Bayesian Hierarchical models for summer ozone exposure and mortality

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On the basis of 19 large U.S. cities included in the National Morbidity, Mortality and Air Pollution Study (NMMAPS) from 1987 to 1994, this project is to estimate the risk of mortality associated with the exposure to air pollution. In order to remove the influences of potential confounders, we need to compare mortality when air pollution is higher to other "similar" days when air pollution is lower[1]. One possibility to define the "similarity" is to match days based on the season and temperature. Particularlly, (1) summer season and (2) quantile levels of temperature are selected in this project.

In the first stage, ***a semi-parametrix Poisson regression model*** is defined to estimate city-specific relative rates of mortality associated with the exposure to ozone as follows.

$$Y_t^c \sim Poisson(\mu_t^c)$$

$$\log(\mu_t^c) = \alpha^c + \beta^c x_t^c + s(t, df) \qquad (1)$$

For a city c, Y_t^c is the mortality count, x_t^c is ozone predictor, $s(t, df)$ accounts for unmeasured confounders, with df * 14 years of data, which is estimated via generalized cross-validation. To evaluate "similarity" of temperature, the overall data set is divided according to different temperature levels :(a) warm: less than 2.5% quantile; (b) hot: between 2.5% and 97.5% quantile ; and (c)extreme: larger than 97.5% quantile, Alternatively, denote z_t^c as a categorical variable corresponding to above temperature ranges, Model (1) could be modified as,

$$\log(\mu_t^c) = \alpha^c + \beta^c x_t^c + \eta z_t^c + s(t, df) \quad (2)$$

The results of this first stage analysis are an estimate and its standard error of the ozone-mortality coefficients in each city, expressed in percent rise in mortality per 10 ppb increase of ozone. As an example, table 1 provides the estimates of Chicago with respect to different model and data selections.

Data and Model Description	$\hat{\beta}$	**Std**
Summer Ozone, all temp ranges	1.79*	0.278*
Summer Ozone, below temp.2.5%	-2.37	2.860
Summer Ozone, between temp.2.5% and 97.5%	1.24*	0.253*
Summer Ozone, above temp 97.5%	8.77	4.265
Summer Ozone, temp.quantile as factors	1.40*	0.232*

For Chicago city, the effect of ozone on mortality during summer season appears to be sensitive to the specification of temperature quantile levels in the model, resulting in a highly positive risk estimate of a 8.77% increase in mortality using "extreme" temperature values and a negative risk estimate of a 2.37% decrease in mortality when temperature is "warm". However, after adjusting the tailed events, model

(2) presents a 1.40% increase in mortality for a 10 ppb change in ozone, together with the lowest standard error.

Then, we develop ***two-stage Bayeisan hierarchical models*** as,

$$\hat{\beta}^c \mid \beta^c \sim N(\beta^c, v^c),$$

$$\beta^c \mid \alpha_0, \alpha_1, \sigma^2 \sim N(\alpha_0 + \alpha_1 City, \sigma^2) \quad ; \qquad (3)$$

where $\hat{\beta}^c$ and v^c are the maximum likelihood estimates of β^c and its statistical variance obtained by fitting model (2) in the first stage, the intercept α_0 is the overall association between daily changes in ozone and mortality, the regression parameter α_1 measures the city-specific variable, and the between-city variance (σ^2) measures the heterogeneity of the true log-relative rates across cities.

Applying the semiparametric Poisson regression model to 19 big U.S. cities, Fig.1 shows maximum likelihood estimates and 95% confidence intervals of $\hat{\beta}^c$. There is large variability of the MLEs (4 are negative, 15 are positive). However, there are also overlaps between the 95% confidence intervals. Such properties could also be presented using different data and models.

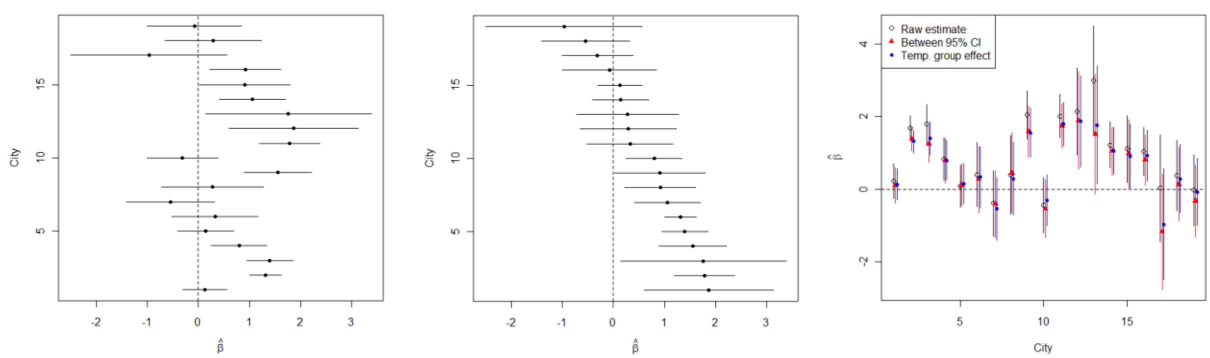

Fig.1 Maximum likelihood esimates and 95% cofidence intervals of $\hat{\beta}^c$. The left panel is ordered by cities; the middle panel is ranked by the estimates from the largest to the smallest; and the righted panel provides results based on different models and data set.

The city-specific relative rates estimates under model (2) and (3) and their 95% posterior regions are reported in Table 2. The heterogeneity of the effects across locations is estimated as 0.69 with 95% credible interval (0.0092, 0.092), which provides evidence that difference across cities exists.

Los Angeles	0.14	(-0.27 , 0.57)	**Philadelphia**	1.65	(1.08 , 2.22)
New York	1.29	(0.98 , 1.59)	**Seattle**	1.52	(0.46 , 2.59)
Chicago	1.31	(0.87 , 1.76)	**San Jose**	1.34	(0.10 , 2.57)
Dallas	0.74	(0.22 , 1.27)	**Cleveland**	0.94	(0.32 , 1.55)

Houston	0.16	(-0.37 , 0.69)	**San Bernardino**	0.88	(0.09 , 1.67)
San Diego	0.43	(-0.34 1.20)	**Pittsburgh**	0.88	(0.23 , 1.53)
Santa Ana	-0.23	(-1.04 0.59)	**Oakland**	-0.31	(-1.51 , 0.89)
Phoenix	0.37	(-0.50 1.23)	**Atlanta**	0.23	(-0.60 , 1.05)
Detroit	1.37	(0.74 2.01)	**San Antonio**	0.17	(-0.72 , 0.94)
Miami	-0.21	(-0.86 0.45)	σ^2	0.69	(0.0092,0.092)

To evaluate associations between summer exposure to ozone and mortality on average across 19 cities, table 2 summarizes posterior mean and 95% posterior region of the overall effect α_0 under alternative specifications for the random effects distribution,

$$cor(\beta^c, \beta^{c'}) = \exp(-\phi \times \text{distance between c and c'}) \quad ; \qquad (4)$$

Where ϕ represents the rate of decay to zero of the correlation as the distance between the two locations increases.

Random effect distribution	**National average esimate**
Normal , ϕ = 0.1	0.826 (0.67, 0.97)
Normal , ϕ = 0.01	0.836 (0.70, 0.96)

In summary, we find the evidence of associations between summer ozone and mortality on average across 19 large cities (0.826) , which is robust to different spatial models.

References:

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