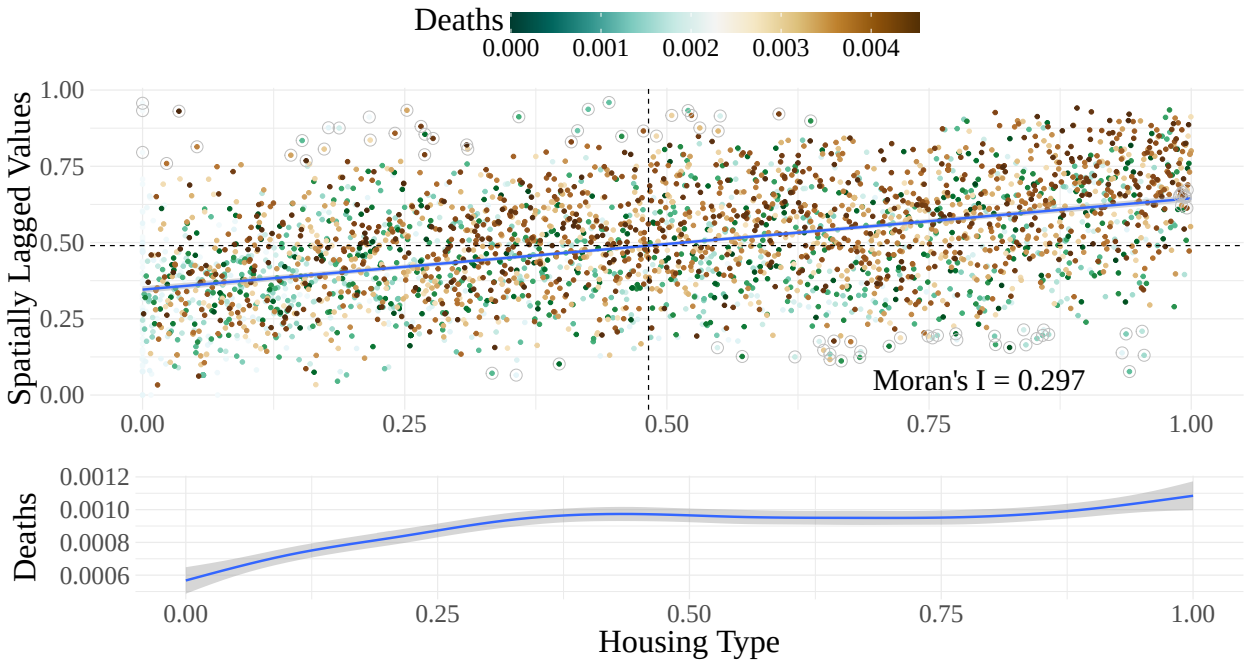
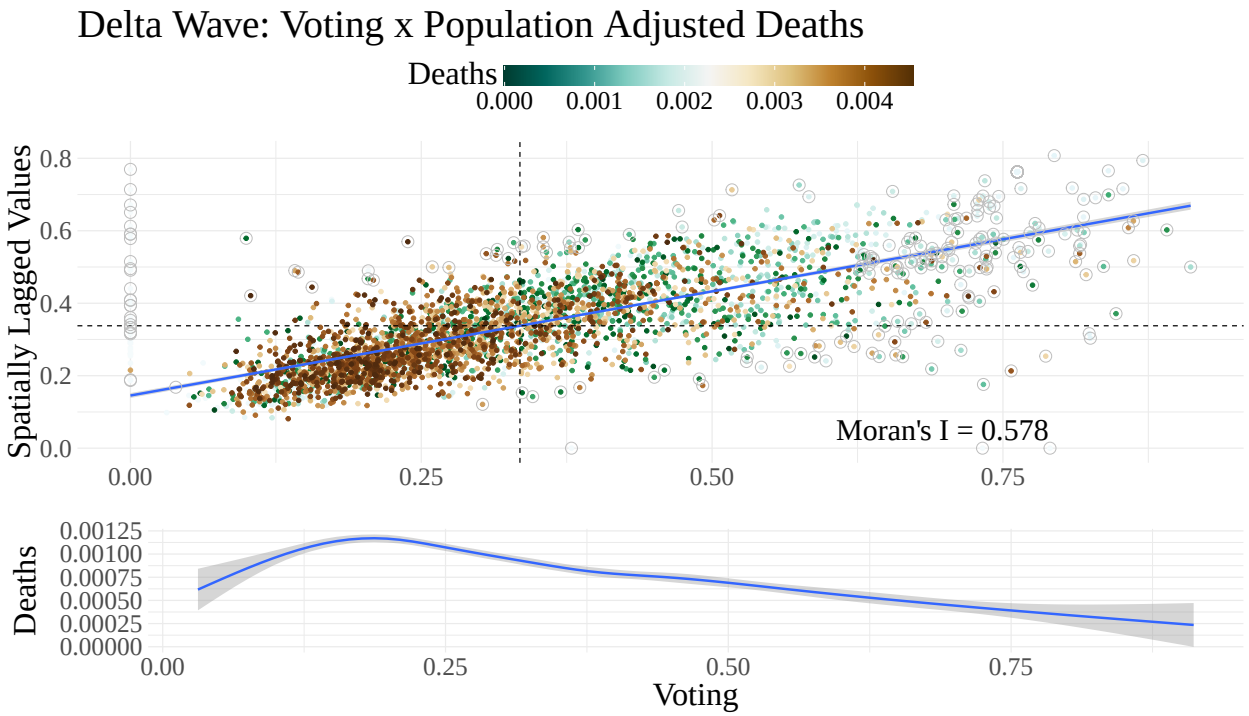


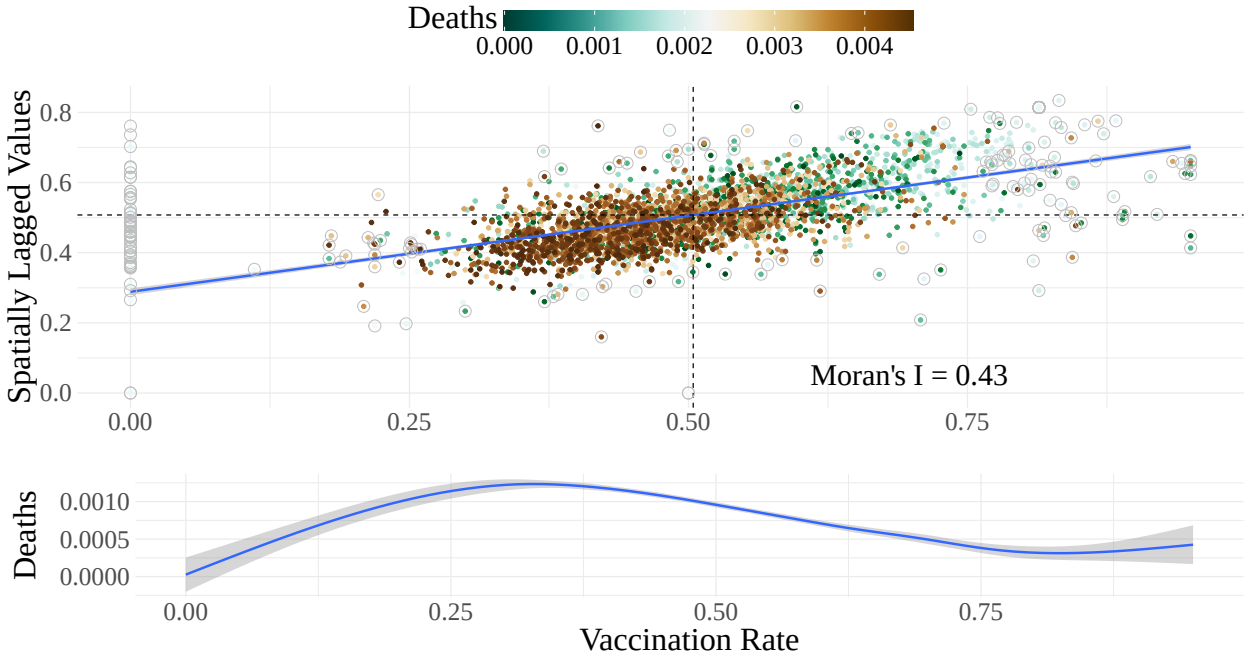
Figure S20: Morans I results: United States - Delta Wave, Independent Variables

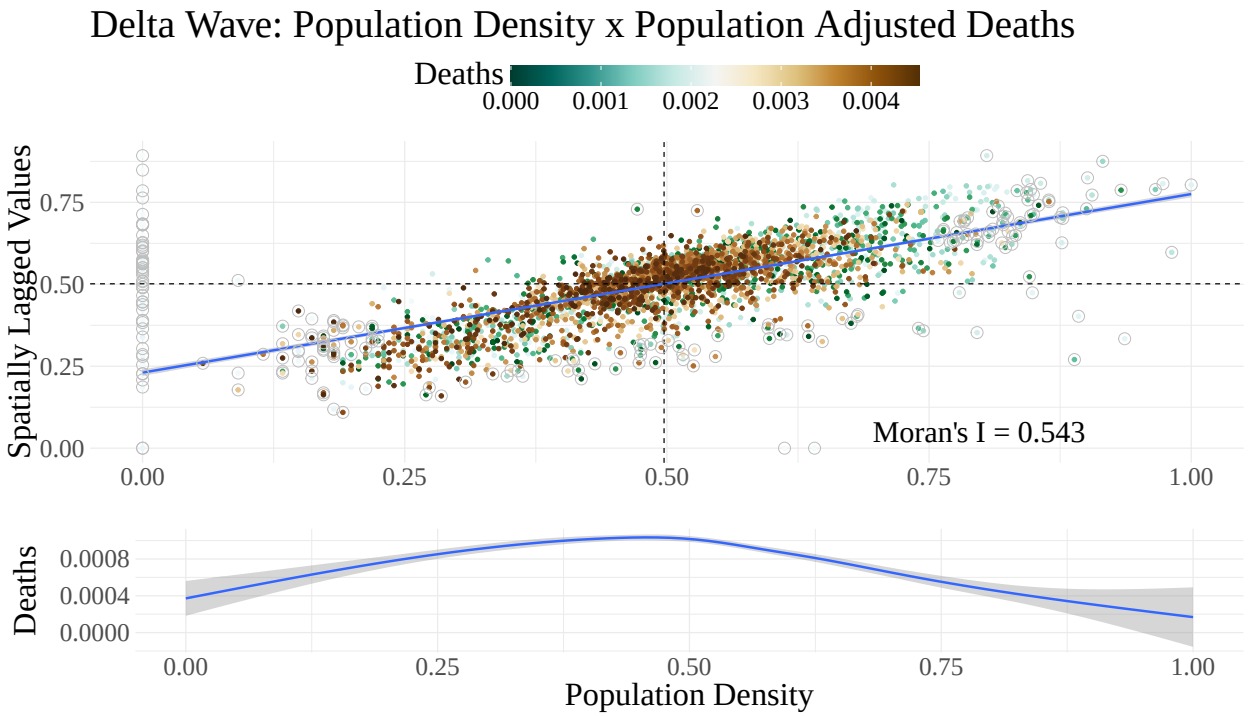


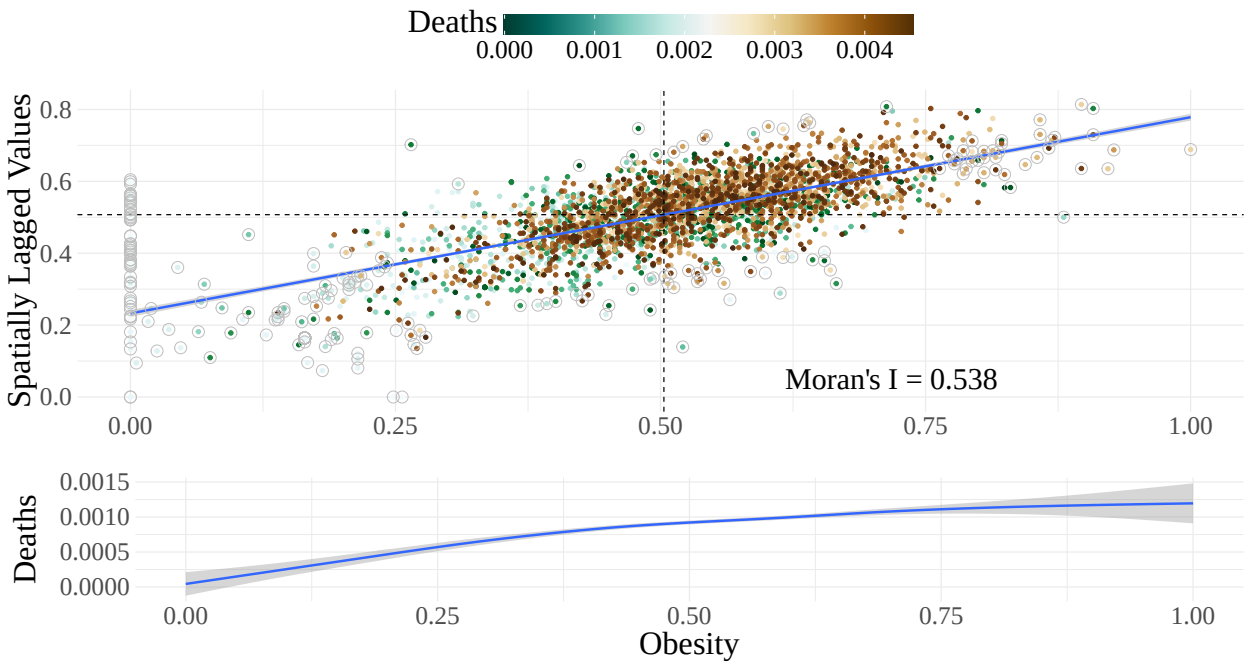

Delta Wave: Household Composition x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
1.00
0.75
0.50
0.25
0.00
Moran's I = 0.586
0.00
0.25
0.50
0.75
1.00
Deaths
0.0010
0.0009
0.0008
Household Composition

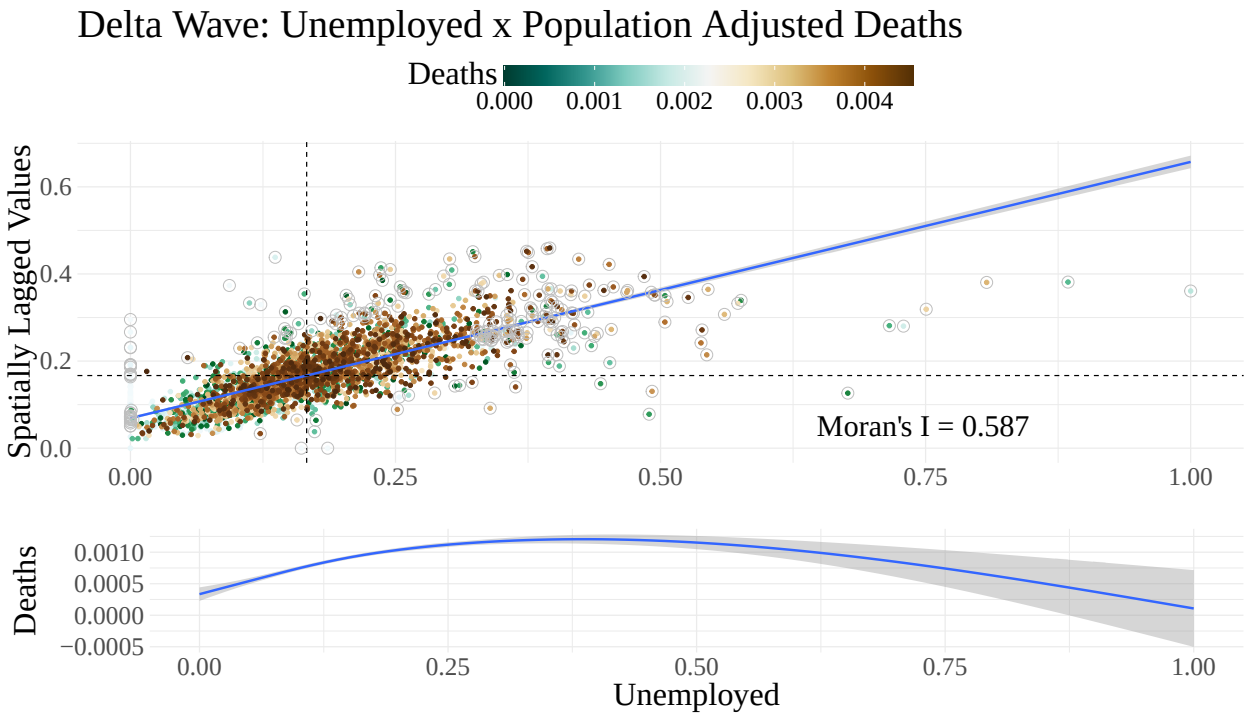

Delta Wave: Housing Type x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
1.00
0.75
0.50
0.25
0.00
Moran's I = 0.297
0.00
0.25
0.50
0.75
1.00
Deaths
0.0012
0.0010
0.0008
0.0006
Housing Type

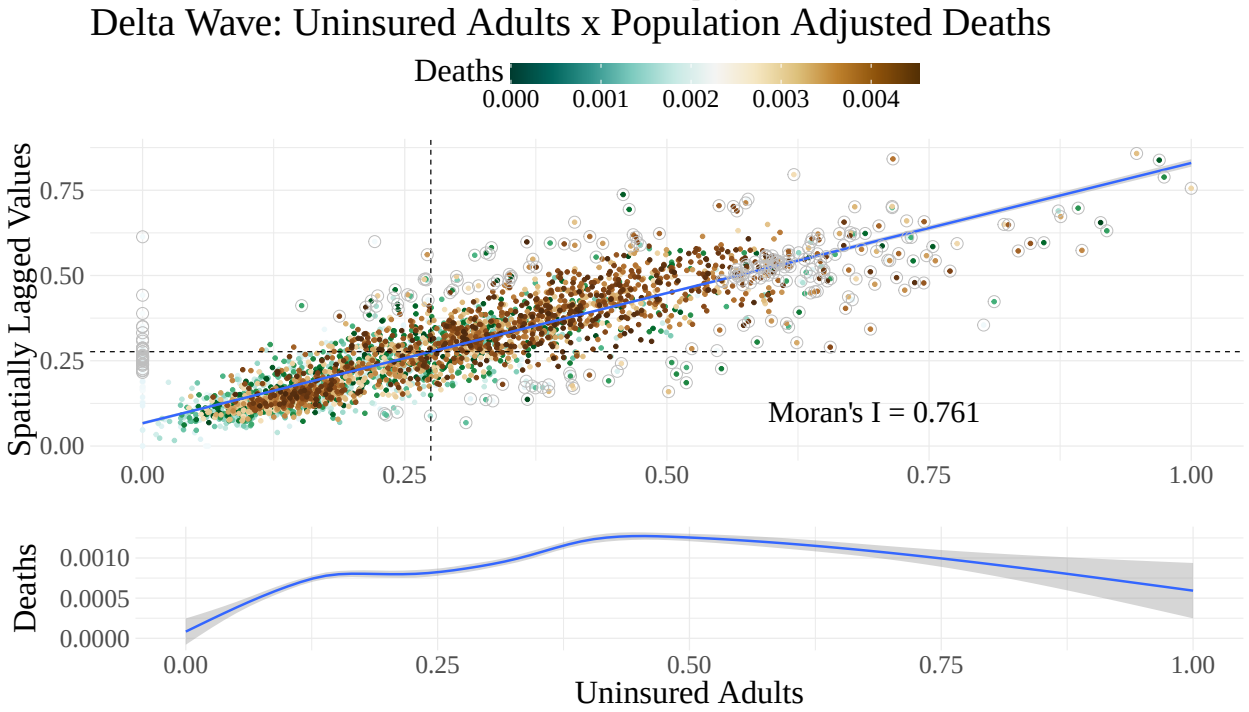

Delta Wave: Voting x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.8
0.6
0.4
0.2
0.0
0.00
0.25
0.50
0.75
Moran's I = 0.578
Deaths
0.00125
0.00100
0.00075
0.00050
0.00025
0.00000
0.00
0.25
0.50
0.75
Voting

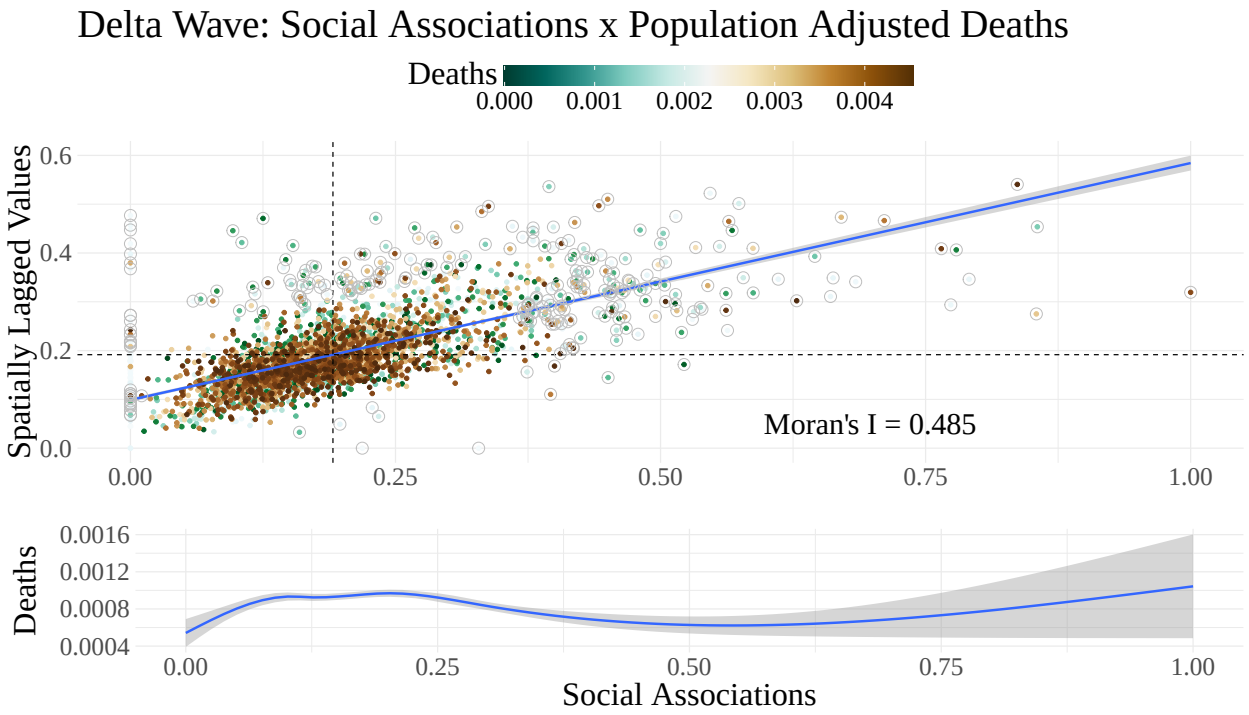

Delta Wave: Vaccination Rate x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.8
0.6
0.4
0.2
0.0
0.00
0.25
0.50
0.75
Moran's I = 0.43
Deaths
0.0010
0.0005
0.0000
0.00
0.25
0.50
0.75
Vaccination Rate

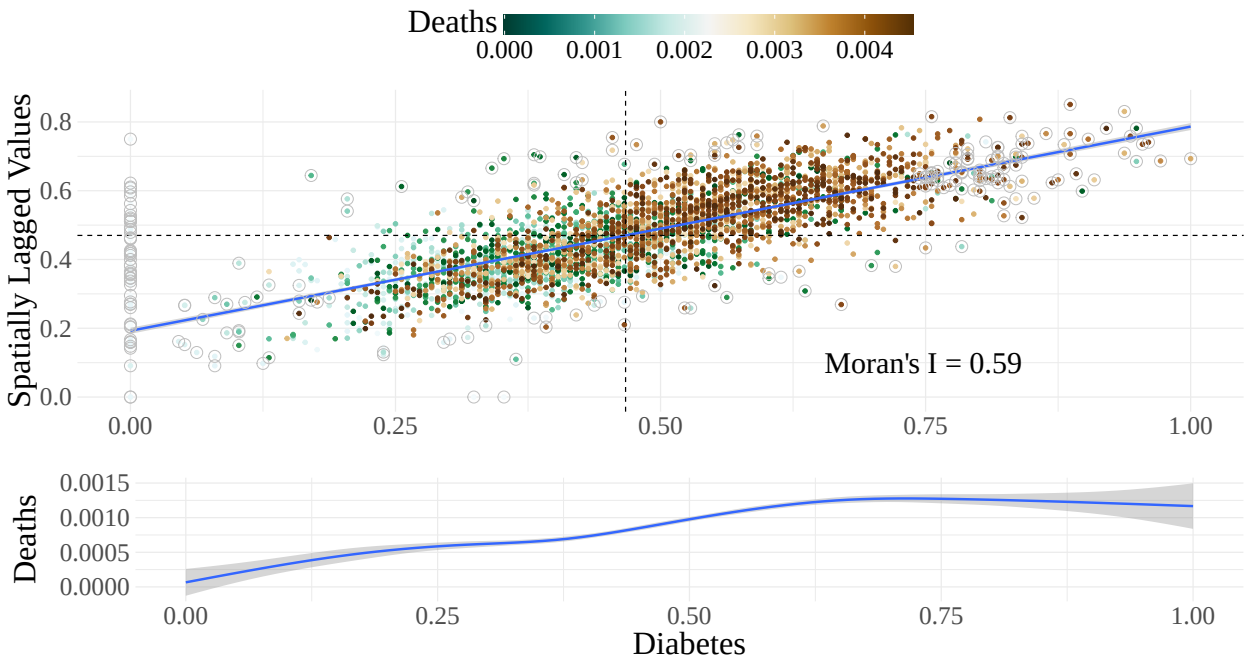

Delta Wave: Population Density x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.00
0.25
0.50
0.75
Moran's I = 0.543
0.00
0.25
0.50
0.75
1.00
Deaths
0.0008
0.0004
0.0000
0.00
0.25
0.50
0.75
1.00
Population Density

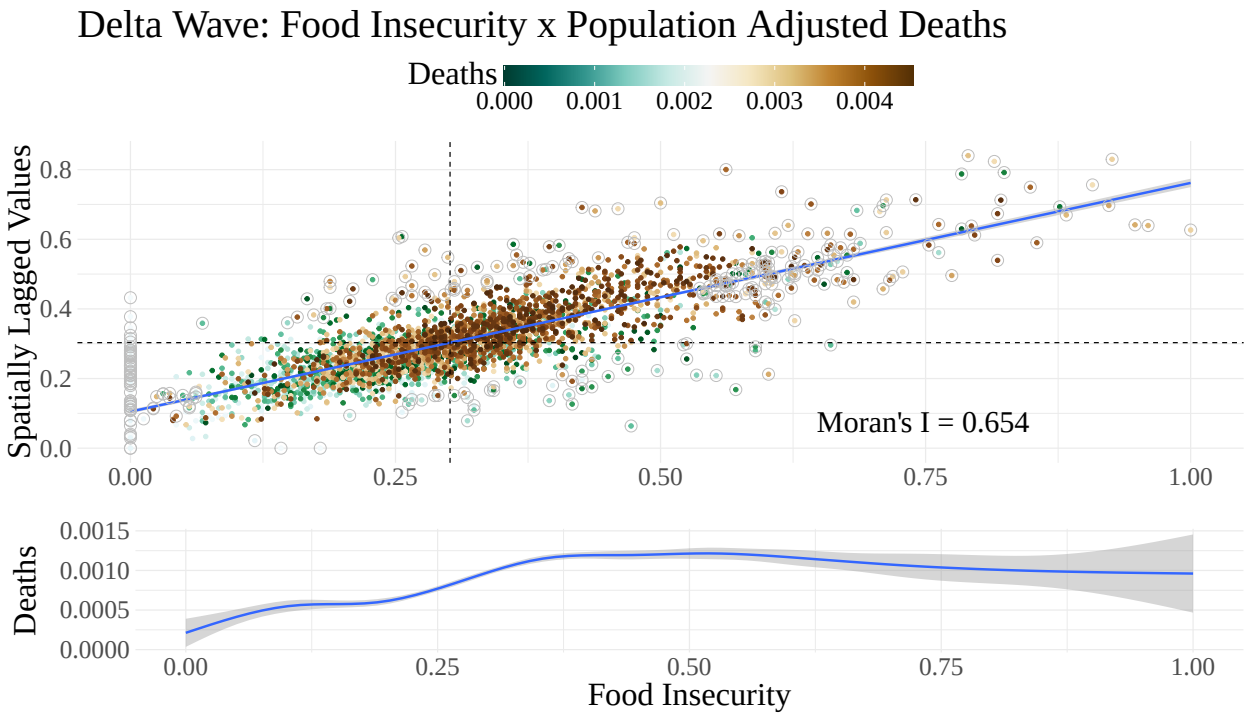

Delta Wave: Obesity x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.0
0.2
0.4
0.6
0.8
Moran's I = 0.538
0.00
0.25
0.50
0.75
1.00
Deaths
0.0015
0.0010
0.0005
0.0000
0.00
0.25
0.50
0.75
1.00
Obesity

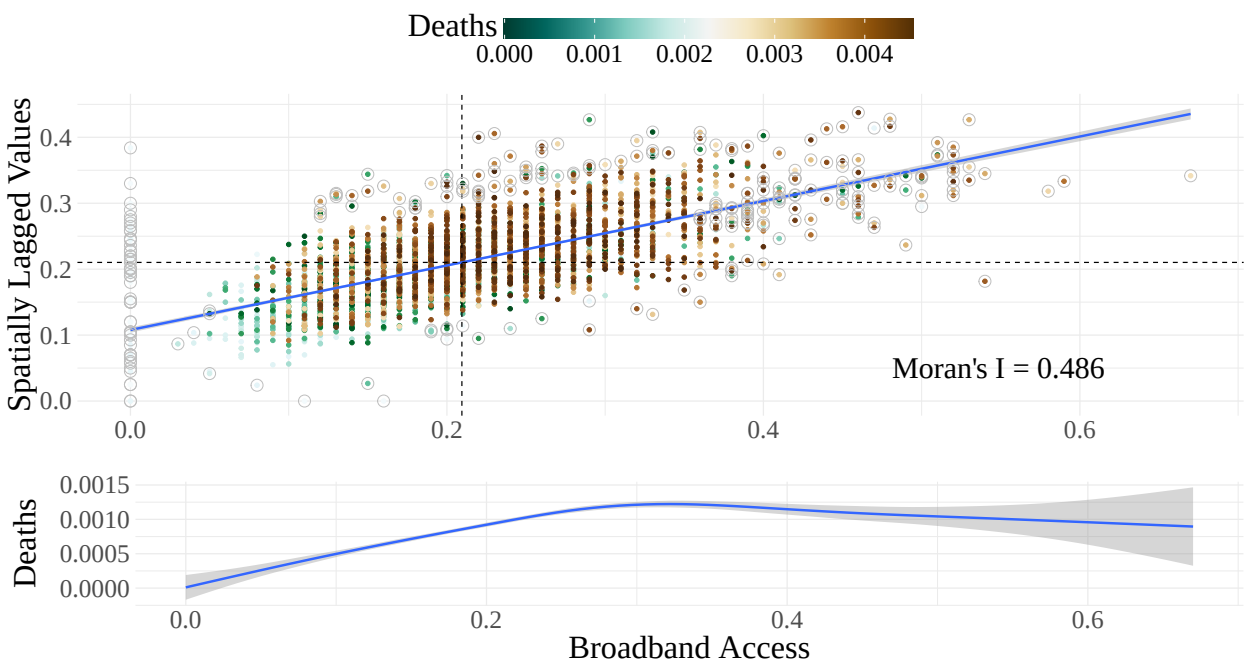

Delta Wave: Unemployed x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.6
0.4
0.2
0.0
Moran's I = 0.587
0.00
0.25
0.50
0.75
1.00
Deaths
0.0010
0.0005
0.0000
−0.0005
Unemployed


Delta Wave: Uninsured Adults x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.75
0.50
0.25
0.00
Moran's I = 0.761
0.00
0.25
0.50
0.75
1.00
Deaths
0.0010
0.0005
0.0000
Uninsured Adults


Delta Wave: Social Associations x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.6
0.4
0.2
0.0
Moran's I = 0.485
0.00
0.25
0.50
0.75
1.00
Deaths
0.0016
0.0012
0.0008
0.0004
Social Associations


Delta Wave: Diabetes x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.8
0.6
0.4
0.2
0.0
Moran's I = 0.59
0.00
0.25
0.50
0.75
1.00
Deaths
0.0015
0.0010
0.0005
0.0000
Diabetes


Delta Wave: Food Insecurity x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.0
0.2
0.4
0.6
0.8
Moran's I = 0.654
0.00
0.25
0.50
0.75
1.00
Deaths
0.0000
0.0005
0.0010
0.0015
Food Insecurity


Delta Wave: Broadband Access x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.0
0.1
0.2
0.3
0.4
Moran's I = 0.486
0.0
0.2
0.4
0.6
Deaths
0.0000
0.0005
0.0010
0.0015
Broadband Access

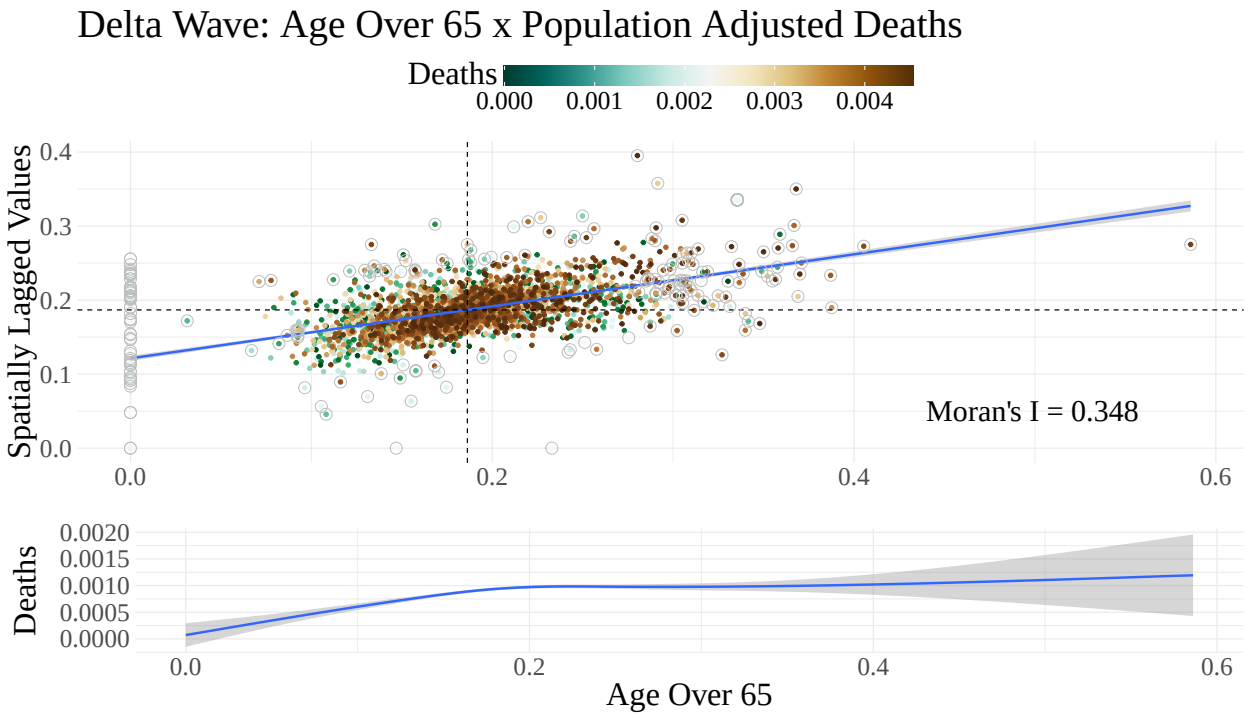

Delta Wave: Age Over 65 x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
0.004
Spatially Lagged Values
0.4
0.3
0.2
0.1
0.0
Moran's I = 0.348
0.0
0.2
0.4
0.6
Deaths
0.0020
0.0015
0.0010
0.0005
0.0000
0.0
0.2
0.4
0.6
Age Over 65

Figure S21: Morans I results: United States - Omicron Wave, Dependent Variable

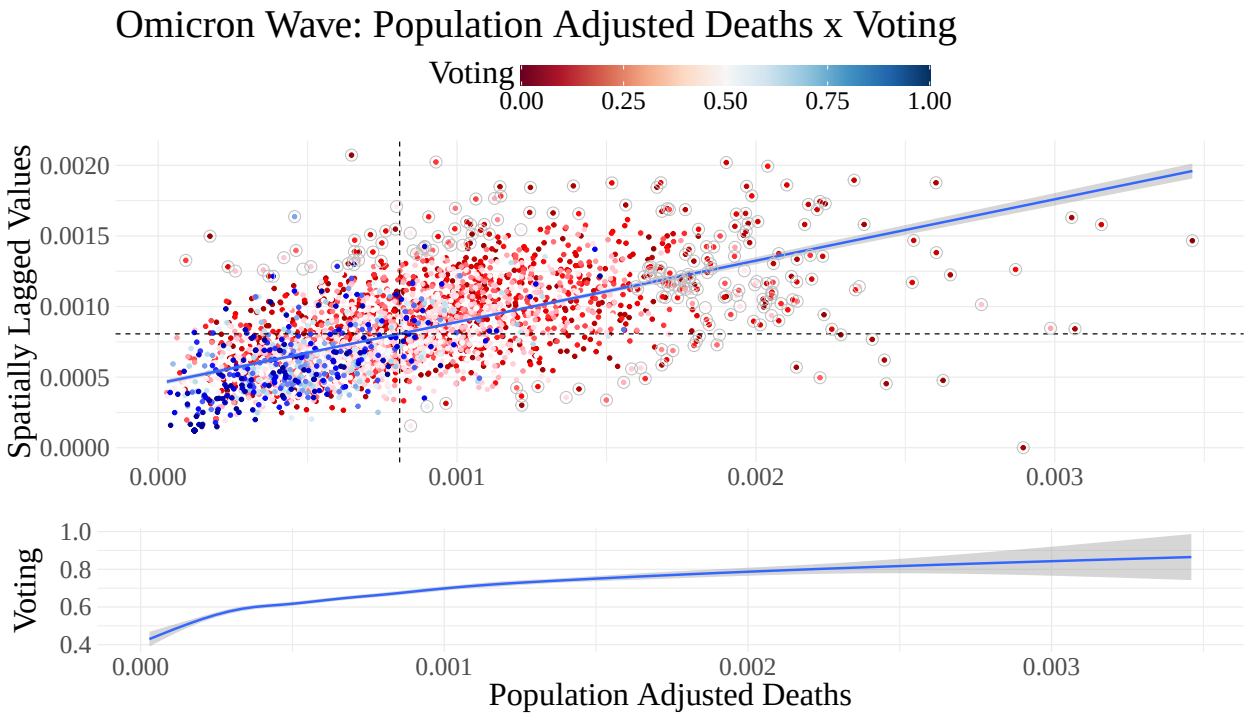
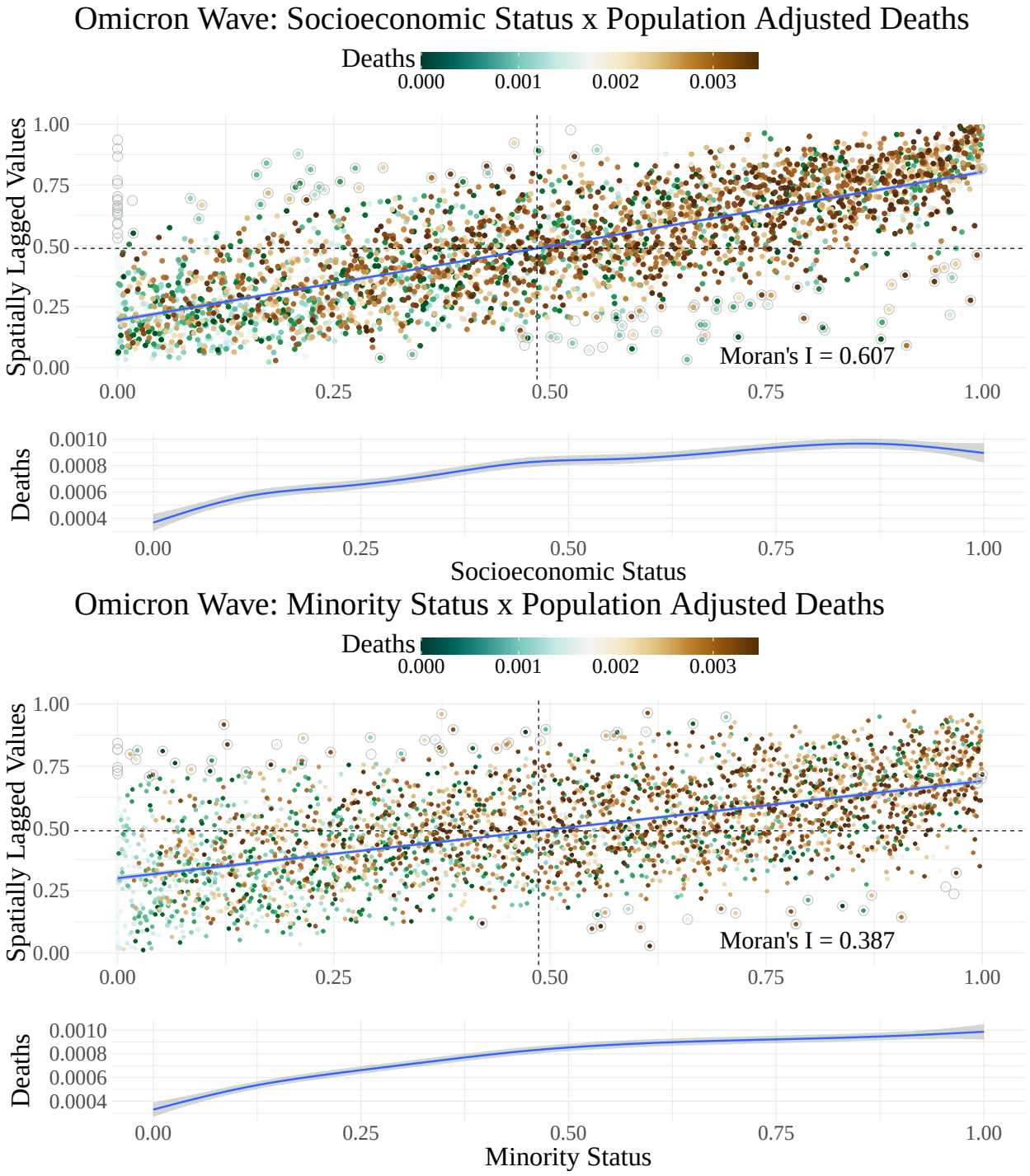
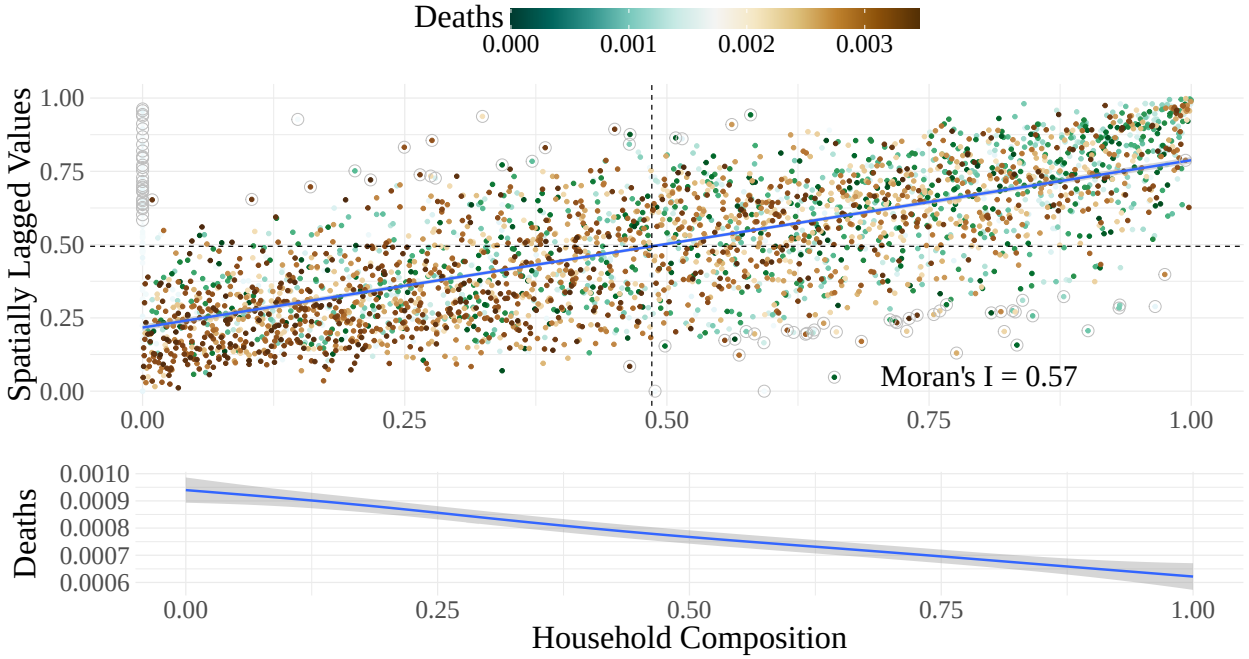


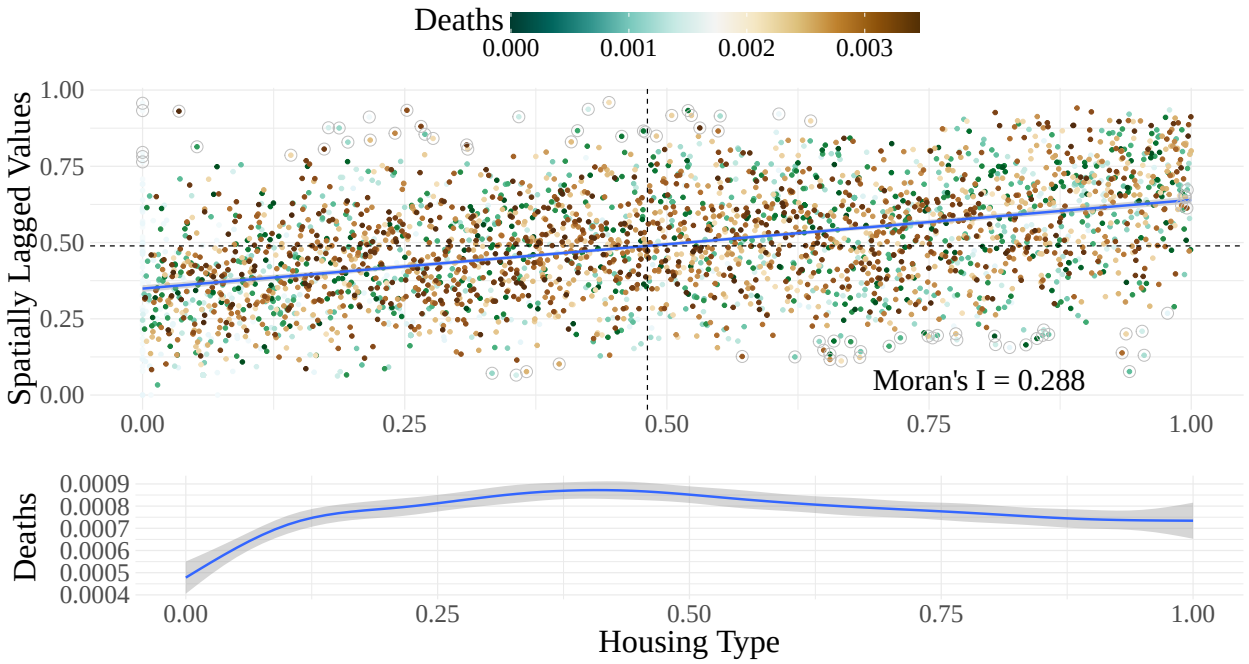
Figure S22: Morans I results: United States - Omicron Wave, Independent Variables

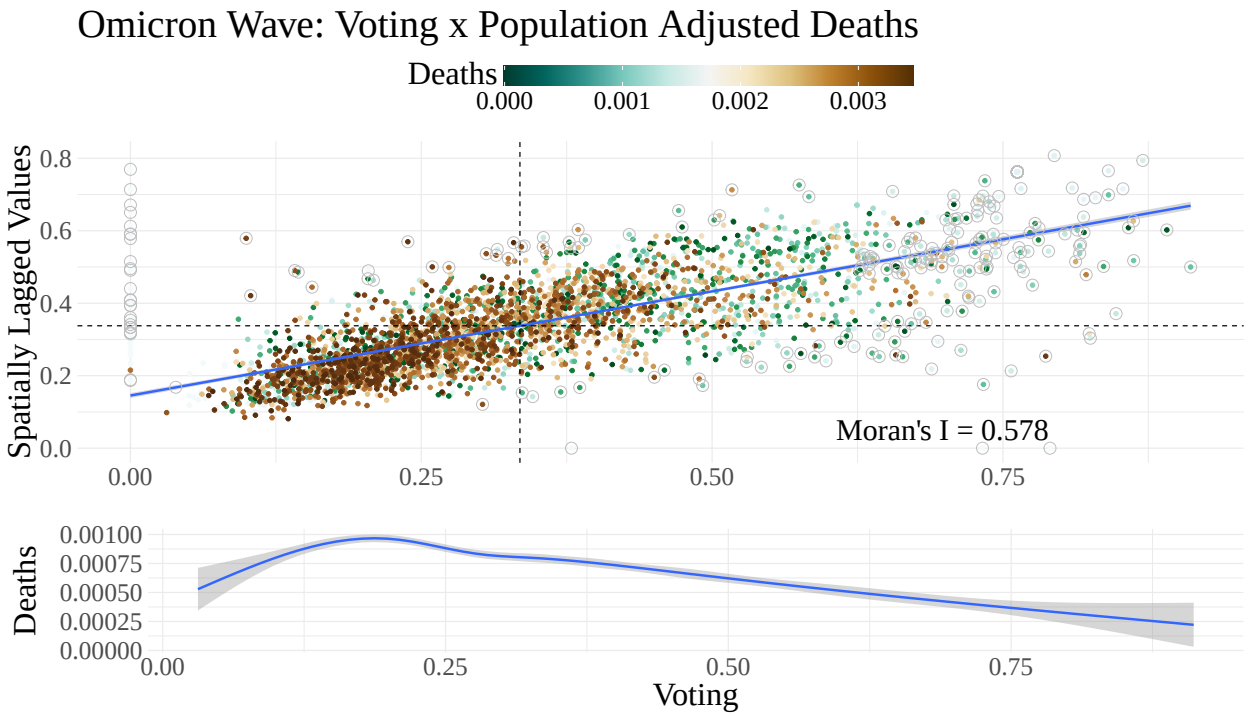


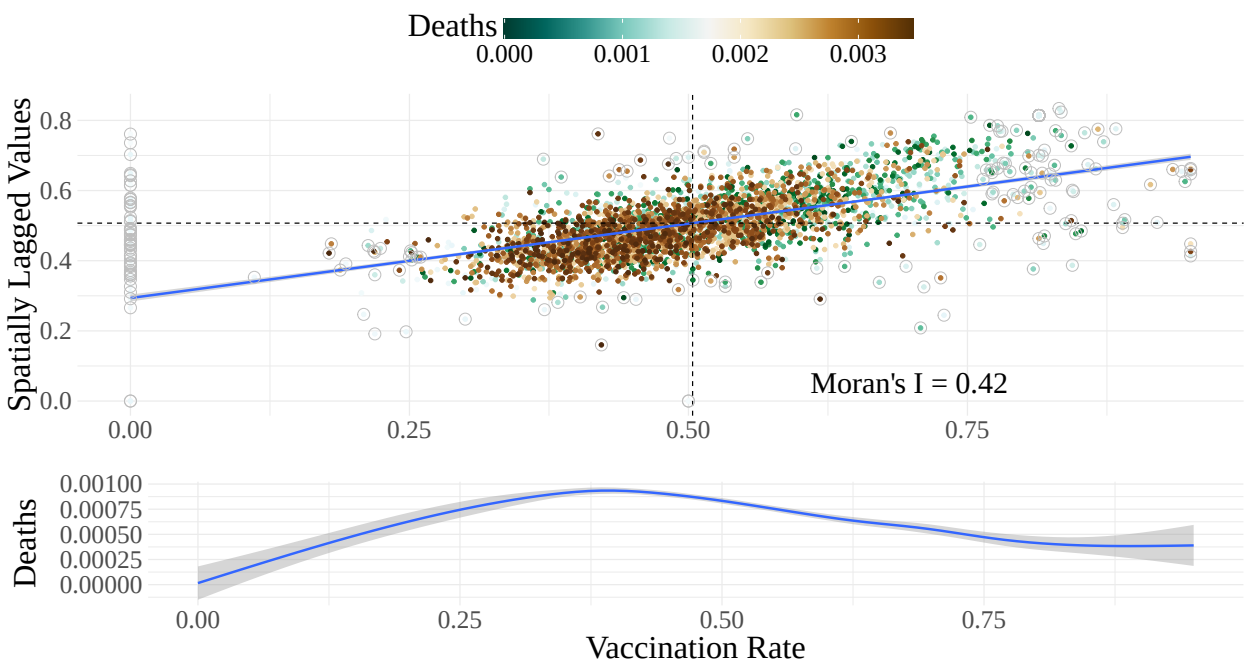
Omicron Wave: Household Composition x Population Adjusted Deaths



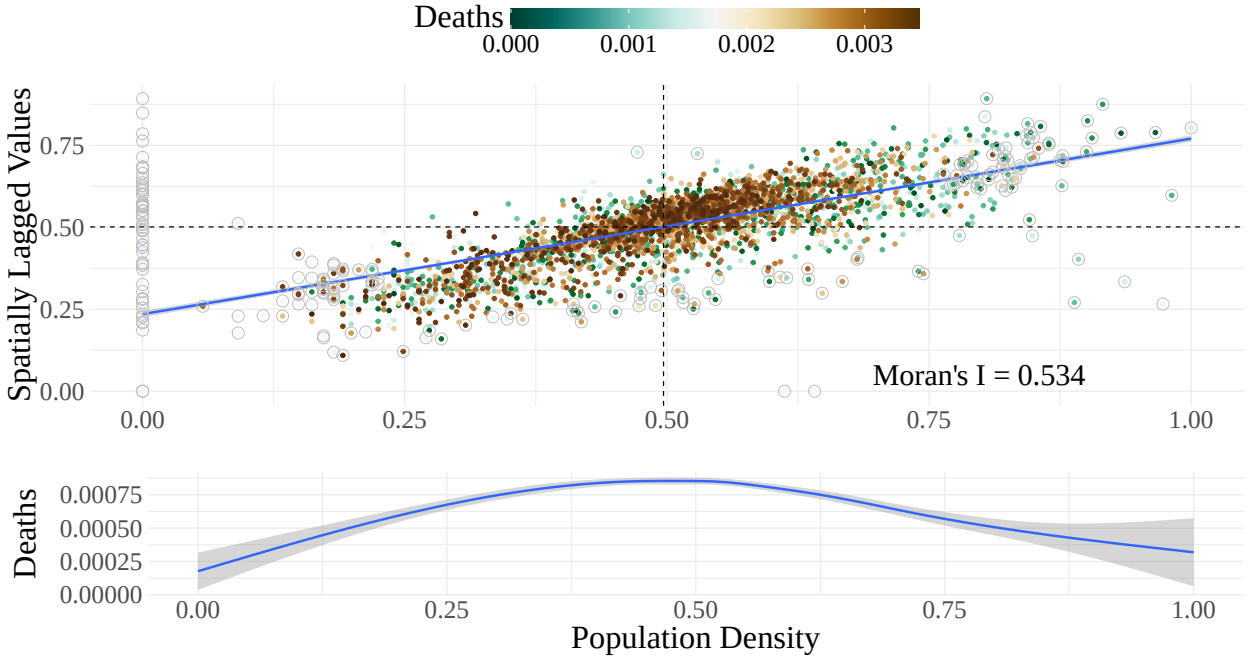
Omicron Wave: Housing Type x Population Adjusted Deaths



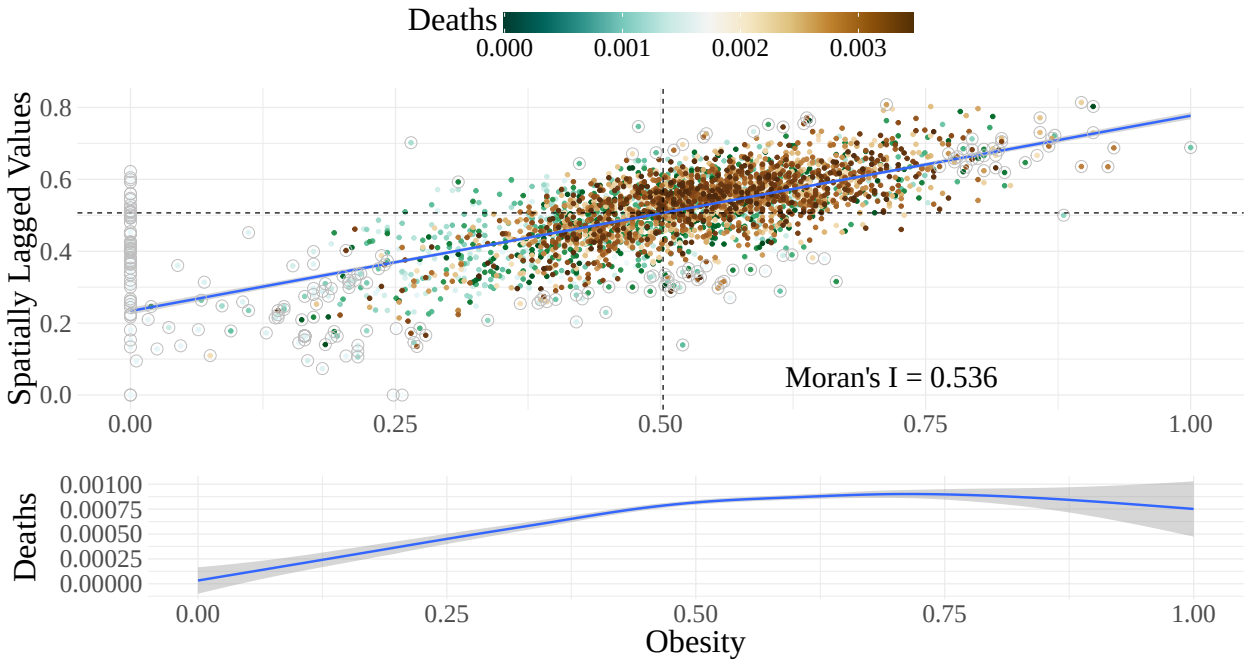

Omicron Wave: Voting x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
Spatially Lagged Values
0.0
0.2
0.4
0.6
0.8
Moran's I = 0.578
0.00
0.25
0.50
0.75
Deaths
0.00000
0.00025
0.00050
0.00075
0.00100
Voting

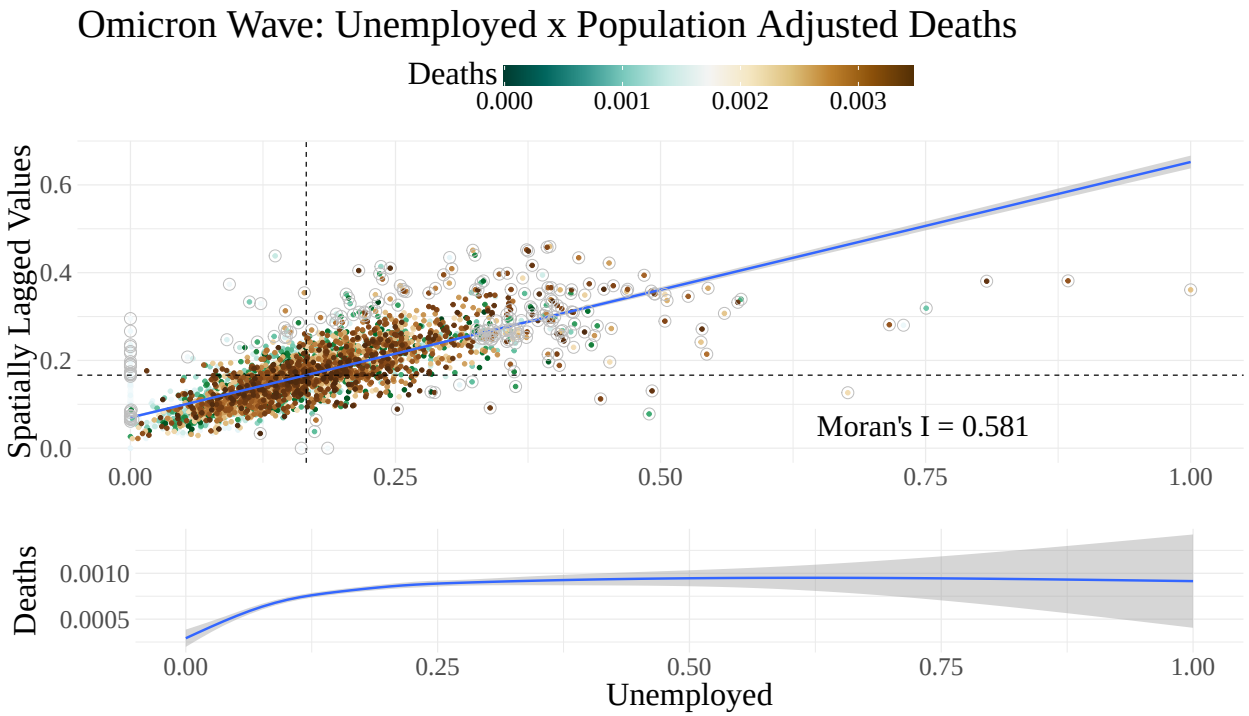

Omicron Wave: Vaccination Rate x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
Spatially Lagged Values
0.0
0.2
0.4
0.6
0.8
Moran's I = 0.42
0.00
0.25
0.50
0.75
Deaths
0.00000
0.00025
0.00050
0.00075
0.00100
Vaccination Rate

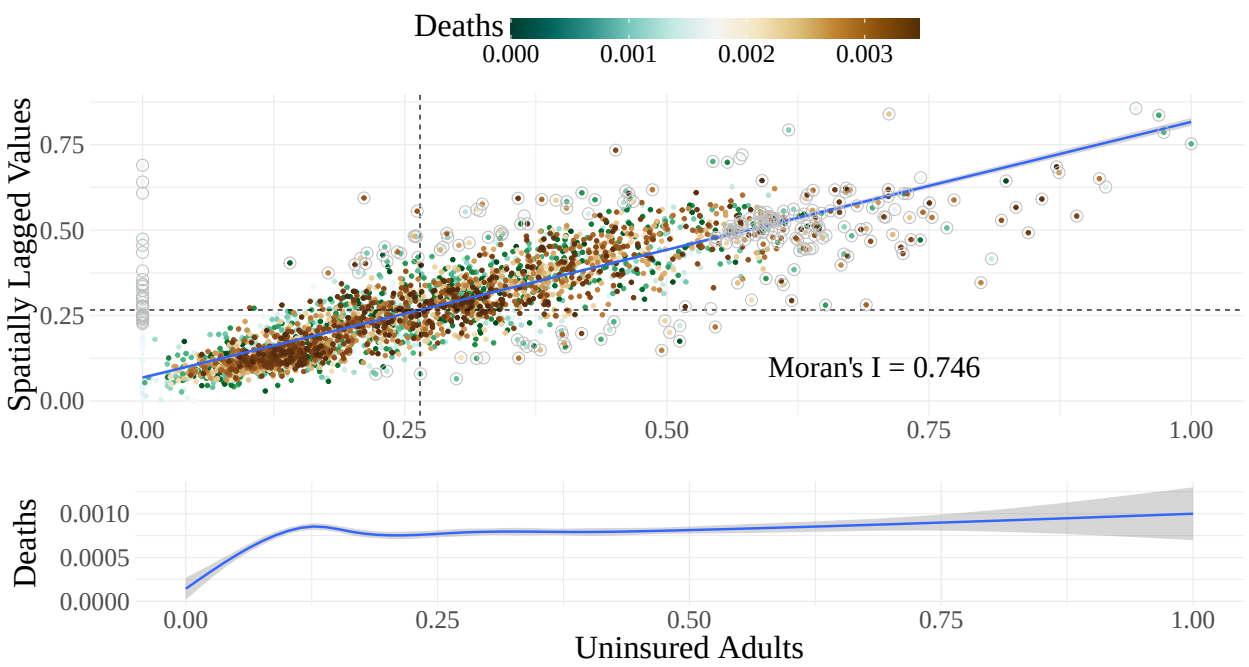
Omicron Wave: Population Density x Population Adjusted Deaths

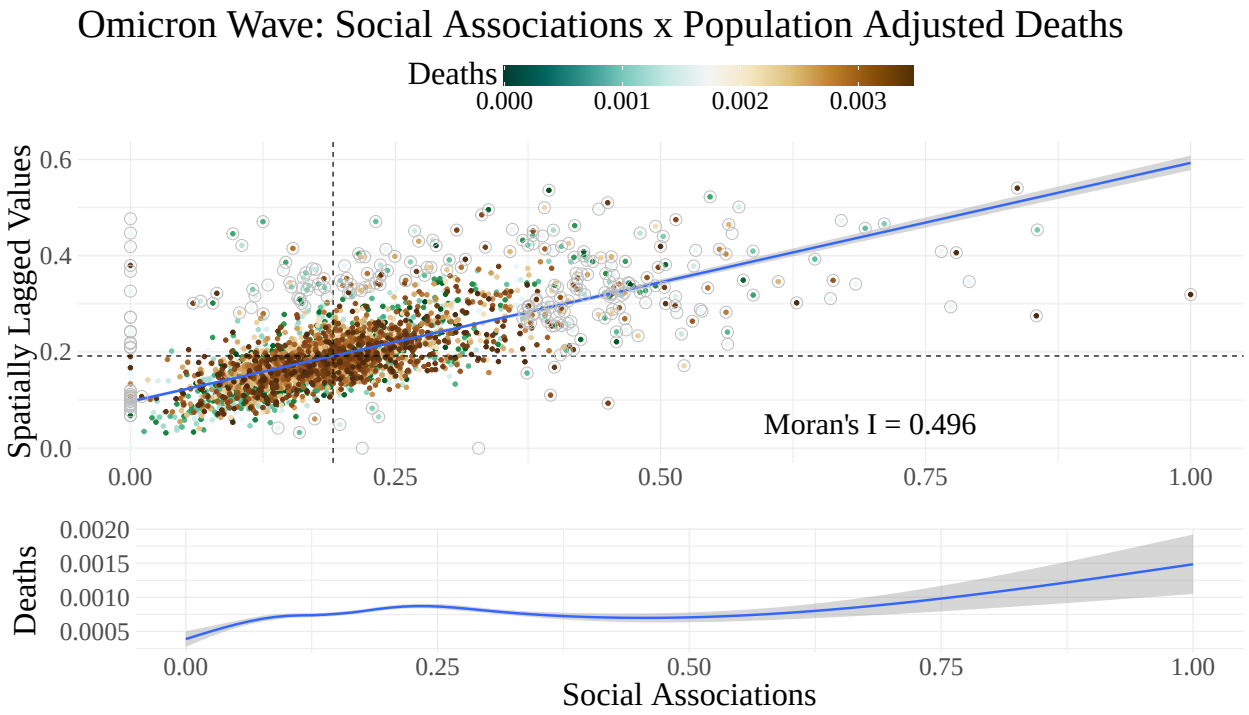


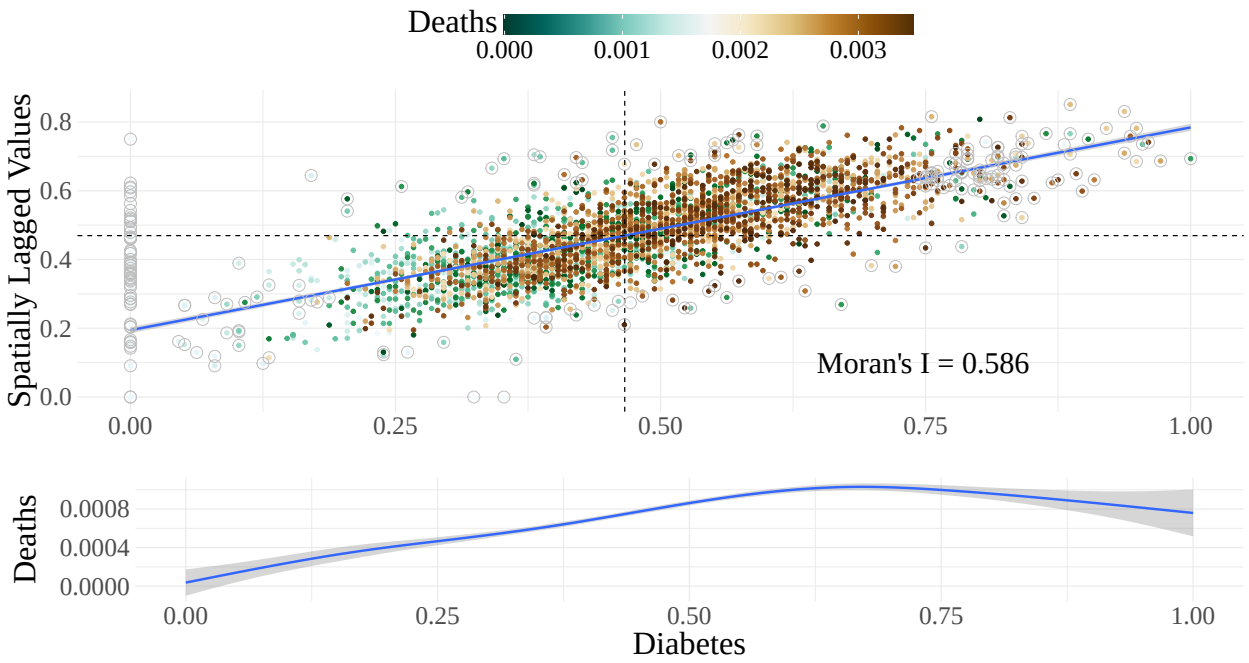
Omicron Wave: Obesity x Population Adjusted Deaths



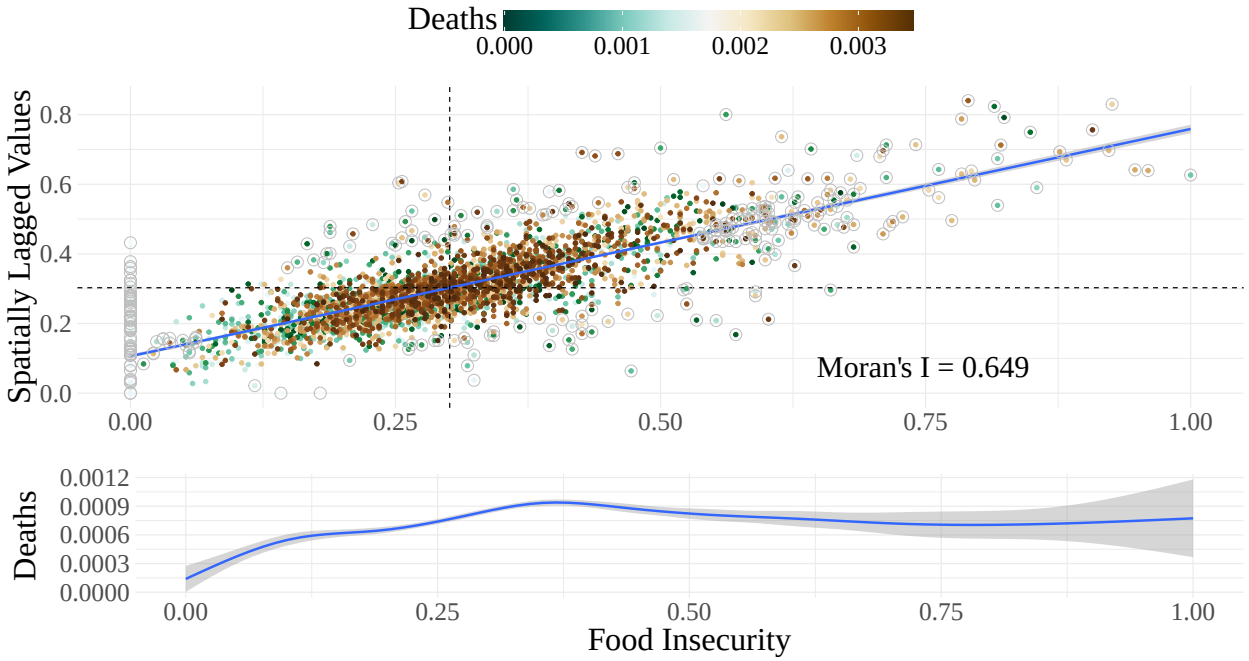

Omicron Wave: Unemployed x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
Spatially Lagged Values
0.6
0.4
0.2
0.0
Moran's I = 0.581
0.00
0.25
0.50
0.75
1.00
Deaths
0.0010
0.0005
Unemployed


Omicron Wave: Uninsured Adults x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
Spatially Lagged Values
0.75
0.50
0.25
0.00
Moran's I = 0.746
0.00
0.25
0.50
0.75
1.00
Deaths
0.0010
0.0005
0.0000
Uninsured Adults

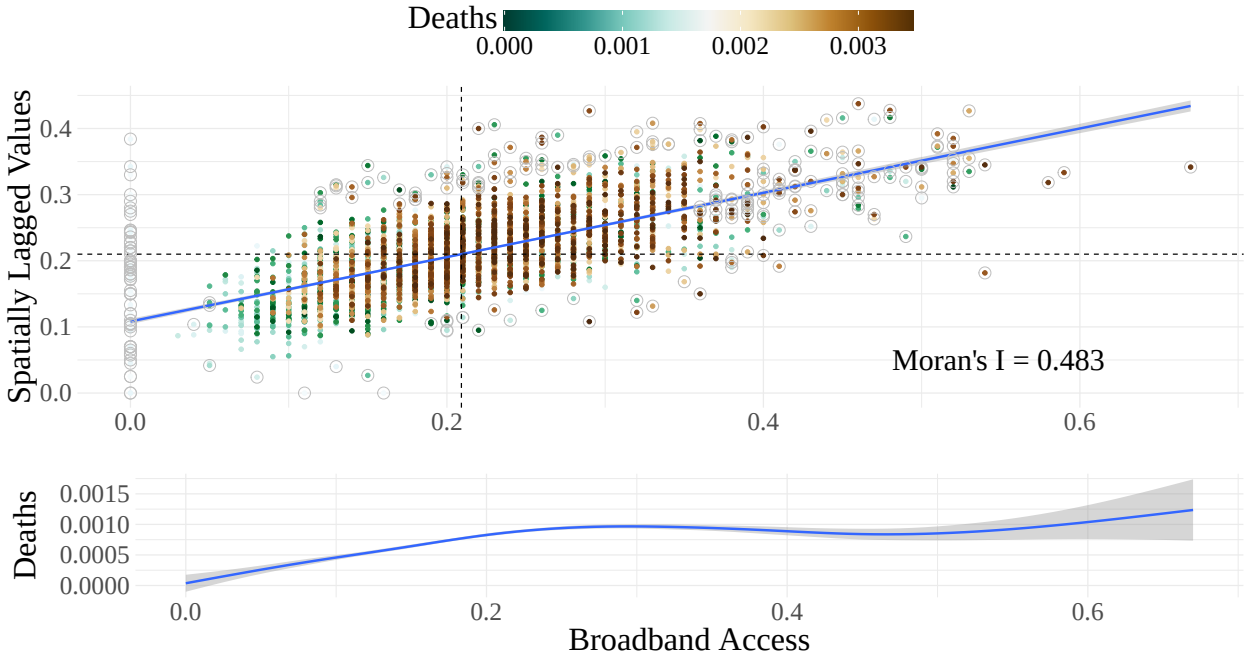

Omicron Wave: Social Associations x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
Spatially Lagged Values
0.6
0.4
0.2
0.0
Moran's I = 0.496
0.00
0.25
0.50
0.75
1.00
Deaths
0.0020
0.0015
0.0010
0.0005
Social Associations

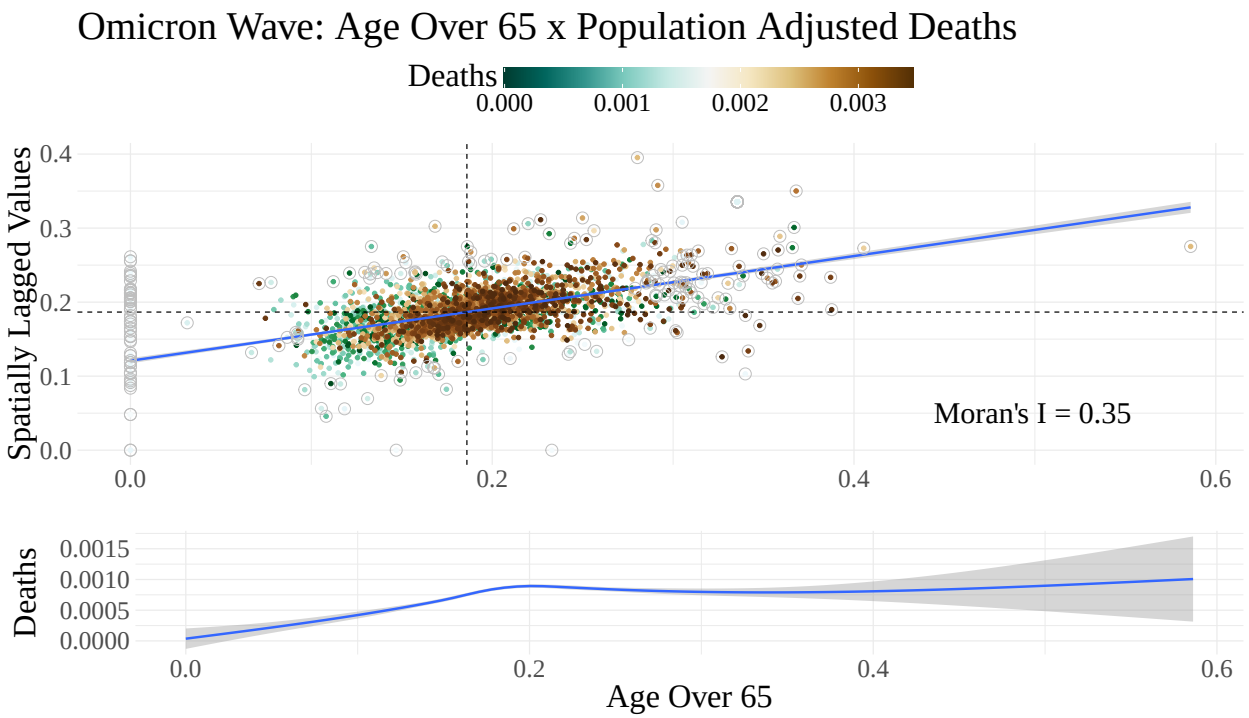

Omicron Wave: Diabetes x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
Spatially Lagged Values
0.8
0.6
0.4
0.2
0.0
Moran's I = 0.586
0.00
0.25
0.50
0.75
1.00
Deaths
0.0008
0.0004
0.0000
Diabetes

Omicron Wave: Food Insecurity x Population Adjusted Deaths



Omicron Wave: Broadband Access x Population Adjusted Deaths




Omicron Wave: Age Over 65 x Population Adjusted Deaths
Deaths
0.000
0.001
0.002
0.003
Spatially Lagged Values
0.4
0.3
0.2
0.1
0.0
Moran's I = 0.35
0.0
0.2
0.4
0.6
Deaths
0.0015
0.0010
0.0005
0.0000
0.0
0.2
0.4
0.6
Age Over 65

Part 5: Geographically Weighted Random Forest Modeling: Model Alpha Wave

Figure S23: GWRF Alpha Wave: Model Weighting

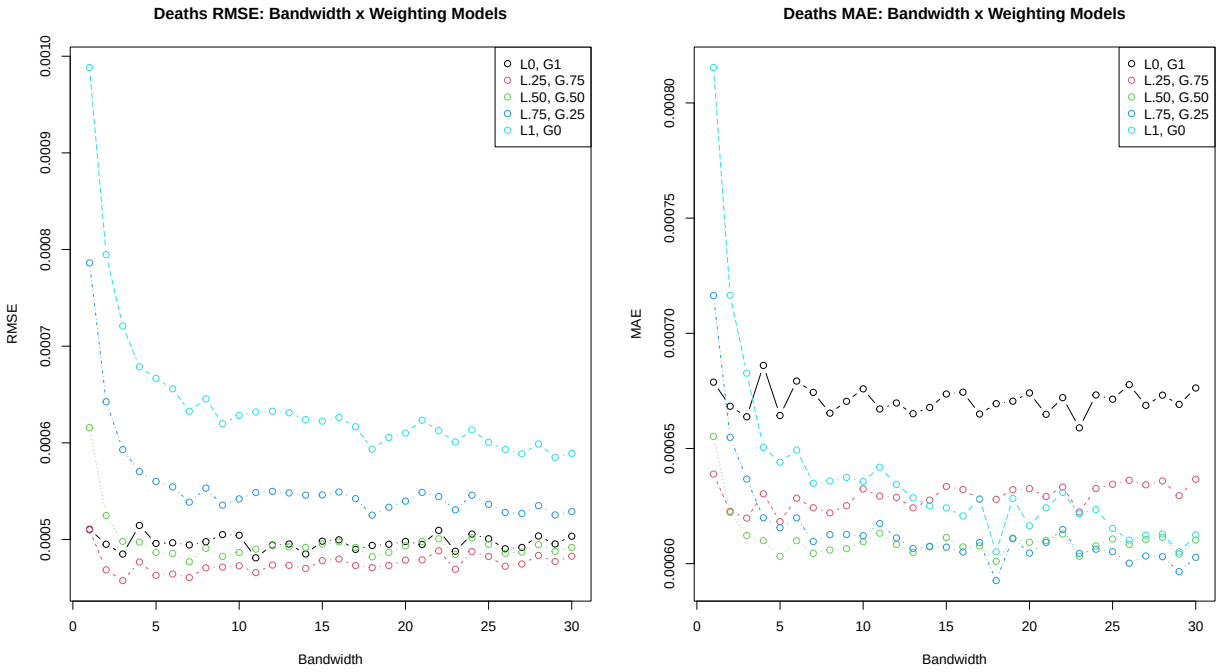
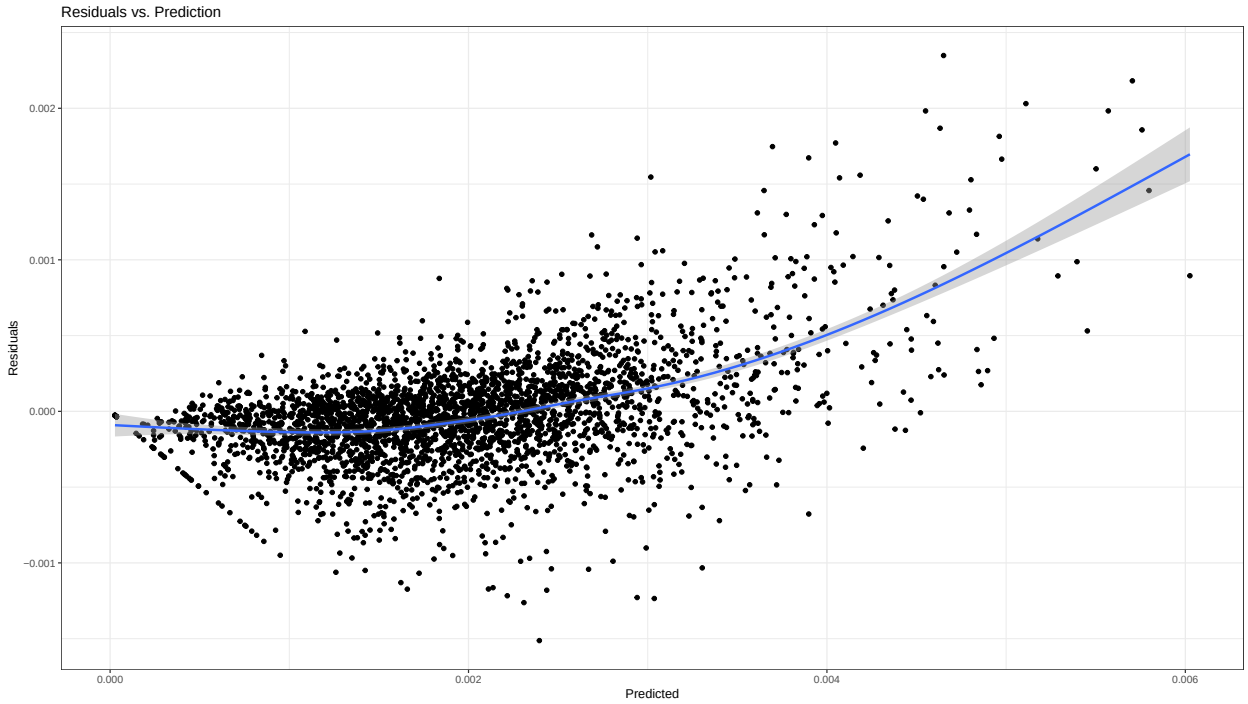


Figure S24: GWRF Alpha Wave: Residuals vs. Predicted



Pearson's product-moment correlation
t = 54.367832977106
Degrees of Freedom = 3151
.05 Confidence Interval = 0.677257938148585
.95 Confidence Interval = 0.713301930268433
p-value < 0.00000000000000022

Figure S25: GWRF Alpha Wave: Model Prediction Results

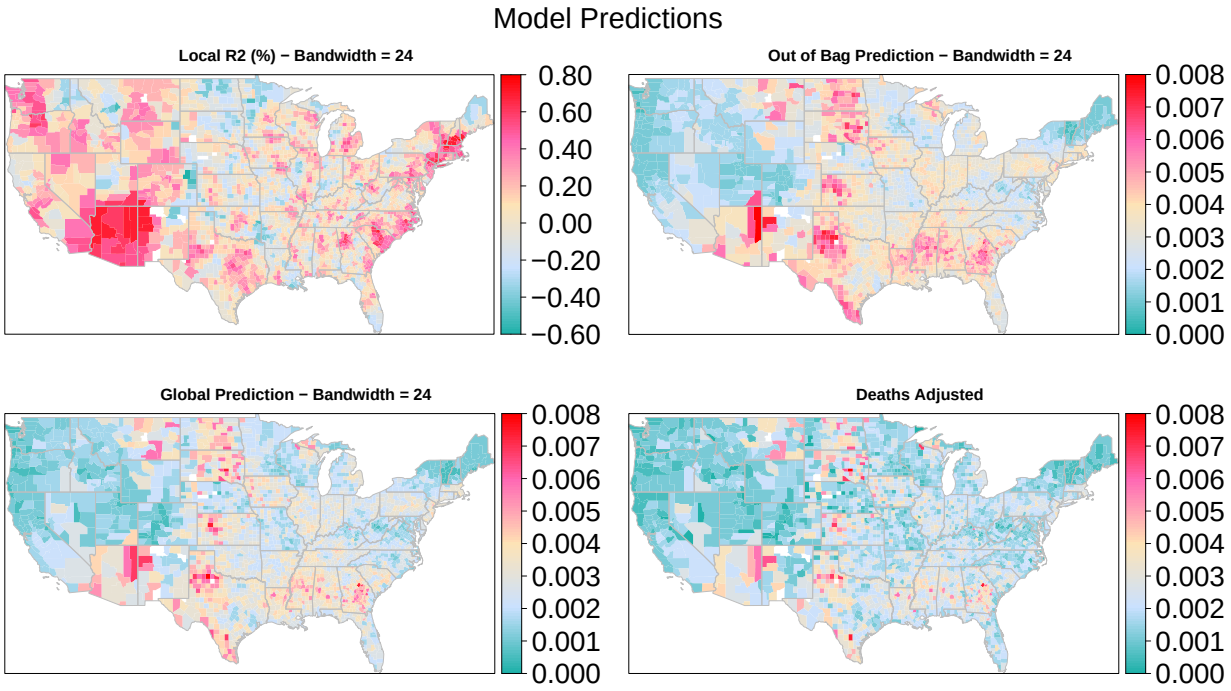
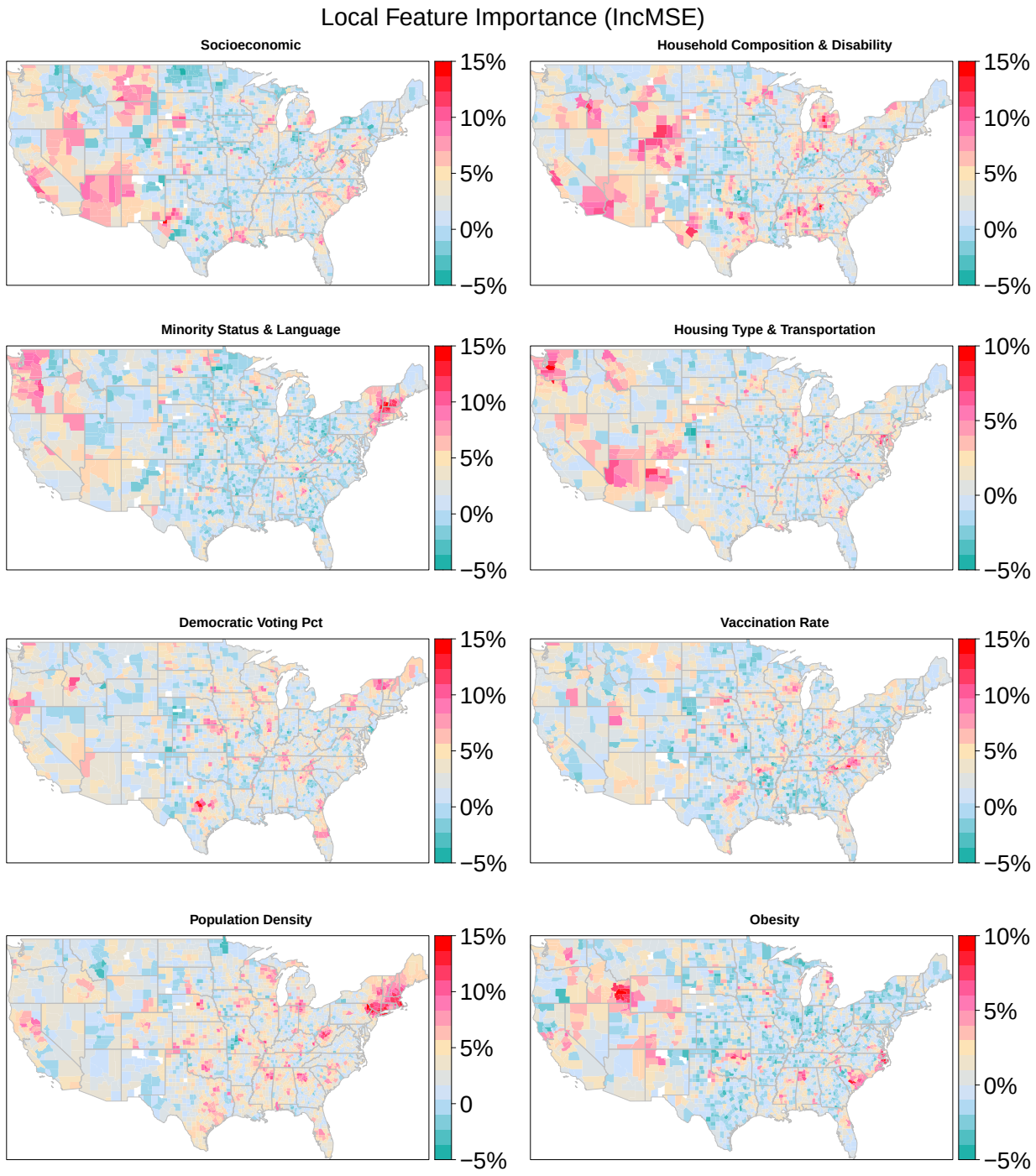


Figure S26: GWRF Alpha Wave: Feature Importance



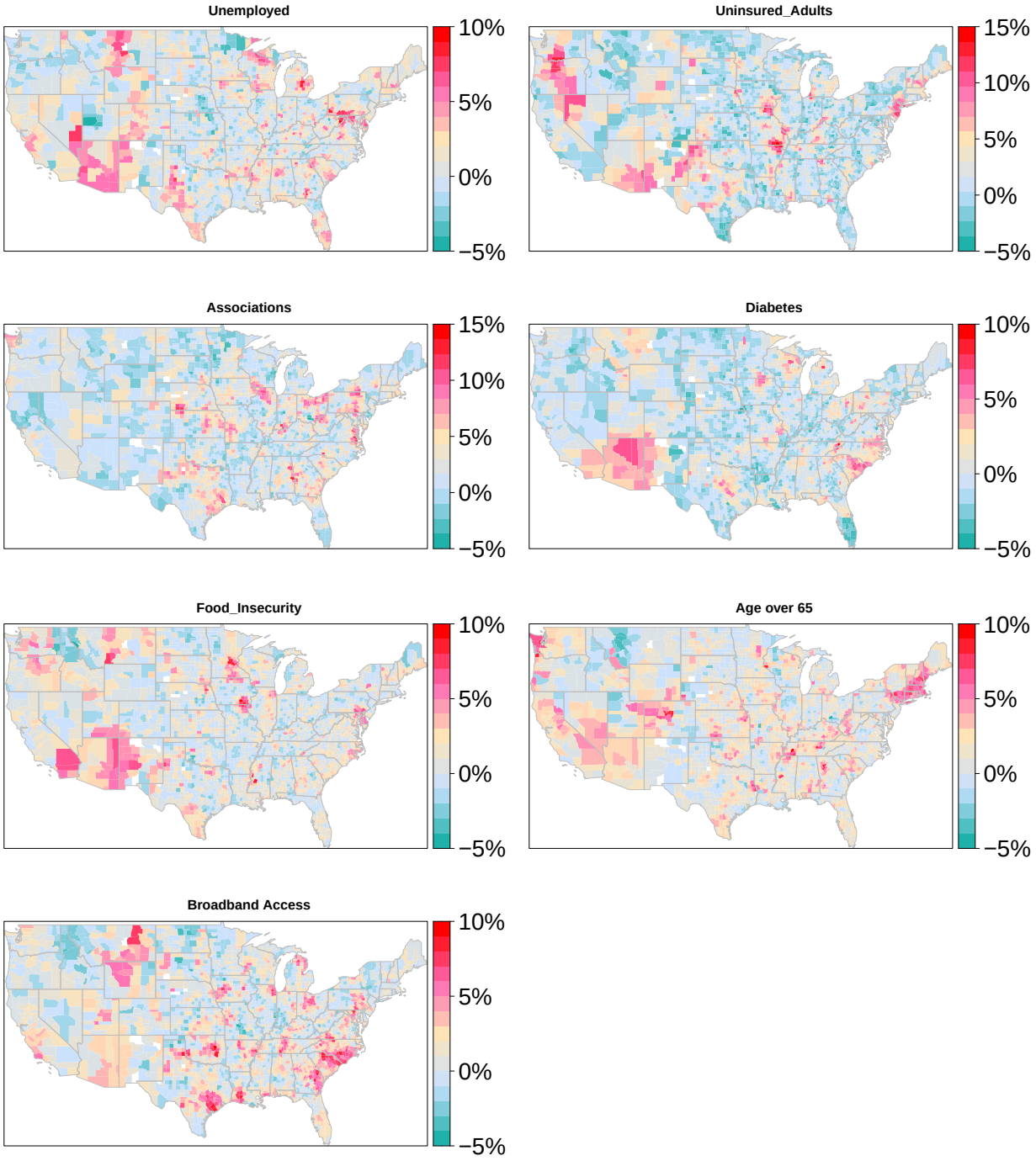


Table T13: GWRF Alpha Wave OOB vs. Global R2

Out of Bag R2	Global R2
0.4070356	0.8951136

Part 5: Geographically Weighted Random Forest Modeling: Delta Wave

Figure S27: GWRF Delta Wave: Model Weighting

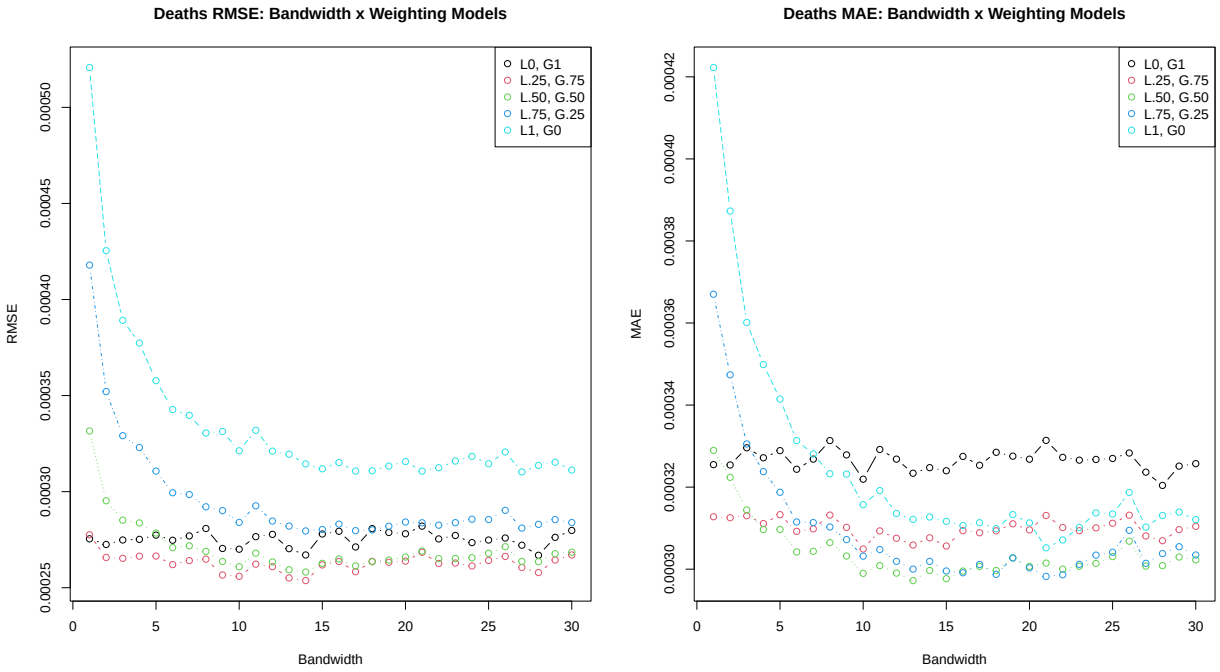
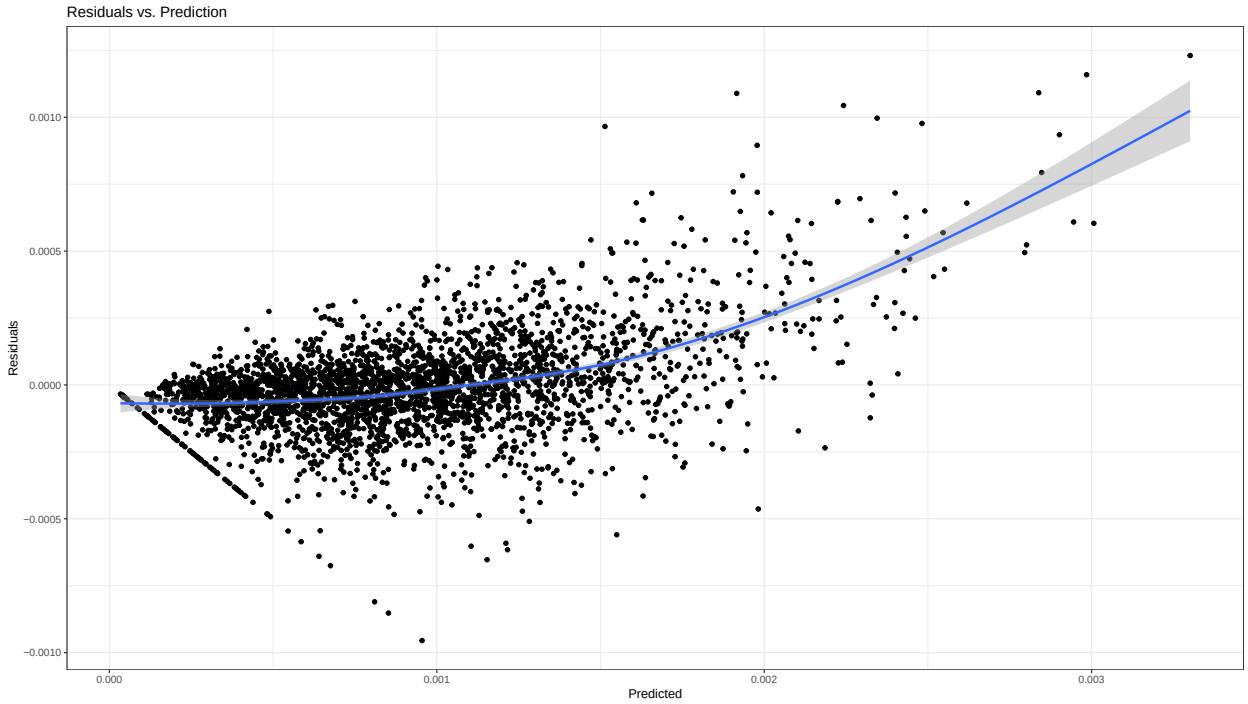


Figure S28: GWRF Delta Wave: Residuals vs. Predicted



Pearson's product-moment correlation
t = 53.0708982164224
Degrees of Freedom = 3146
.05 Confidence Interval = 0.668406135732034
.95 Confidence Interval = 0.705292876845388
p-value < 0.00000000000000022

Figure S29: GWRF Delta Wave: Model Prediction Results

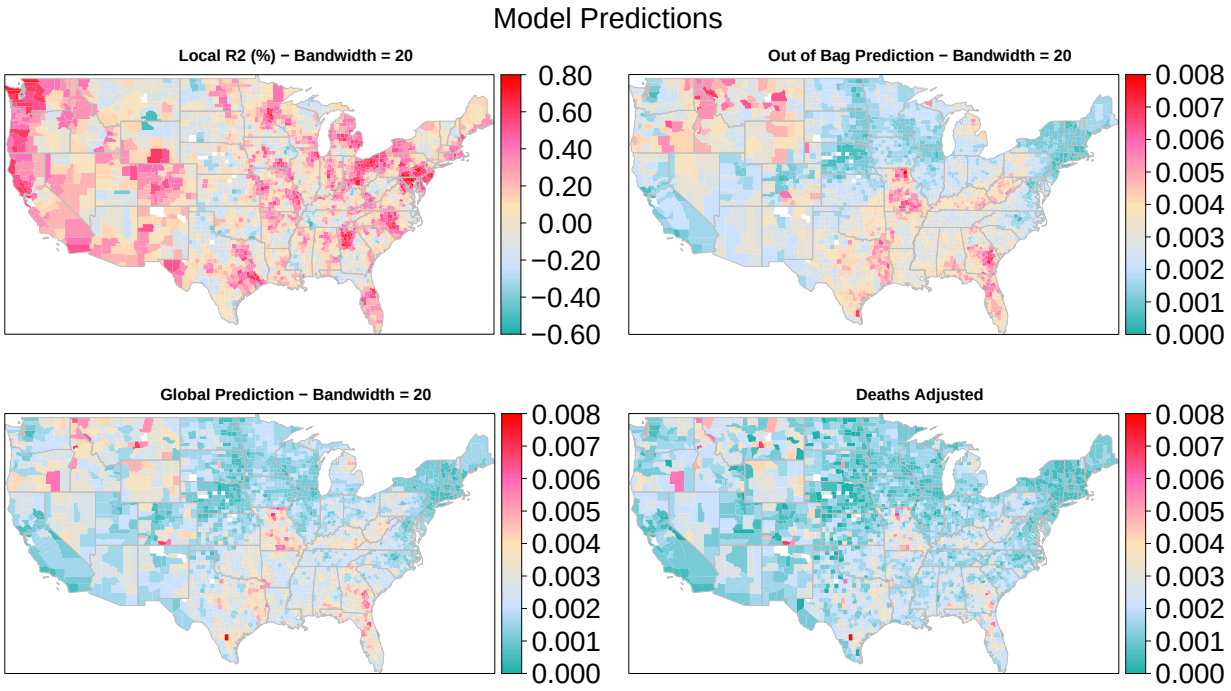
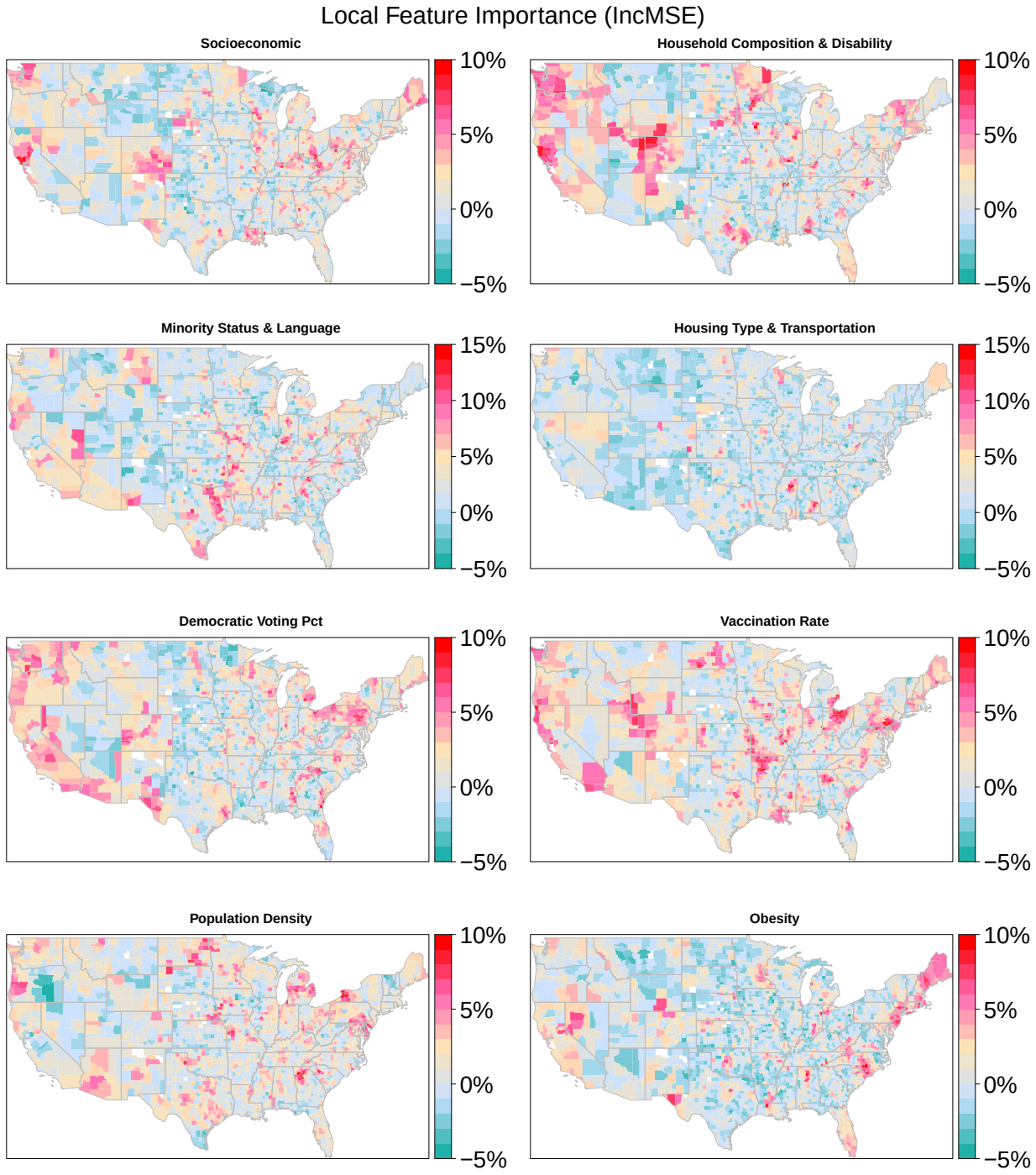


Figure S30: GWRF Delta Wave: Model Feature Importance



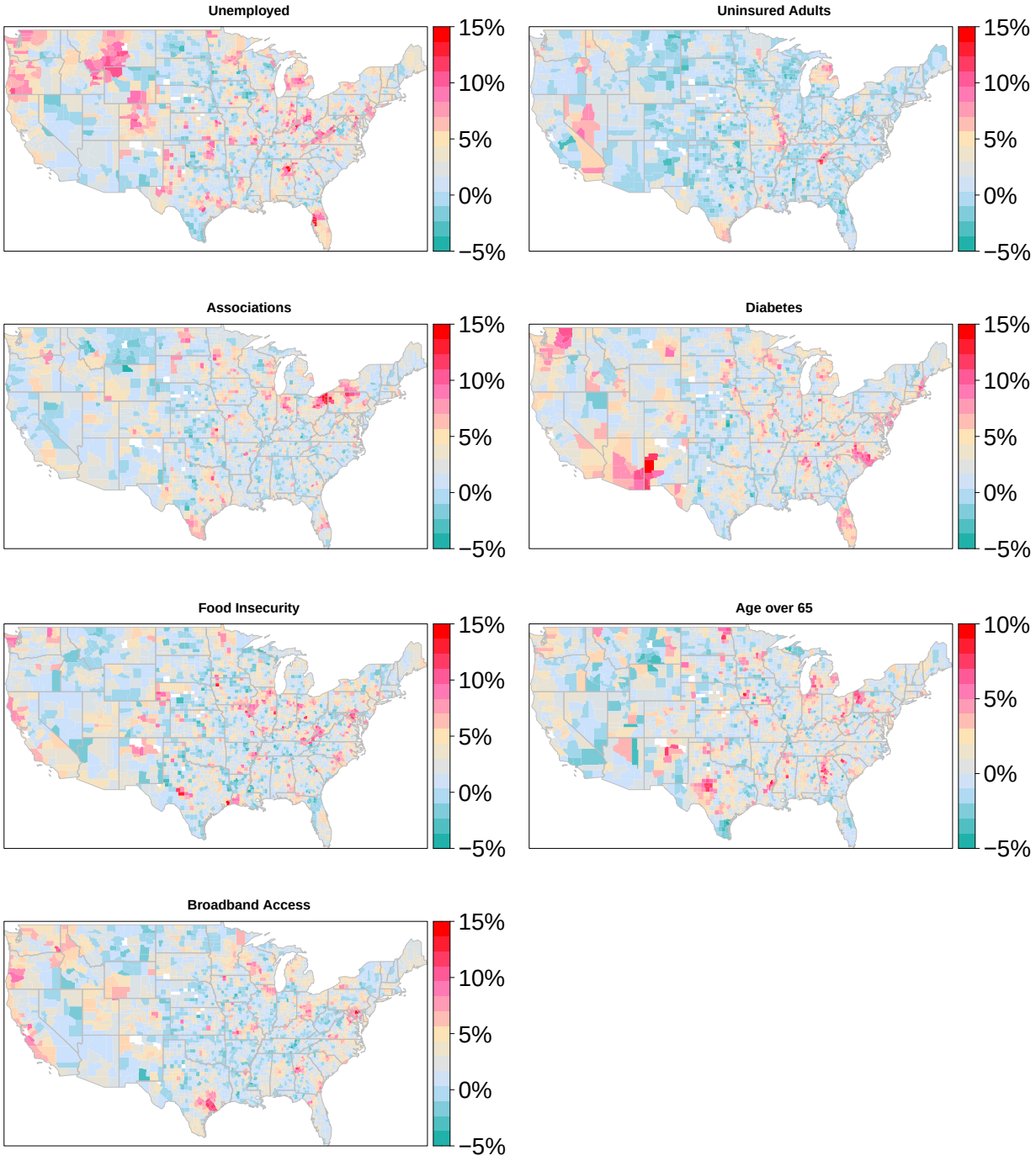


Table T14: GWRF Delta Wave: OOB vs Global R2

Out of Bag R2	Global R2
0.4390217	0.9012575

Part 5: Geographically Weighted Random Forest Modeling: Omicron Wave

Figure S31: GWRF Omicron Wave: Model Weighting

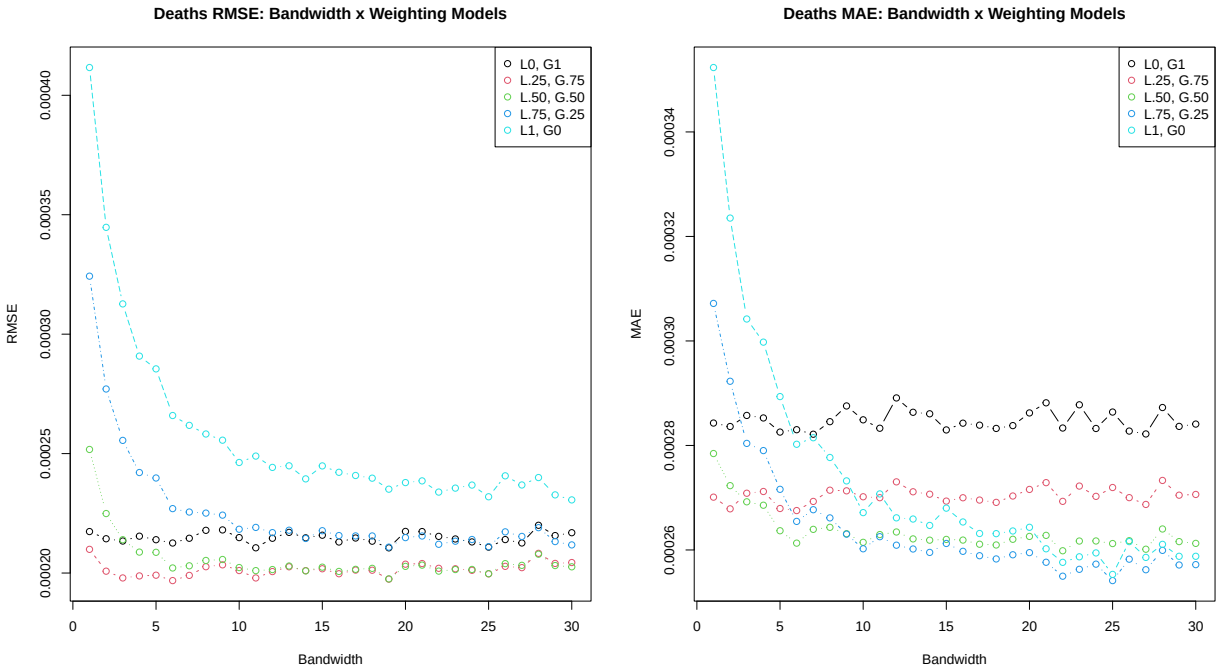
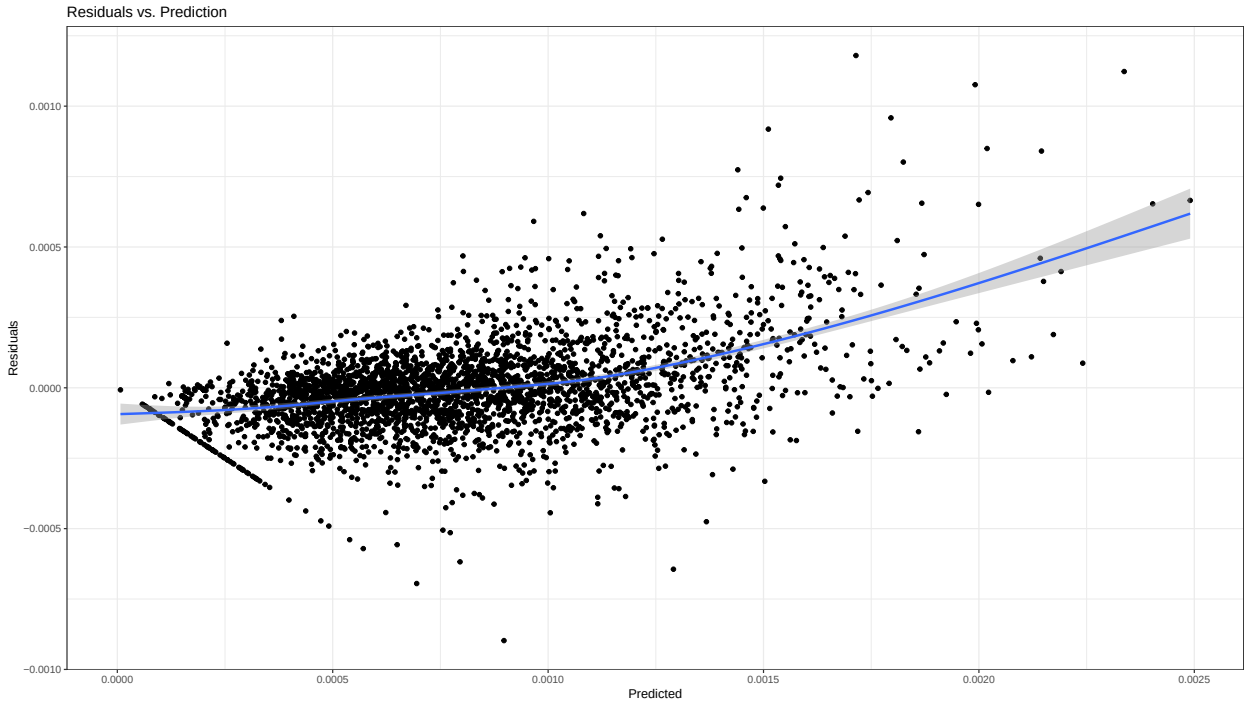


Figure S32: GWRF Omicron Wave: Residuals vs. Predicted



Pearson's product-moment correlation
t = 54.3314749122461
Degrees of Freedom = 3140
.05 Confidence Interval = 0.677631355461191
.95 Confidence Interval = 0.713700758130268
p-value < 0.00000000000000022

Figure S33: GWRF Omicron Wave: Model Prediction Results

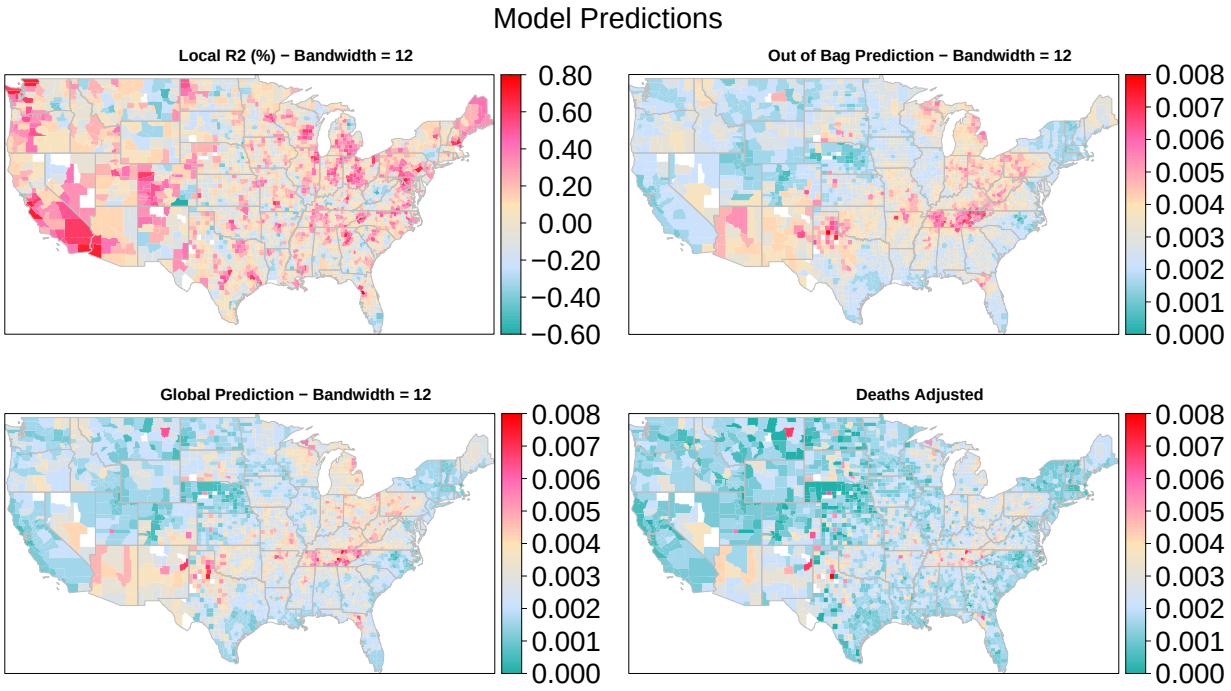
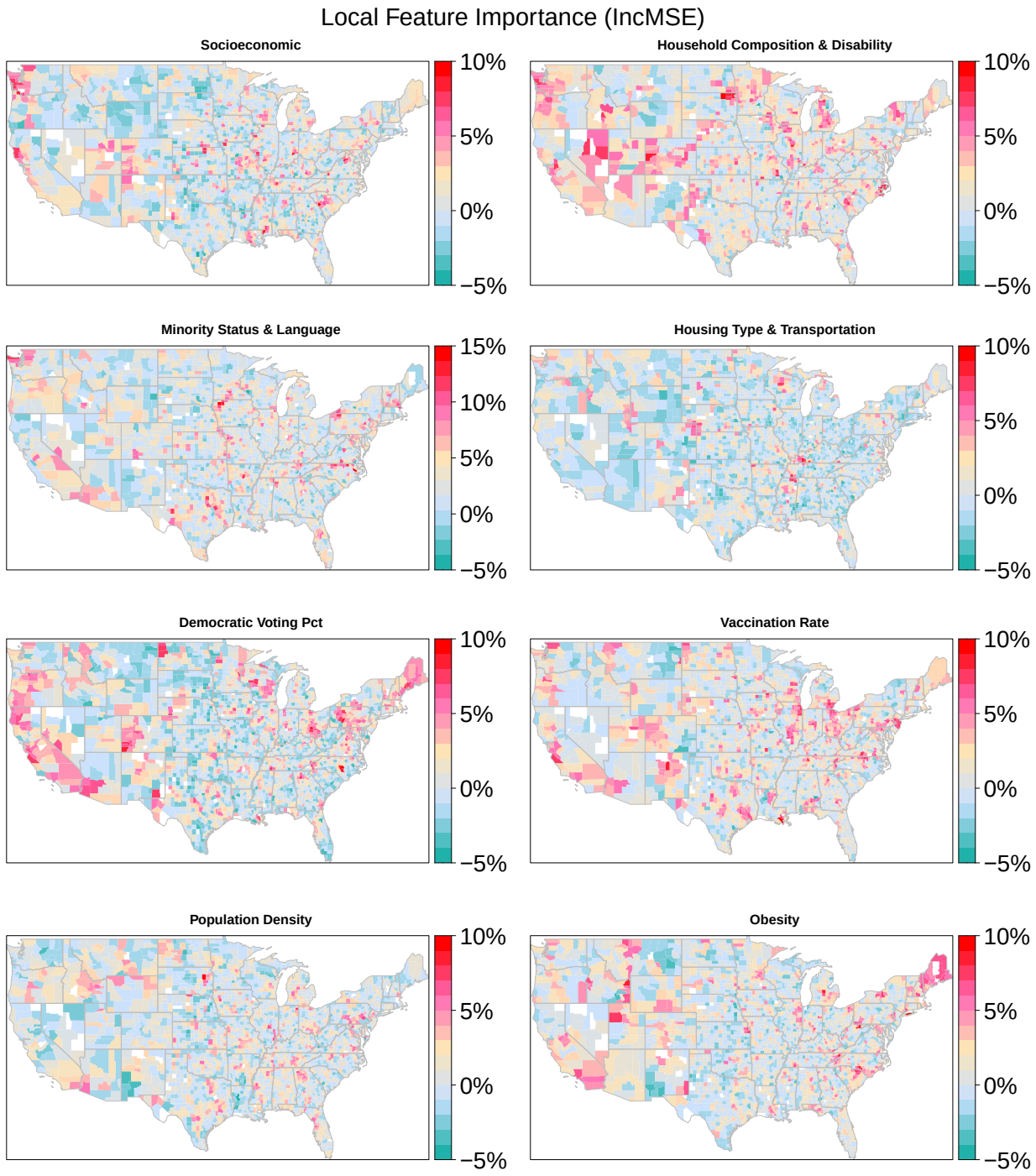


Figure S34: GWRF Omicron Wave: Model Feature Importance



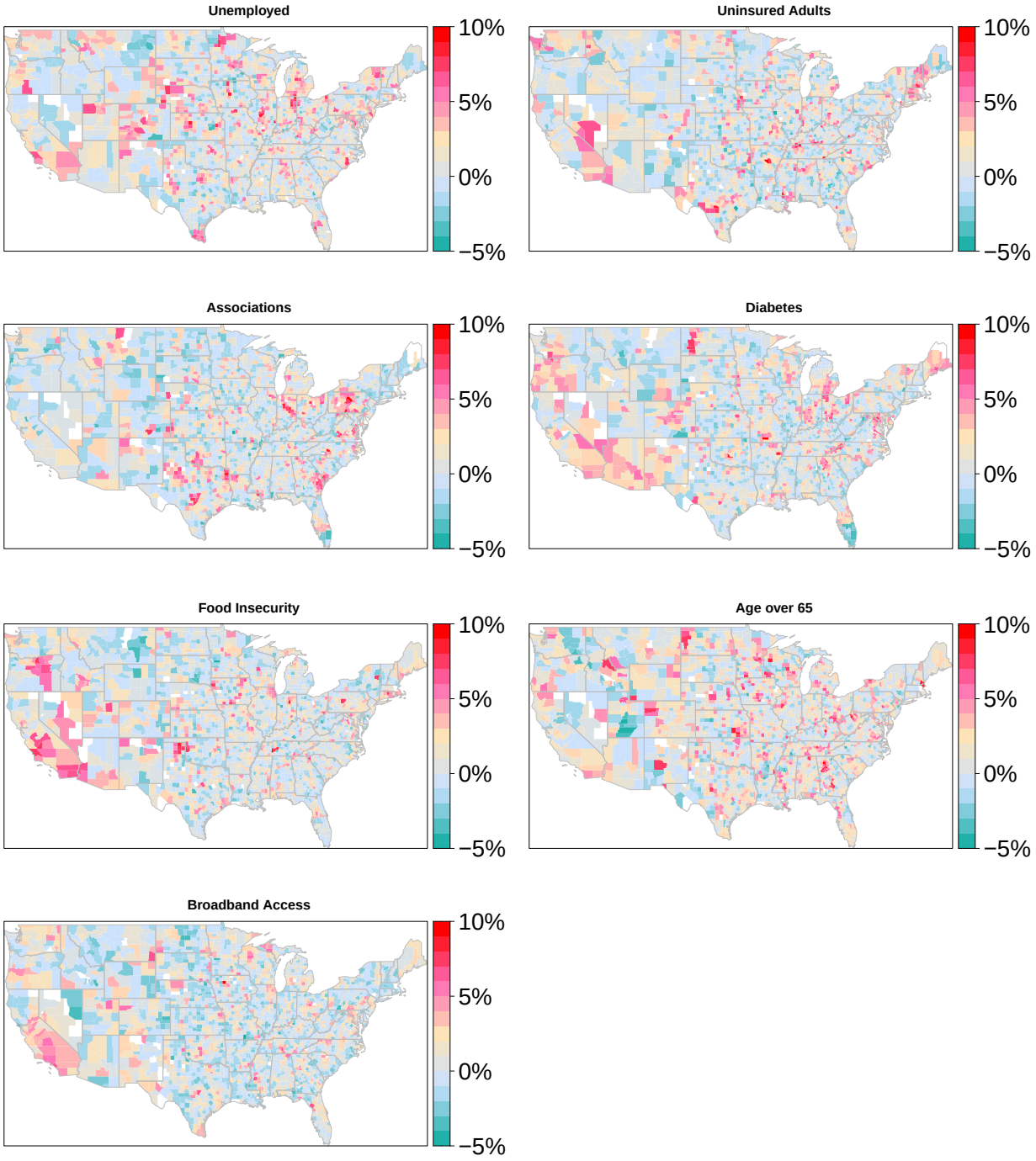


Table T15: GWRF Omicron Wave: OOB vs Global R2

Out of Bag R2	Global R2
0.3426573	0.8806753