

How Changing the Ozone Standard Might Affect Mortality

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Introduction

- Background
 - Ground-level ozone is a pollutant that is monitored by the Environmental Protection Agency (EPA)
 - In March of this year, EPA promulgated a reduction in the current ozone regulation standard from 84 ppb to 75 ppb based on the 4th largest daily maximum 8-hour ozone (AQI).
 - Critical in the EPA's scientific review were two papers from the NMMAPS group
 - * Bell et al. (JAMA 2004, EHP 2006)
- Goal: Understand effects of ozone regulation on human health using epidemiologic data

What is NMMAPS?

- National Morbidity Mortality and Air Pollution Study: A large multi-city air pollution study based at Johns Hopkins since 1997
- Original focus was particulate matter (PM_{10}) but since 2004, main focus has been on ozone (O_3)
- 108 cities (98 in ozone study) collected daily mortality data from 1987 to 2000, together with data on meteorology (temperature, dewpoint, etc.) and air pollution (O_3 , PM_{10} , SO_2 , NO_2 , CO)
- Objective: study how mortality is affected by the air pollutants when controlling for other known factors including other air pollutants

Statistical Modeling for Ozone Health Effects

Stage I: NMMAPS modeling

- Fit GLM (or GAM) model based on overdispersed Poisson model for mortality
- Fit one model to all three age categories (< 65 , $65 - 74$, ≥ 75) but with interaction terms to allow different long-term trends in three groups
- Covariates
 - Temperature, dewpoint (nonlinear)
 - Long term trends (via splines with 7 knots per year)
 - Day of week
 - Co-pollutants (in some analyses)
- Different lags for O_3

Statistical Modeling for Ozone Health Effects

Ozone risk exposure model

$$E(y_t^c) = (\mu_t^c) \text{ and } Var(y_t^c) = \phi_c \mu_t^c,$$

where y_t^c is the number of daily nonaccidental deaths for community c on day t and ϕ_c is a dispersion parameter.

$$\begin{aligned} \log \mu_t^c &= \beta^c \mathbf{x}_t^c + \alpha^c DOW_t + ns(time, 7/year) + ns(T_t^c, 6) \\ &+ ns(T_{t-1, t-3}^c, 6) + ns(D_t^c, 3) + ns(D_{t-1, t-3}^c, 3) \\ &+ \text{age} \times \text{time interaction} \end{aligned}$$

For example,

$$\underbrace{\beta^c \mathbf{x}_t^c = \beta_0^c x_t + \beta_1^c \bar{x}_{t:t-3}^c + \beta_2^c \bar{x}_{t:t-6}^c}_{CDL} \quad \text{or} \quad \underbrace{\beta^c \mathbf{x}_t^c = \sum_{j=0}^6 \beta_j^c x_{t-j}^c}_{UDL}$$

Statistical Modeling for Ozone Health Effects

Stage II: Hierarchical modeling for ozone effect

The effect of O_3 on mortality for each community c is

$$\hat{\beta}^c | \beta^c, \hat{\Sigma}^c \sim MVN(\beta^c, \hat{\Sigma}^c),$$

where $\hat{\beta}^c$ is an estimate of the true community-specific relative rate, β^c , and $\hat{\Sigma}^c$ is the corresponding estimated covariance matrix.

The prior for β^c is

$$\beta^c | \mu, \Omega \sim MVN(\mu, \Omega),$$

where μ is the true national average relative rate and Ω is the covariance matrix of the true community-specific relative rates, β^c .

To generate sample of β^c from posterior distribution:

- Gibbs sampler
- Rejection-sampling (TLNISE algorithm of Everson & Morris, 2000)

Rollback Issues

- Recently (March 2008), EPA promulgated a reduction in the current ozone regulation standard from 84 ppb to 75 ppb.
- Rollback function attempts to “predict” how a given ozone series would change under a new regulation scenario, and it is needed to investigate health effects
 - Approach based on attainment years satisfying new regulation standard
 - Modification based on current AQI and new regulation standards
 - * based on a common AQI (**Common Rollback**)
 - * based on citywise different AQI (**City-specific Rollback**)

Rollback Issues

Rollback functions (Johnson, 2002)

- Proportional rollback

$$\text{Adjusted Ozone} = \rho \times \text{Current Ozone}$$

- Proportional rollback with background BG

$$\text{Adjusted Ozone} = \text{BG} + \rho \times (\text{Current Ozone} - \text{BG})_+$$

- Quadratic rollback

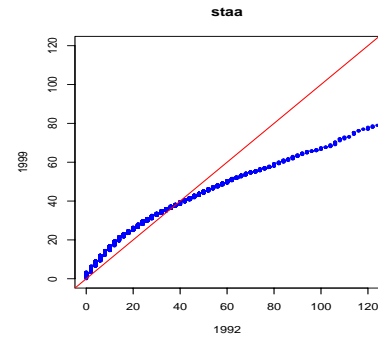
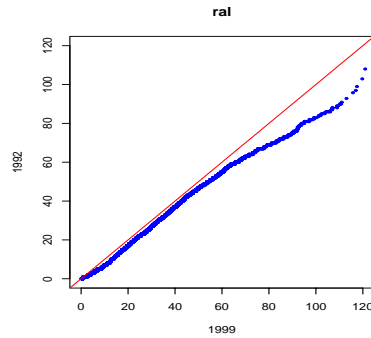
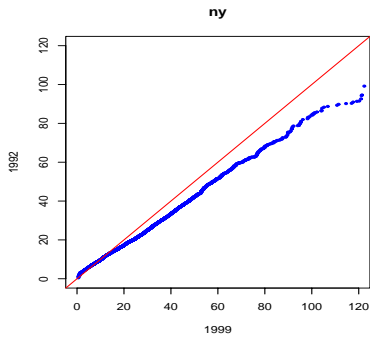
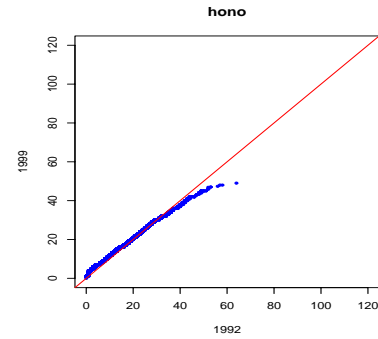
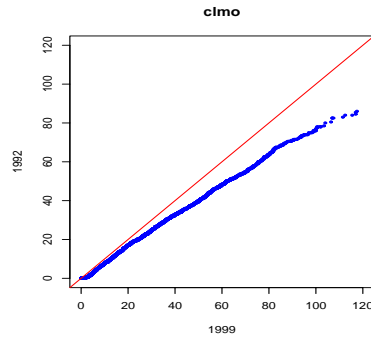
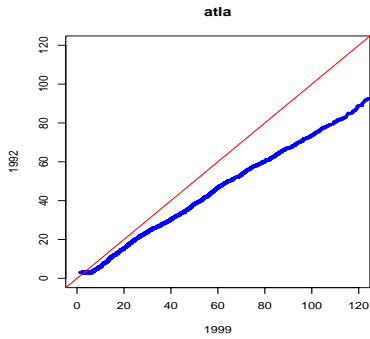
$$\text{Adjusted Ozone} = (\alpha - \beta \times \text{Current Ozone}) \times \text{Current Ozone}$$

- Weibull rollback

$$\text{Adjusted Ozone} = \lambda \times (\text{Current Ozone})^\kappa$$

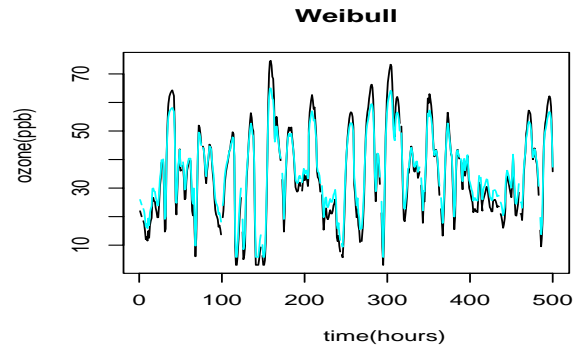
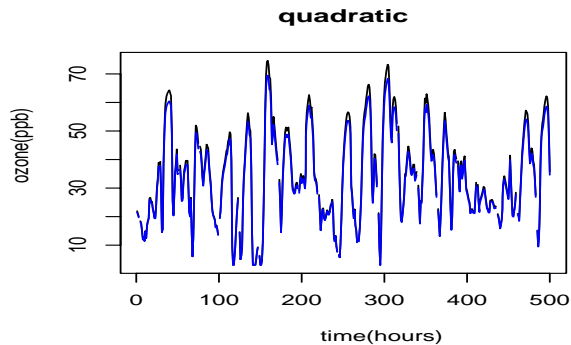
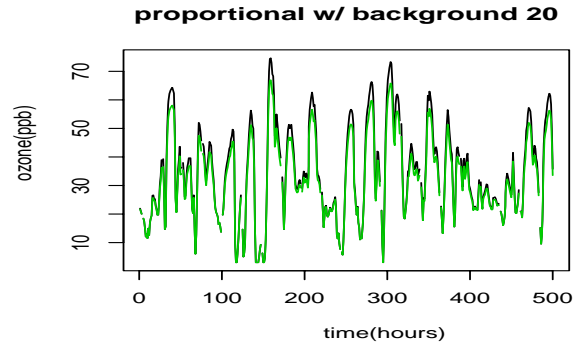
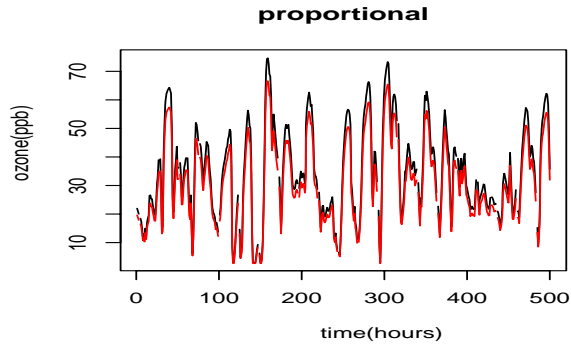
Rollback Issues

Comparison between high and low ozone years (1992 & 1999)



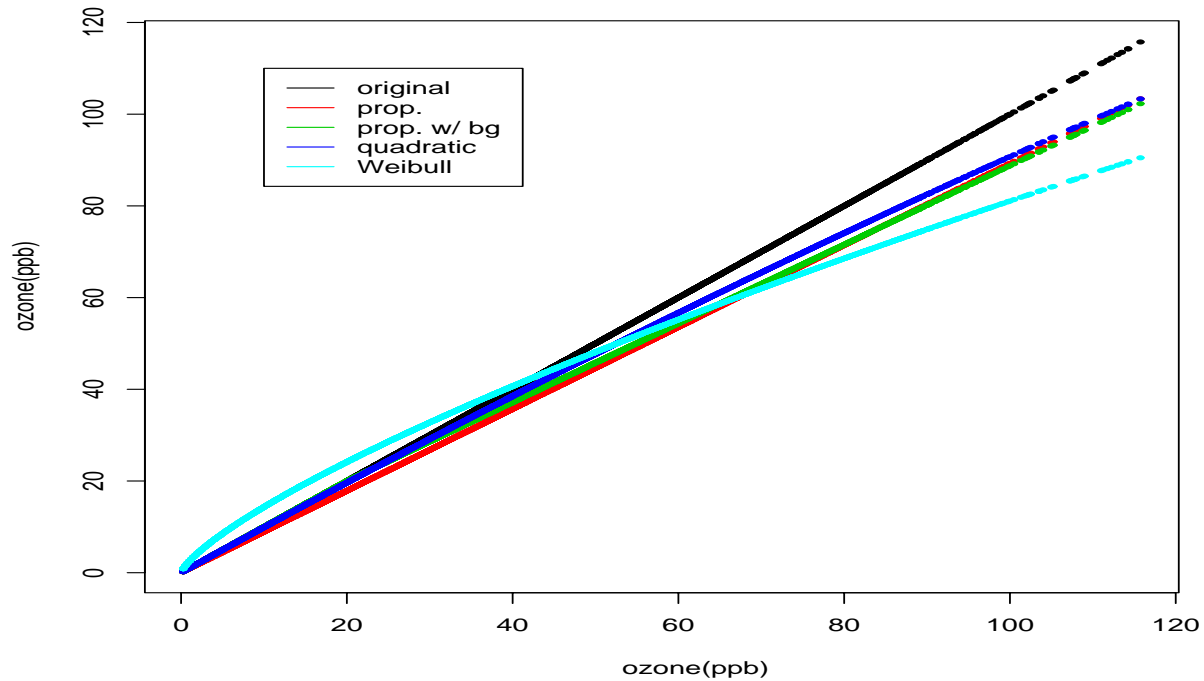
Rollback Issues

Different rollback functions (Raleigh, 2000)



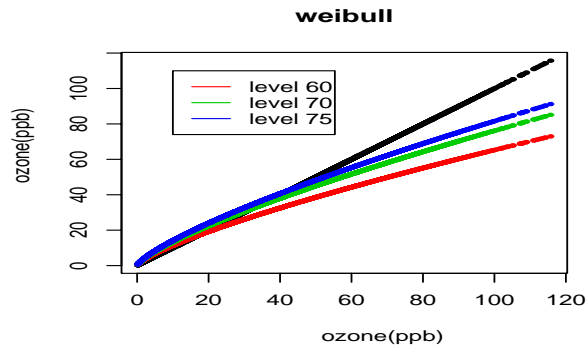
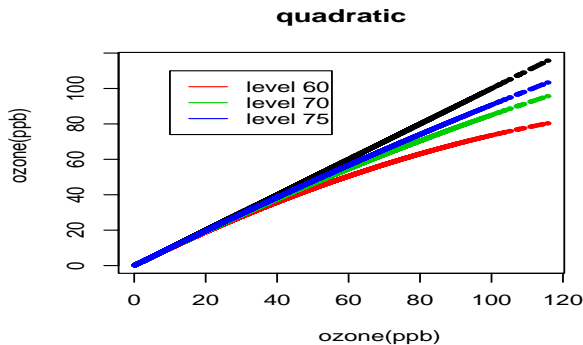
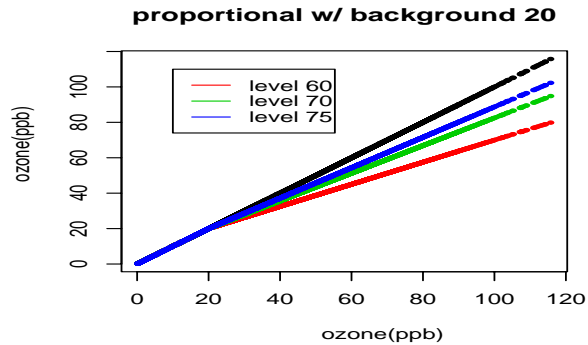
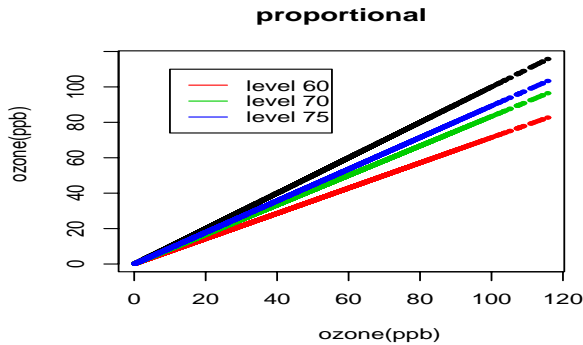
Rollback Issues

Different rollback functions (Raleigh, 2000)



Rollback Issues

Different potential ozone regulations (Raleigh, 2000)



Rollback Issues

Numbers of cities in compliance with potential regulations

Common Rollback: 1998-2000

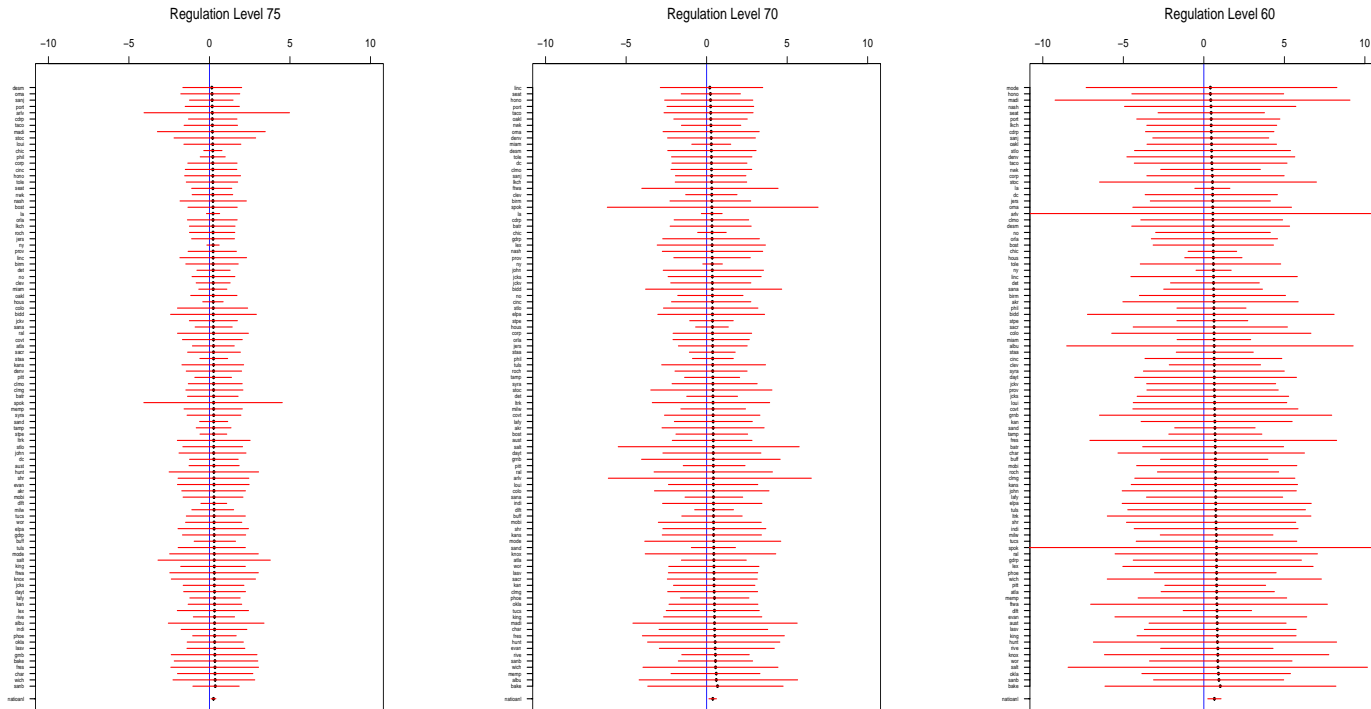
	Regulation			
	current level 84	level 75	level 70	level 60
Before Rollback	47	20	14	3
Proportional		47	47	47
Prop with BG		47	47	47
Quadratic		47	47	47
Weibull		47	47	47

City-specific Rollback: 1998-2000

	Regulation			
	current level 84	level 75	level 70	level 60
Before Rollback	47	20	14	3
Proportional		96	96	96
Prop with BG		96	96	96
Quadratic		96	96	96
Weibull		96	96	96

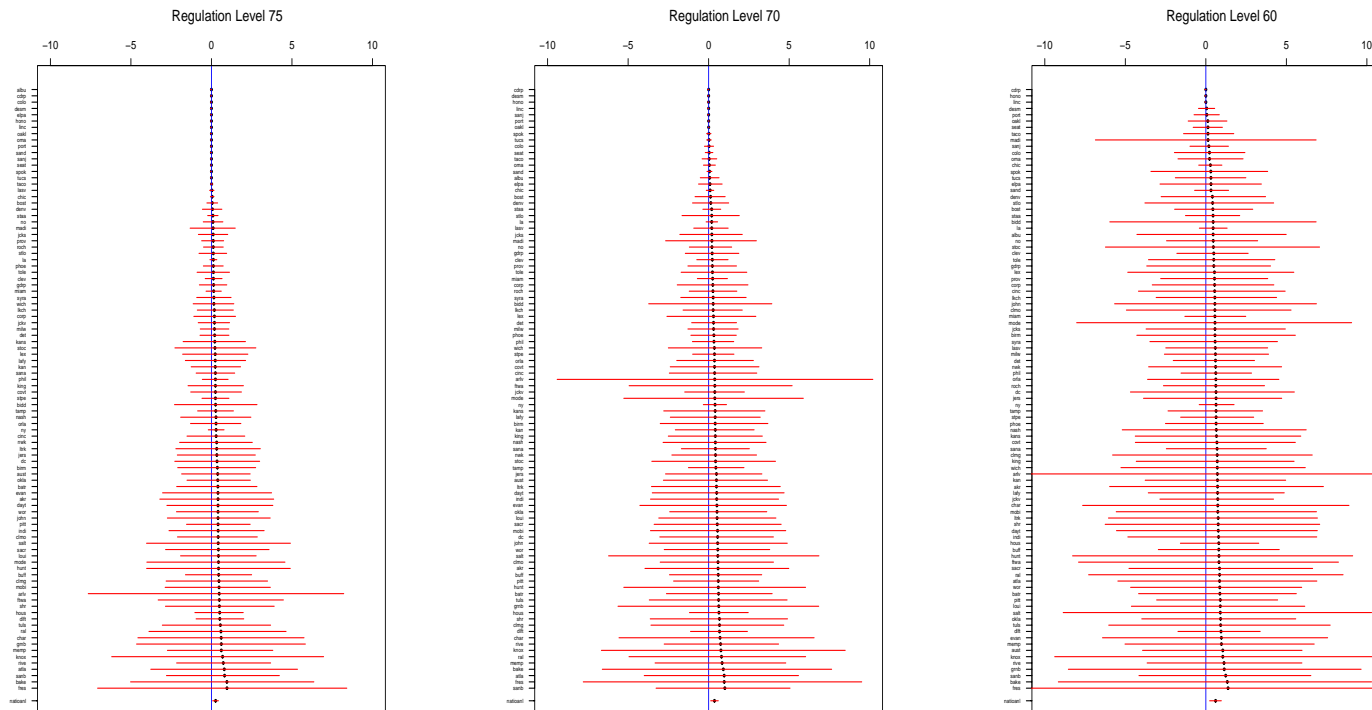
Rollback Issues

Posterior means and 95% CI of reduction in Mortality(%) for COMMON proportional rollback



Rollback Issues

Posterior means and 95% CI of reduction in Mortality(%) for CITY-SPECIFIC proportional rollback



Rollback Issues

Posterior means and 95% CI of Total Mortality Reduction per 1000 Deaths (1998-2000): Common Rollback and **UDL**

Covariate	Regulation	Proportional	Prop with BG	Quadratic	Weibull
Daily Ave	level 75	1.91 (1.09, 2.69)	1.11 (0.64, 1.57)	0.97 (0.54, 1.40)	0.70 (0.27, 1.13)
	level 70	2.96 (1.78, 4.17)	1.72 (1.00, 2.44)	1.47 (0.88, 2.09)	1.19 (0.55, 1.84)
	level 60	4.96 (2.89, 7.00)	2.89 (1.62, 4.11)	2.44 (1.38, 3.47)	3.02 (1.64, 4.37)
Daily Max	level 75	2.32 (1.54, 3.14)	1.91 (1.26, 2.59)	1.66 (1.09, 2.27)	2.48 (1.62, 3.40)
	level 70	3.56 (2.35, 4.74)	2.92 (1.93, 3.91)	2.48 (1.60, 3.37)	3.00 (1.94, 4.02)
	level 60	6.19 (4.11, 8.31)	5.10 (3.33, 6.87)	4.25 (2.79, 5.75)	5.13 (3.41, 6.91)
Daily 8hr Max	level 75	2.10 (1.26, 2.92)	1.61 (0.96, 2.23)	1.36 (0.79, 1.94)	1.90 (1.13, 2.67)
	level 70	3.29 (2.12, 4.59)	2.52 (1.59, 3.52)	2.07 (1.30, 2.91)	2.44 (1.53, 3.43)
	level 60	5.53 (3.37, 7.50)	4.23 (2.52, 5.76)	3.43 (1.99, 4.69)	4.34 (2.52, 5.91)

Rollback Issues

Posterior means and 95% CI of Total Mortality Reduction per 1000 Deaths (1998-2000): City-specific Rollback and **UDL**

Covariate	Regulation	Proportional	Prop with BG	Quadratic	Weibull
Daily Ave	level 75	2.13 (0.62, 3.60)	1.33 (0.33, 2.28)	1.04 (0.35, 1.70)	0.74 (0.19, 1.3)
	level 70	2.77 (1.43, 4.00)	1.67 (0.84, 2.46)	1.37 (0.73, 1.96)	1.39 (0.63, 2.15)
	level 60	4.80 (2.67, 6.84)	2.87 (1.56, 4.16)	2.40 (1.33, 3.46)	3.00 (1.62, 4.39)

Summary

- **Common Rollback and UDL**

- All the Bayesian credible intervals have lower limits > 0 , indicating that the reduction is statistically significant.
- Lower regulation increases the reduction in mortality, as expected and general pattern similar to CDL.
- Over all models and rollback functions, the point estimates for reduction range roughly 1.1-2.5 for 75ppb, 1.2-3.6 for 70ppb and 2.4-6.2 for 60 ppb.

- **City-specific Rollback and UDL**

- Over all rollback functions, the point estimates for reduction range roughly 1.0 - 2.1 for 75ppb, 1.4-2.8 for 70ppb and 2.9-4.8 for 60 ppb.

- Different rollbacks provide different posterior city-specific variance of the relative risks

Rollback Issues

Parametric (Bayesian) rollback approach

Let $F(x; \boldsymbol{\theta})$ and $G(z; \boldsymbol{\gamma})$ be the ozone distribution functions based on the baseline condition and attainment scenario, respectively.

1. For $j = 1, \dots, m$, generate sample $\boldsymbol{\theta}^j$ and $\boldsymbol{\gamma}^j$ from posterior distributions

$$\pi(\boldsymbol{\theta}|\mathbf{x}) \propto f(\mathbf{x}|\boldsymbol{\theta})\pi(\boldsymbol{\theta}) \text{ and } \pi(\boldsymbol{\gamma}|\mathbf{z}) \propto g(\mathbf{z}|\boldsymbol{\theta})\pi(\boldsymbol{\theta}).$$

2. Based on $\boldsymbol{\theta}^j$ and $\boldsymbol{\gamma}^j$,

- (a) Given current ozone x_i for $i = 1, \dots, n$, corresponding rollback value y_i^j can be obtained by

$$y_i^j = G^{-1}(F(x_i; \boldsymbol{\theta}^j); \boldsymbol{\gamma}^j).$$

- (b) Iterate previous step for $j = 1, \dots, m$.

Rollback Issues

- Remark

- Ozone distribution can be generalized to a mixture of the form

$$f(x) = \begin{cases} (1 - w)h(x|\boldsymbol{\theta}_1) & x < u \\ wk(x|\boldsymbol{\theta}_2) & x \geq u \end{cases},$$

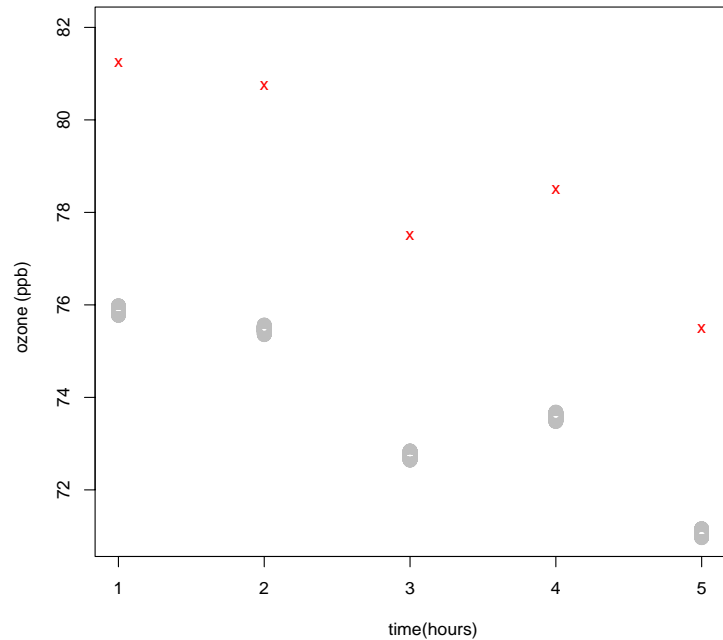
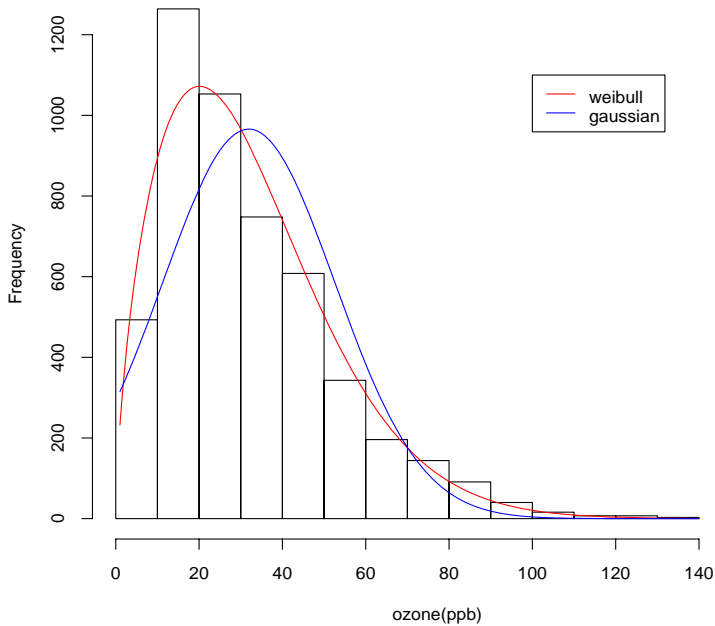
where h is any parametric distribution and k is a Generalized Pareto distribution (GPD).

- F and G can be estimated based on baseline and attainment years' ozone data.
- G may need adjustment based on $\rho(s) = \frac{x(b)}{x(s)}$, where $x(b)$ is current design value and $x(s)$ is design value under scenario s .
- In proportional rollback view, $G(z; \boldsymbol{\gamma}) = F(z; \rho\theta_1, \theta_2)$, where θ_1 is a scale parameter ($\boldsymbol{\theta} = (\theta_1, \theta_2)$) if F is invariant w.r.t. scale transformation (e.g. Weibull).
- This approach introduces uncertainty in rollback.

Rollback Issues

Application to ozone data (Raleigh, 2000)

Histogram of ozone



Further discussions

- Sensitivity issues
 - Different time lag models with the constrained / unconstrained distributed lags
 - PM10 as a co-pollutant (e.g. see Bell et al.)
 - Dealing with high temperature days (e.g. drop top 1 % or over 29°C for each city)
 - Using respiratory deaths instead of non-accidental deaths
 - Using different background levels (e.g. 30, 40, 50)
- Collinearity between ozone and other covariates (e.g. temp)
- Regional and spatial analysis
- Uncertainty in ozone process itself in rollback
- Optimal distribution for Parametric rollback approach