

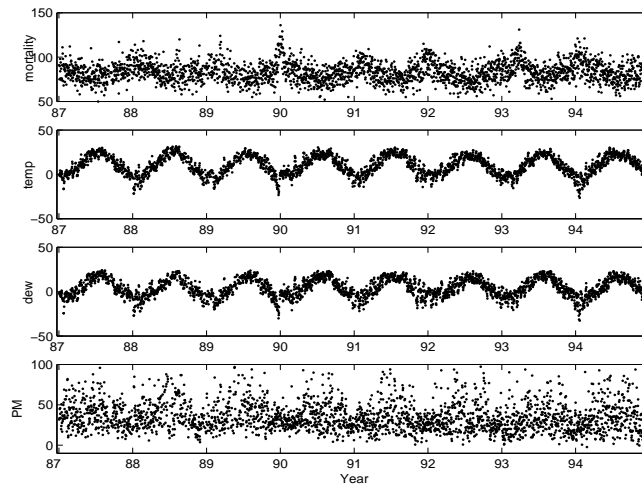
# Mortality displacement in the association between air pollution and mortality

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## Time-series studies

- Time-series studies are commonly used to investigate the association between air pollution and mortality.
- These studies relate daily time-series data of weather variables and pollutants to time-series of daily mortality.
- Adjusting for weather variables helps avoid spurious results.
- Example: Days of high temperature may be positively correlated with both air pollution and mortality.

## Example data – Cook County



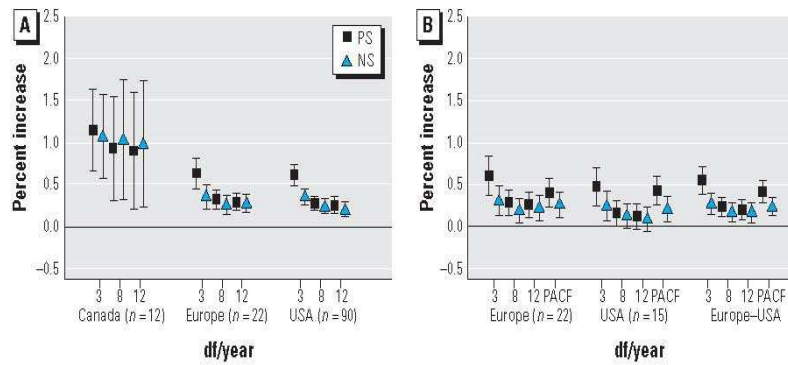
### Typical time-series study

- Poisson log-linear models of the following basic form are often used:

$$\log(\mu_t) = S_{t1}(\text{time}, 7\alpha \text{ df/yr}) + S_{t2}(\text{temp}, 6 \text{ df}) + S_{t4}(\text{dew}, 3 \text{ df}) + \gamma \text{DOW}_t + \beta X_t$$

- $X_t$  is the air pollutant time-series.
- $\beta$  quantifies the association between the air pollutant and mortality.

## Samoli et al. (2008) EHP, 116:1480-1486



**Figure 1.** Percent increase in the daily number of deaths, for all ages, associated with a 10-µg/m<sup>3</sup> increase in PM<sub>10</sub>: lag 1 (A) and lags 0 and 1 (B) for all three centers. PACF indicates df based on minimization of PACF.

## Kan et al. (2008) EHP, 116:1183-1188

**Table 4.** Percent increase in number of deaths due to total, cardiovascular, and respiratory causes associated with a 10-µg/m<sup>3</sup> increase in air pollutants by educational attainment.<sup>a</sup>

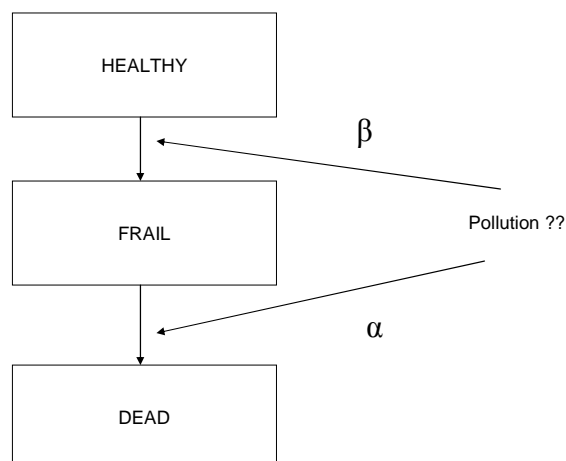
Mortality	Educational attainment	Mean daily deaths (n)	Pollutant			
			PM <sub>10</sub>	SO <sub>2</sub>	NO <sub>2</sub>	O <sub>3</sub>
Total	Low	67.3	0.33 (0.19 to 0.47)	1.19 (0.77 to 1.61)	1.27* (0.89 to 1.66)	0.26 (-0.09 to 0.60)
	High	42.1	0.18 (0.01 to 0.36)	0.66 (0.16 to 1.17)	0.62 (0.15 to 1.09)	0.30 (-0.11 to 0.71)
Cardiovascular	Low	27.8	0.30 (0.10 to 0.51)	1.08 (0.47 to 1.69)	1.15 (0.58 to 1.72)	0.33 (-0.13 to 0.90)
	High	16.4	0.23 (-0.03 to 0.50)	0.57 (-0.20 to 1.35)	0.73 (0.01 to 1.45)	0.26 (-0.38 to 0.91)
Respiratory	Low	8.9	0.36 (0.00 to 0.72)	1.54 (0.43 to 2.66)	1.59 (0.57 to 2.62)	0.20 (-0.74 to 1.16)
	High	5.4	0.02 (-0.43 to 0.47)	0.73 (-0.61 to 2.09)	0.34 (-0.69 to 1.60)	0.27 (-0.66 to 1.41)

<sup>a</sup>We used current day temperature and humidity (lag 0) and 2-day moving average of air pollutants concentrations (lag 01) and we applied 3 df to temperature and humidity. \*Significantly different from high educational attainment ( $p < 0.05$ ).

## Interpreting results of time-series studies

- Is a difficult problem: measurement error, confounder adjustment, model selection etc.
- Who is being harmed by exposure to ambient air pollution?
- The public health burden of air pollution will be different if “frail” rather than “healthy” individuals are being harmed by exposure to ambient air pollution.
- *Mortality displacement* refers to the situation where air pollution exposure affects a frail subset of the population with a relatively short expected future lifetime.
- Important to know whether the association between air pollution and mortality is mortality displacement only.

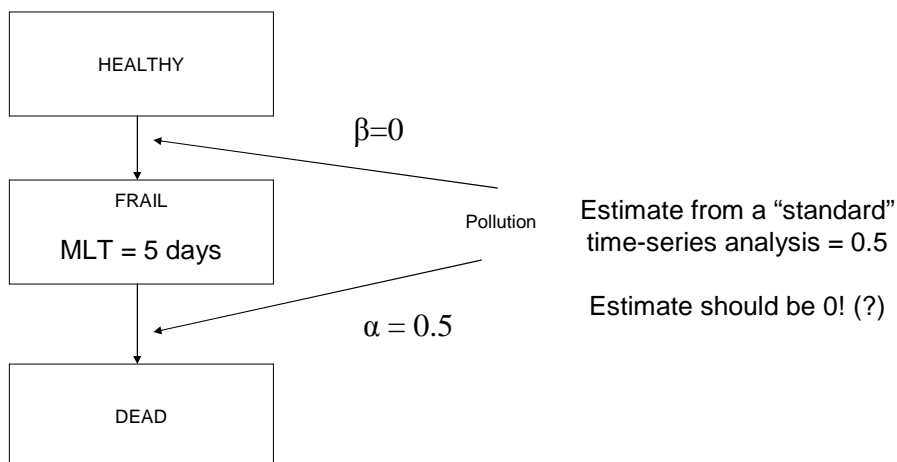
## Mortality Displacement – three-state model



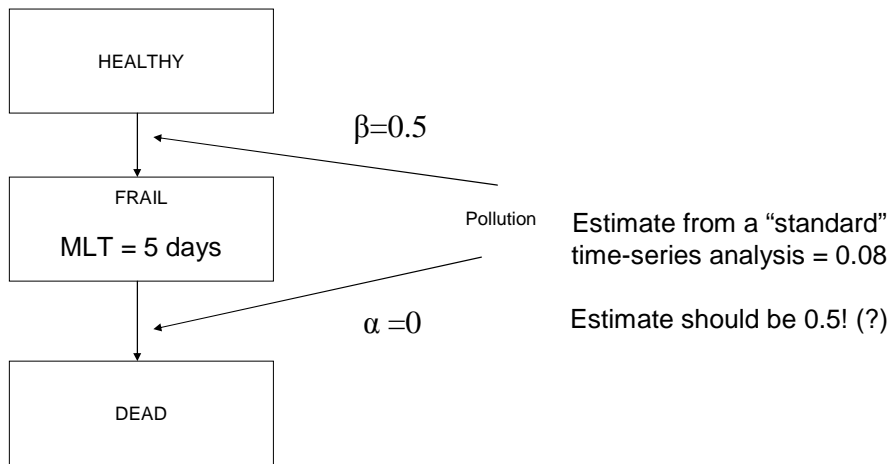
## Mortality displacement – three-state model

- In three-state model mortality displacement is the situation where air pollution only impacts movement from frail state to death [ $\beta=0$ ;  $\alpha>0$ ]
- The important quantity for public health assessment may be the effect of air pollution on the healthy population  $\beta$ .
- $\beta$  represents the effect of air pollution on mortality that is more than just the displacement of mortality by a few days to weeks.
- Is it possible to estimate  $\beta$ , the effect of air pollution net of mortality displacement?
- Problem: Only daily deaths are observable.

## Example 1 – Mortality displacement only



## Example 2 – No Mortality displacement



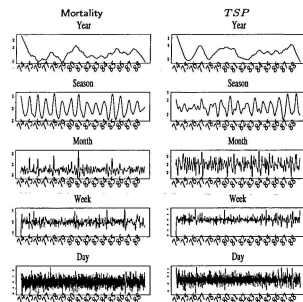
## Mortality displacement – three-state model

- These two examples clearly illustrate the problems of interpretation that can arise if mortality displacement and frail populations exist.
- A number of different methods have been proposed to adjust for mortality displacement in time-series studies.
- How effective are these methods?

## Decomposition of air pollution effects

- These methods decompose the mortality effects of air pollution into long and short time scales.
- Rely on the supposition that that mortality displacement alone will create associations only at short time scales.

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Zeger et al. (1999) *Epidemiology*, 10:171-175

FIGURE 2. Decomposition into five-component series for the mortality and total suspended particles ( $\mu\text{g}/\text{m}^3$ ) series (on squared root scale) from Philadelphia for the period 1974–1988. Each plot represents the residual time series in respect to the previous component.

## Estimating the size of the frail population

- These methods explicitly estimate the expected longevity in the frail population.
- Develop models where the observed daily mortality depends on the size of the frail population and some measure of air pollution.

Results of Smith et al. (1999) Human health effects of environmental pollution in the atmosphere, pp 91-115

Parameter	Posterior	Posterior
	Mean	SD
Mean frail population size	823	221
PM <sub>10</sub> in $\mu_t$	5.23	7.04
PM <sub>10</sub> in $\phi_t$	8.17	2.50
Mean days lost	.081	.033

**Table 1:** Posterior means and standard deviations for the four key parameters graphed in Fig. 5

## Distributed lag models (DLMs) of air pollution

- DLMs of air pollution extend “standard” time-series analysis by including up to 40 lags of the air pollutant.
- The rationale for DLMs is that they are able to capture the replenishment and/or depletion of the frail population.

88 Zanobetti *et al*

Zanobetti et al. (2002) *Epidemiology*, 13:87-93

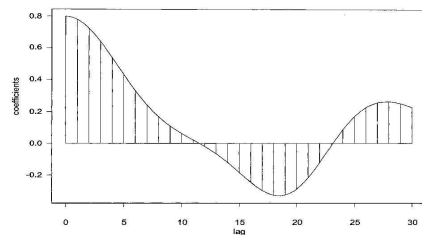


FIGURE 1. Hypothetical lag structure corresponding to the mortality displacement effect.

## Example: DLMs Roberts + Switzer (2004), IT 16:879-888.

**TABLE 1**  
Sum of lagged PM coefficients in a DLM based on concurrent daily time series of length 2603, such that total PM *enter* effects are 2.53%

MLT	Number of PM lags in DLM ( <i>k</i> )			
	0	10	40	80
	<i>enter</i> model ( $\theta^* = 2.53\%$ )			
5	0.18 <sup>a</sup> (0.15)	2.25 (0.40)	2.85 (1.12)	2.60 (3.73)
15	0.04 (0.15)	1.09 (0.41)	2.68 (1.08)	2.43 (3.71)
30	0.01 (0.15)	0.53 (0.39)	1.87 (1.07)	1.94 (3.64)
60	0.00 (0.16)	0.25 (0.39)	1.08 (1.07)	1.11 (3.78)
300	0.01 (0.15)	0.05 (0.40)	0.20 (1.06)	0.28 (3.69)
	<i>exit</i> model ( $\theta^* = 0.00\%$ )			
5	0.94 (0.15)	0.27 (0.41)	-0.35 (1.06)	-0.22 (3.74)
15	1.08 (0.15)	1.43 (0.40)	-0.24 (1.05)	0.23 (3.69)
30	1.10 (0.15)	2.00 (0.40)	0.67 (1.04)	0.73 (3.54)
60	1.11 (0.15)	2.28 (0.40)	1.49 (1.07)	1.30 (3.64)
300	1.12 (0.15)	2.49 (0.40)	2.30 (1.07)	2.23 (3.62)
	<i>enter/exit</i> model ( $\theta^* = 2.53\%$ )			
5	0.48 (0.15)	2.15 (0.40)	2.56 (1.06)	2.52 (3.62)
15	0.39 (0.15)	1.44 (0.40)	2.30 (1.07)	2.64 (3.64)
30	0.37 (0.16)	1.13 (0.39)	1.82 (1.06)	2.18 (3.66)
60	0.36 (0.15)	0.96 (0.39)	1.40 (1.08)	1.72 (3.78)
300	0.37 (0.15)	0.86 (0.39)	0.96 (1.05)	1.06 (3.71)

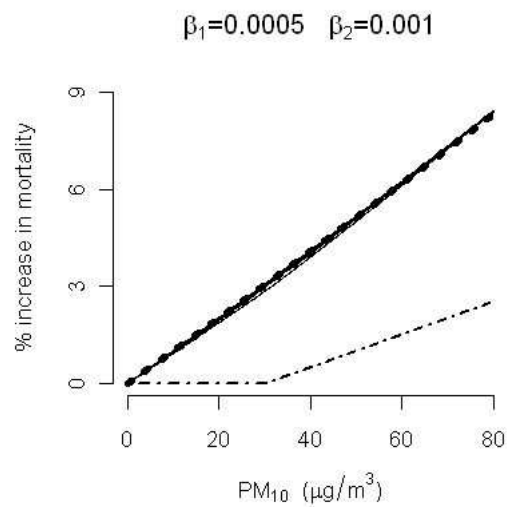
*Note.* MLT, mean lifetime in days for the frail population.  $\theta^*$ , incremental contribution of PM to mortality that is not simply mortality displacement.

<sup>a</sup>Average PM coefficient sum derived from 2000 simulations, with standard deviations shown in parentheses. The average coefficient sum is expressed as a mortality increase percentage for each PM increase of 10  $\mu\text{g}/\text{m}^3$ .

## Concentration response relation

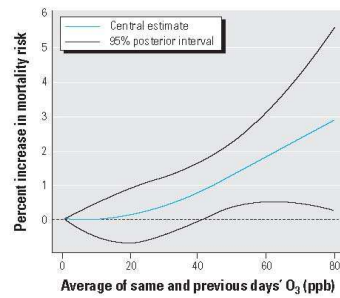
- The shape of the concentration-response relation is critical for the public health assessment of exposure to air pollution.
- Numerous studies have concluded that the relation is approximately linear.
- Example: Threshold versus linear relation.

## Threshold versus Linear relation



## Bell et al. (2006) EHP, 114:532-536

CONCENTRATIONS (Figure 3).



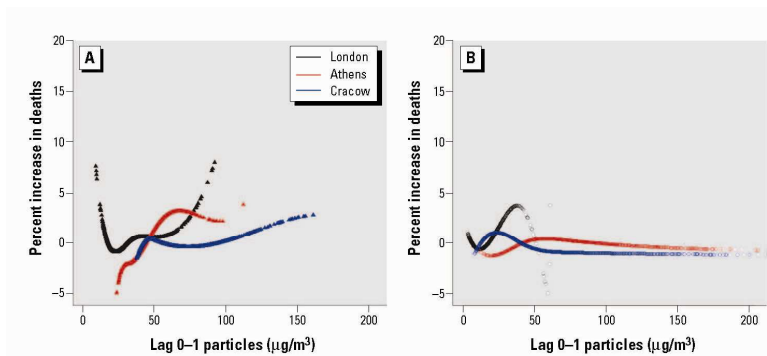
Baton Rouge, Louisiana  
 Biddeford, Maine  
 Birmingham, Alabama  
 Boston, Massachusetts  
 Buffalo, New York  
 Cedar Rapids, Iowa  
 Charlotte, North Carolina  
 Chicago, Illinois  
 Cincinnati, Ohio  
 Cleveland, Ohio  
 Colorado Springs, Colorado  
 Columbus, Georgia  
 Columbus, Ohio  
 Corpus Christi, Texas  
 Coventry, Rhode Island  
 Dallas/Fort Worth, Texas  
 Dayton, Ohio  
 Denver, Colorado

Descriptive statistics for

**Figure 3.** Exposure-response curve for  $O_3$  and mortality using the spline approach: percentage increase in daily nonaccidental mortality at various  $O_3$  concentrations.

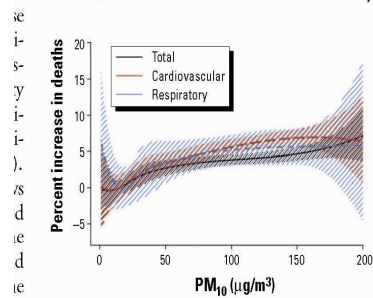
Environmental Health Perspectives • VOLUME 114 | NUMBER 4 | April 2006

## Samoli et al. (2005) EHP, 113:88-95

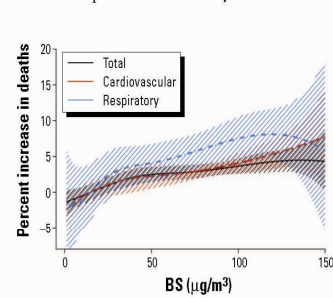


**Figure 1.** Exposure-response curves of  $PM_{10}$  (A) and BS (B) with total mortality in London, Athens, and Cracow.

## Samoli et al. (2005) EHP, 113:88-95



**Figure 2.** Exposure–response curves and 95% CIs of PM<sub>10</sub> and total, cardiovascular, and respiratory mortality.

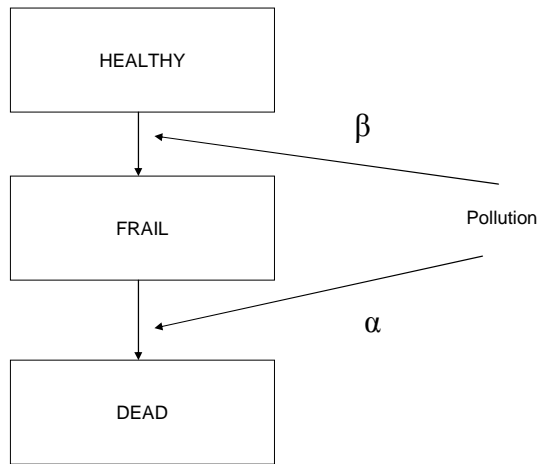


**Figure 3.** Exposure–response curves and 95% CIs of BS and total, cardiovascular, and respiratory mortality.

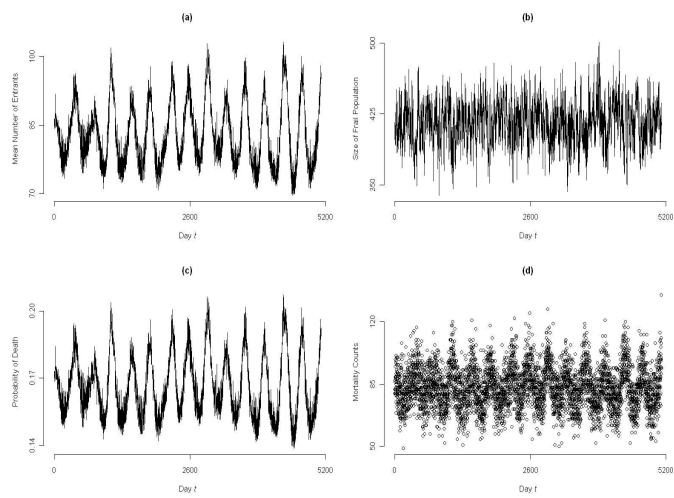
## Mortality displacement and the concentration response relation between PM and mortality

- What is the shape of concentration-response relation between PM and mortality, as “estimatable” from time-series data, in the presence of mortality displacement and/or a frail population.
- Study is conducted in the context of the three-state population model.
- Illustrate that thresholds in the concentration-response relation can be masked.

## Mortality simulation model



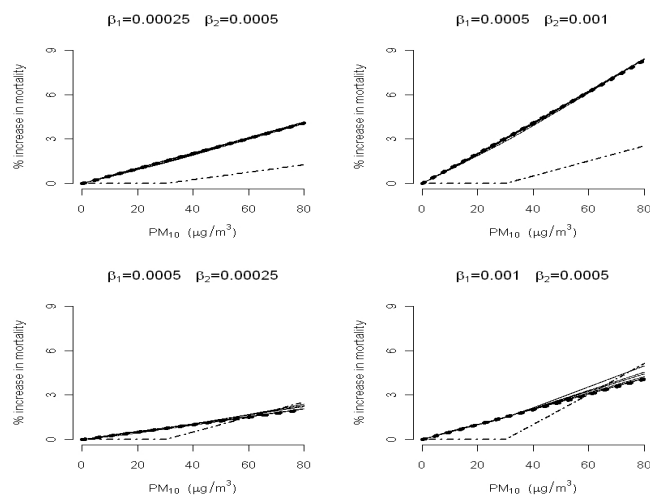
## Example of simulated mortality



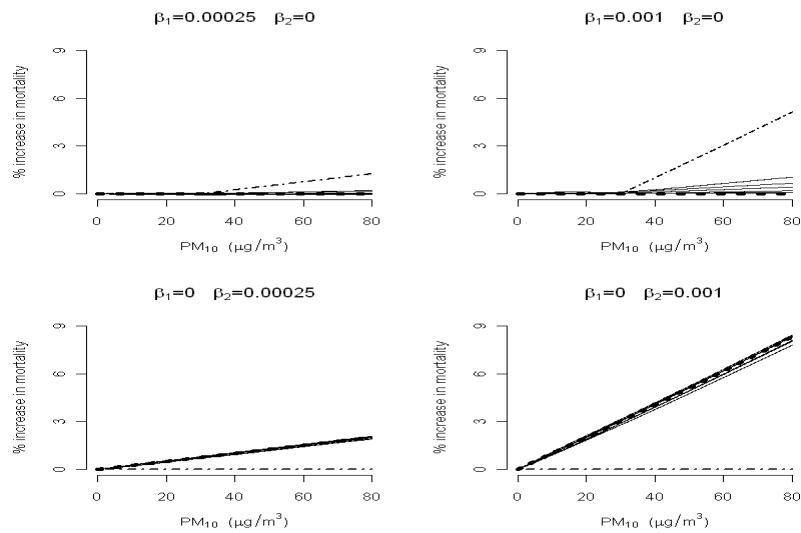
## Description of simulations

- Generated sets of 3000 mortality time-series where the shape of the concentration-response relation on both the healthy and frail populations was known.
- Investigated the shape of the concentration-response relation that was observable in the simulated mortality time-series.
- The observed concentration-response relation is a function of the frail population sizes and the effect of PM on the healthy and frail populations.

## Some results 1



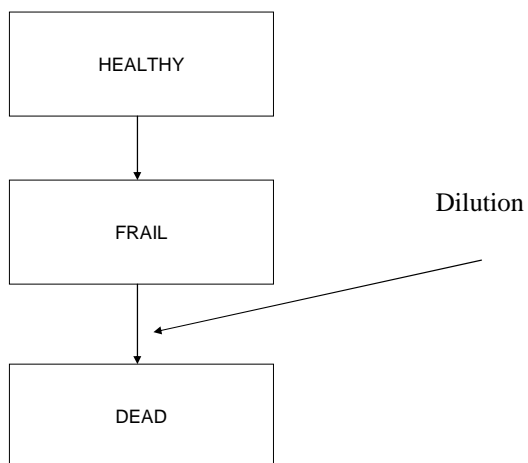
## Some results 2



## Some results 3

- The presence of, even a very small, frail population can mask the shape of the concentration-response relation between PM and mortality that is not simply short-term mortality displacement
- The reason for this masking is due to the deaths of the individuals moved into the frail population, as a result of PM exposure, not being observed immediately but rather being spread out (or diluted) over a period of time.
- If a frail population exists it may only be possible to determine the shape of the relation between PM and exit from this frail population and *not* the more important relation between PM and entry into this frail population.

## “Dilution”

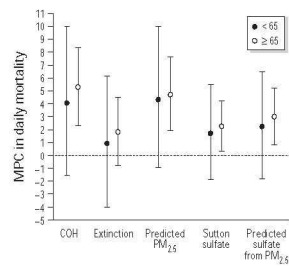


## Other options

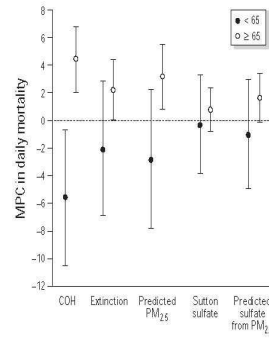
- Investigate whether there are populations vulnerable to ambient air pollution.
- Investigate other endpoints such as hospital admissions (common).

## Goldberg et al. (2001) EHP, 109:487-494

### sceptible subgroups and particulate air pollution



**Figure 1.** MPC in daily mortality among persons with acute lower respiratory diseases 2 months before death, evaluated at the 3-day mean for increases in the IQs of selected measures of particulates, by age group. The estimated MPC in daily nonaccidental mortality across the IQ is shown by the circles within the vertical lines (95% CIs).



**Figure 2.** MPC in daily mortality among persons with chronic coronary artery diseases 1 year before death, evaluated at the 3-day mean for increases in the IQs of selected measures of particulates, by age group. The estimated MPC in daily nonaccidental mortality across the IQ is shown by the horizontal bars within the vertical lines (95% CIs).

## Future work

- Extension of three-state model
- Other methods for adjusting for mortality displacement
- Thank you for your time