Assessing Low Levels of Air Pollution: A Historical Perspective

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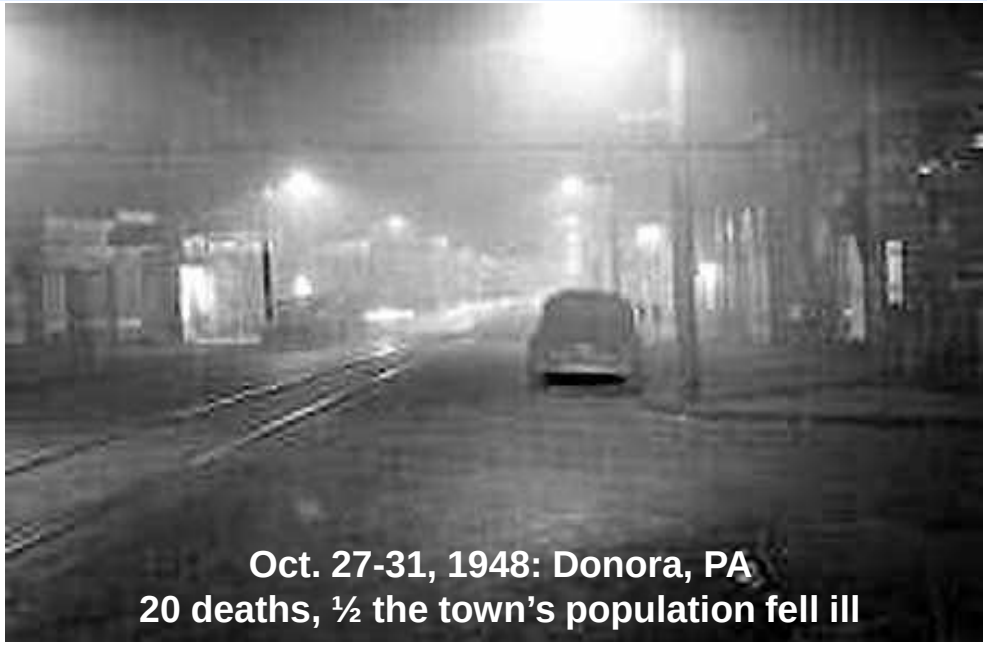
Early **“Killer smog”** episodes demonstrated that air pollution at extreme levels can contribute to respiratory and cardiovascular disease and death

Dec. 1-5, 1930: Meuse Valley, *Belgium*
60 deaths (10x expected)

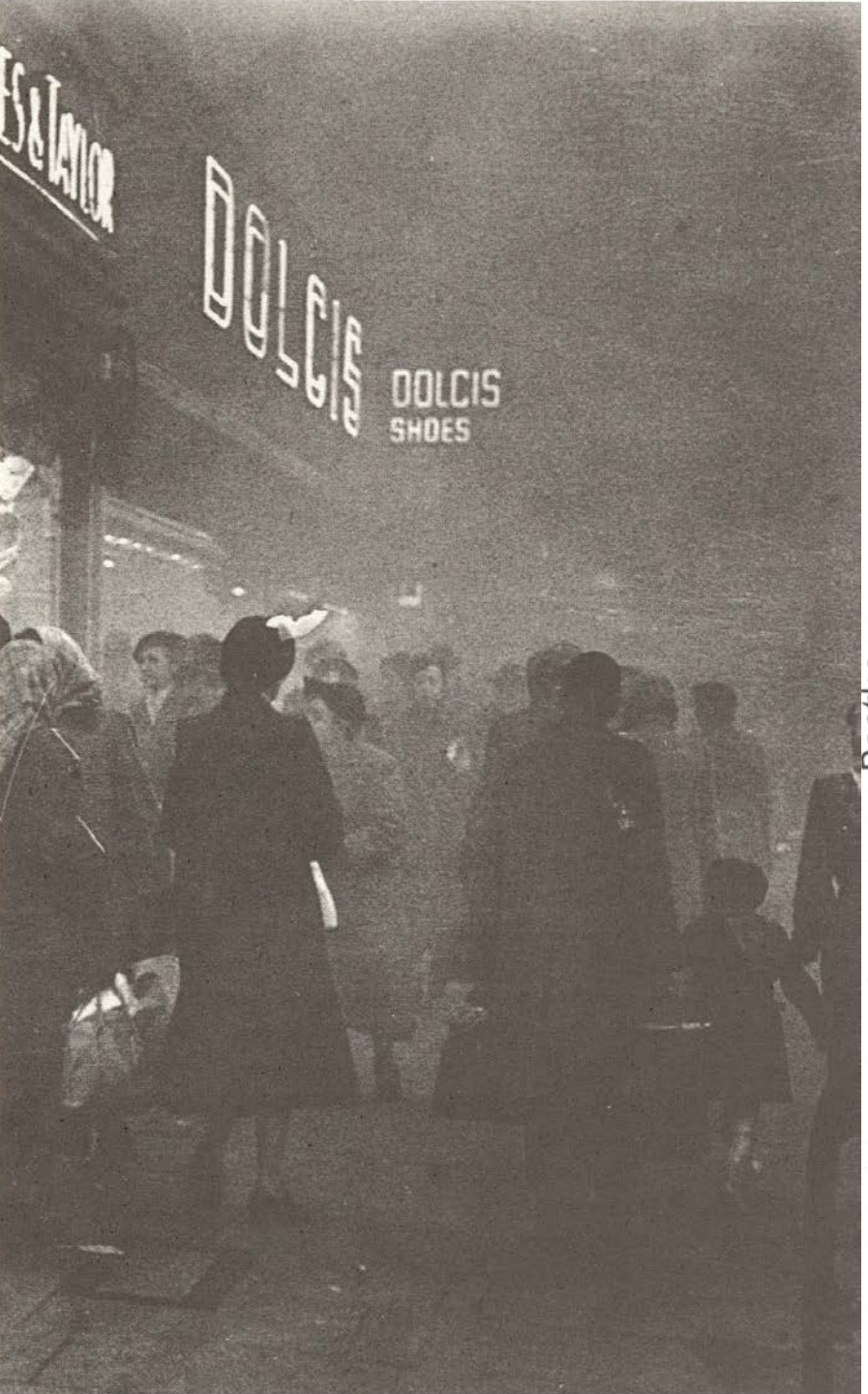


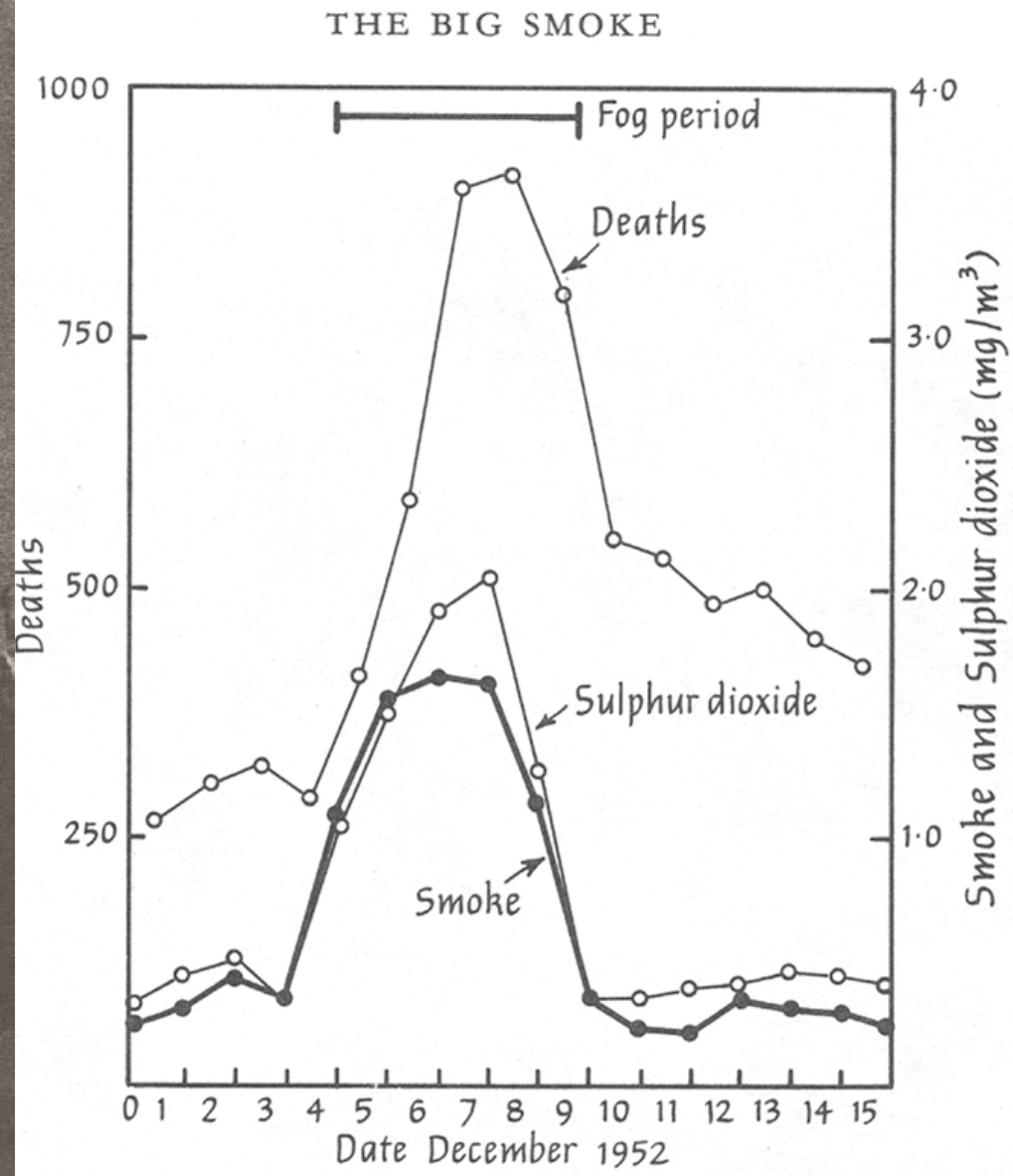
Oct. 27-31, 1948: Donora, PA
20 deaths, ½ the town’s population fell ill

Dec. 5-9, 1952: London--1000’s of excess deaths

Respiratory and cardiovascular disease and death

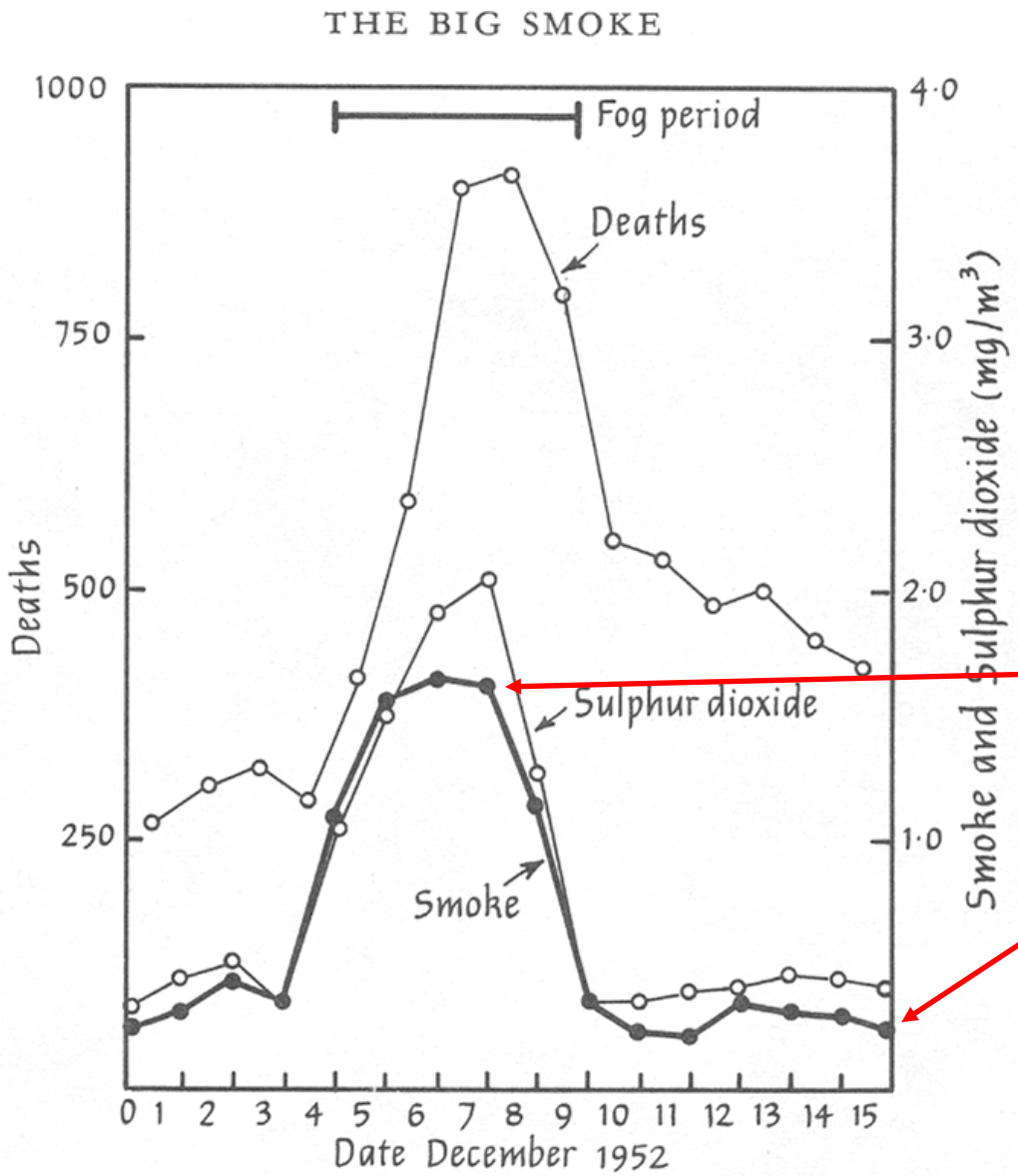
London Fog Episode, Dec. 1952





From: Brimblecombe P. The Big Smoke, Methuen 1987

London Fog Episode, Dec. 1952



From: Brimblecombe P. The Big Smoke, Methuen 1987

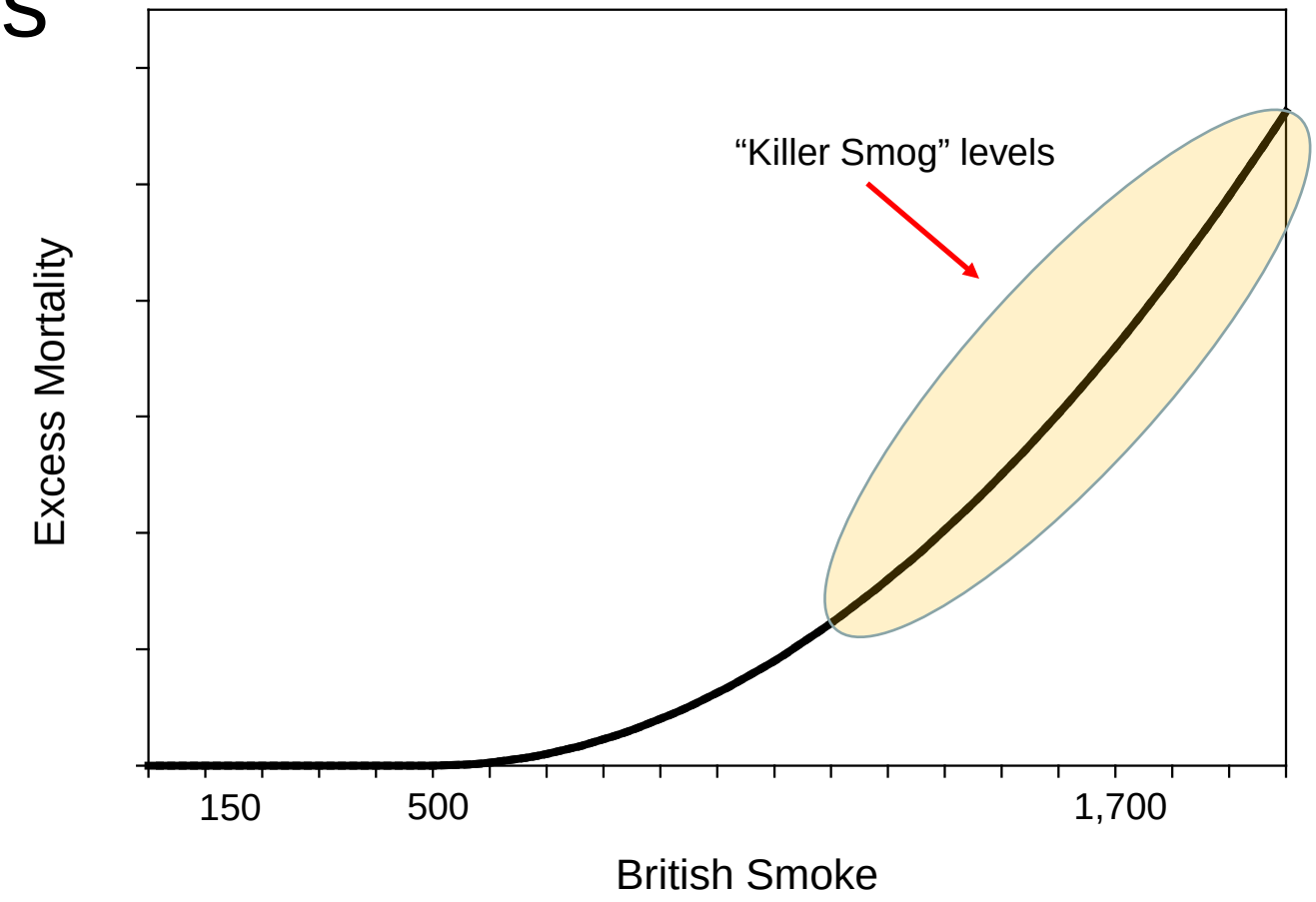
Note the concentrations of PM or BS (British Smoke):

High concentrations about

1.7 milligrams (mg/m^3) or 1,700 micrograms (µg/m^3)

Low concentrations about 150 µg/m^3

1970's



The Clean Air Act and NAAQSs basically assumed "threshold" exposure-response relationships between adverse health effects and "criteria" pollutants. Debate was largely about "**where is the threshold**" and "**what is an adequate margin of safety**."

Environmental Health Perspectives
Vol. 58, pp. 397-399, 1984

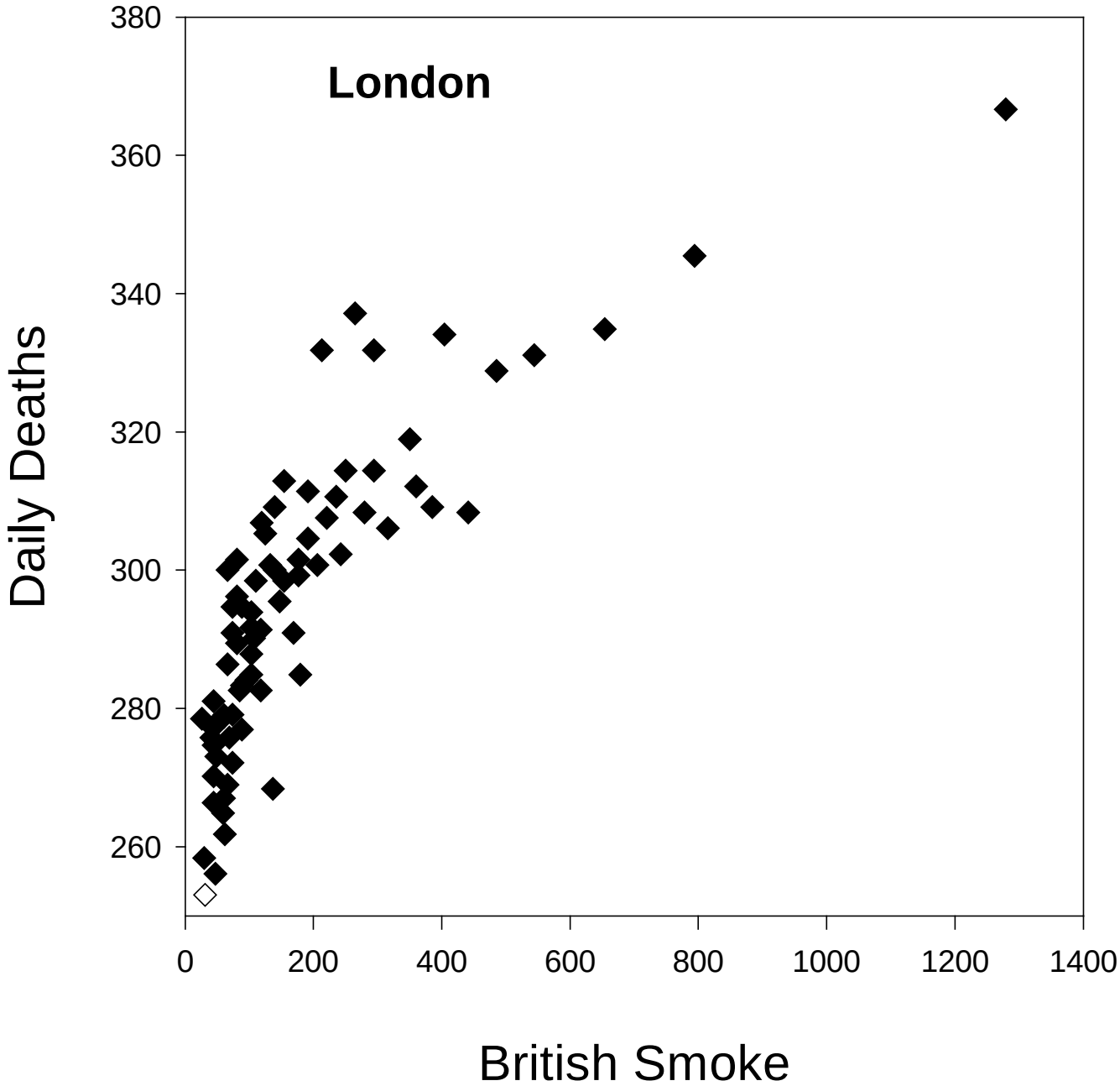
1984

A Search for a Threshold in the Relationship of Air Pollution to Mortality: A Reanalysis of Data on London Winters

by Bart Ostro*

The relationship between air pollution and increased risk of mortality has been explored previously using data on 14 winters in London. The results of these analyses have been used to determine a no-observable-effects level. This reanalysis of the data finds no evidence to support the existence of a no-effects level. Further, the reanalysis suggests that the estimated pollution-mortality relationship exists even in nonepisodic winters, when British Smoke readings were less than 500 $\mu g/m^3$.

Our perspective about what consists of “low-level air pollution has changed over the last several decades



1990

Early analyses of concentration-response function.

Used London mortality data for 14 winters

C-R function less steep at higher concentrations

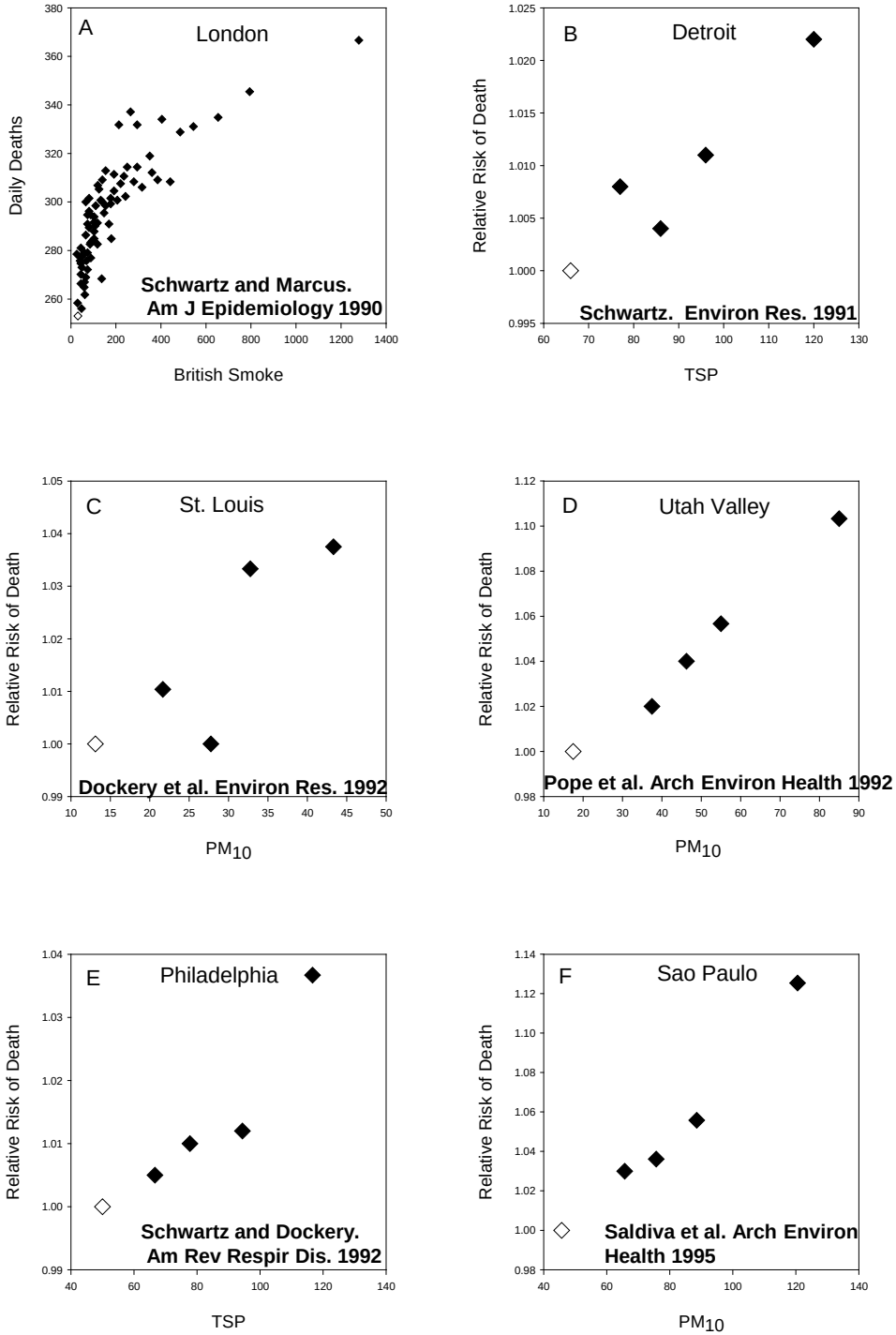
No evidence of a threshold

Schwartz and Marcus. Am J Epidemiology 1990

Early 1990's

To explore for effects at low pollution levels, many early single-city time-series Studies used quintile (or quartile) Analysis where indicator variables for Different ranges of air pollution were Included in the time-series regression models.

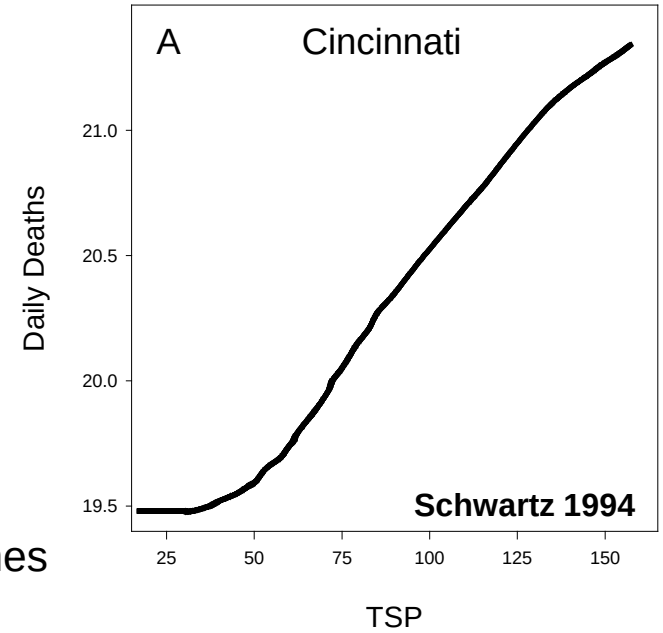
Examples . . . .

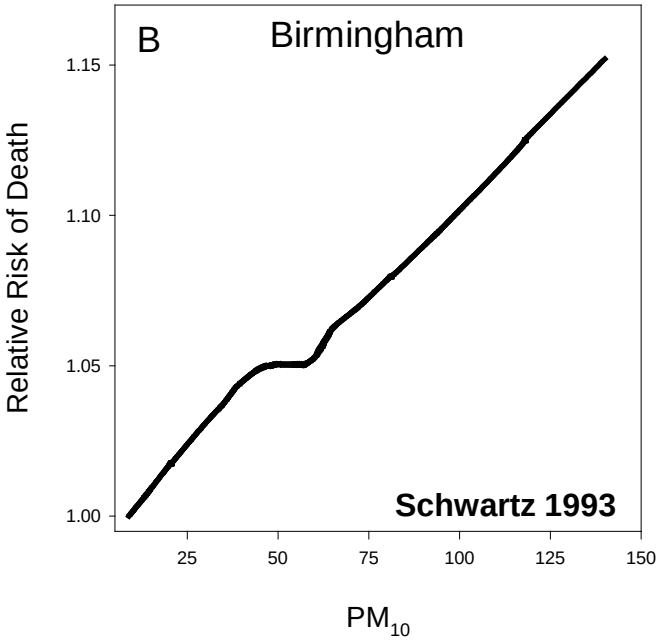


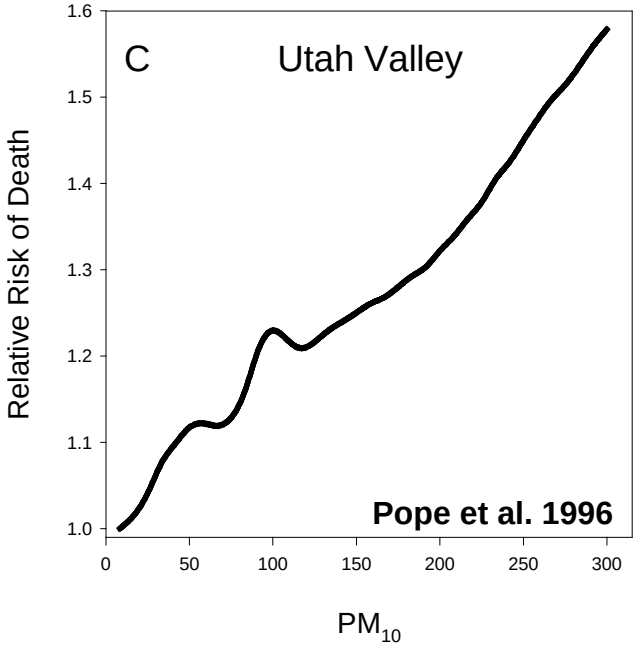
Mid to late 1990's

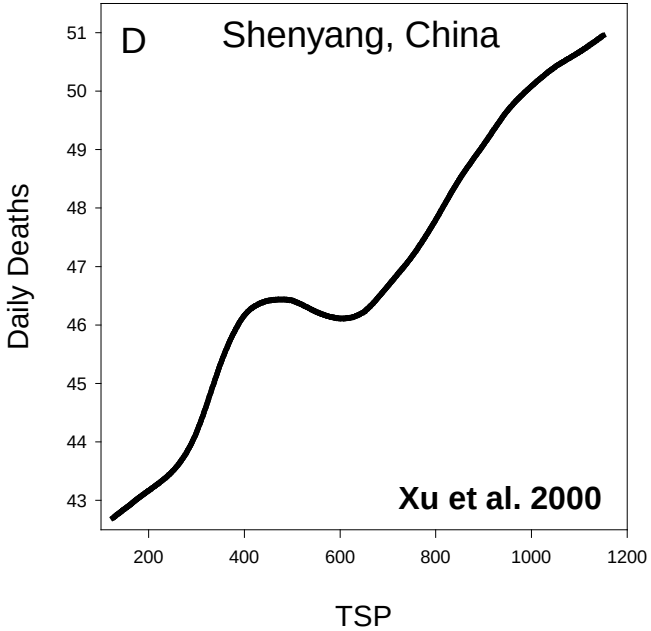
Various parametric (spline functions) or non-parametric smoothing approaches to allow for flexible fitting of C-R.

Examples:





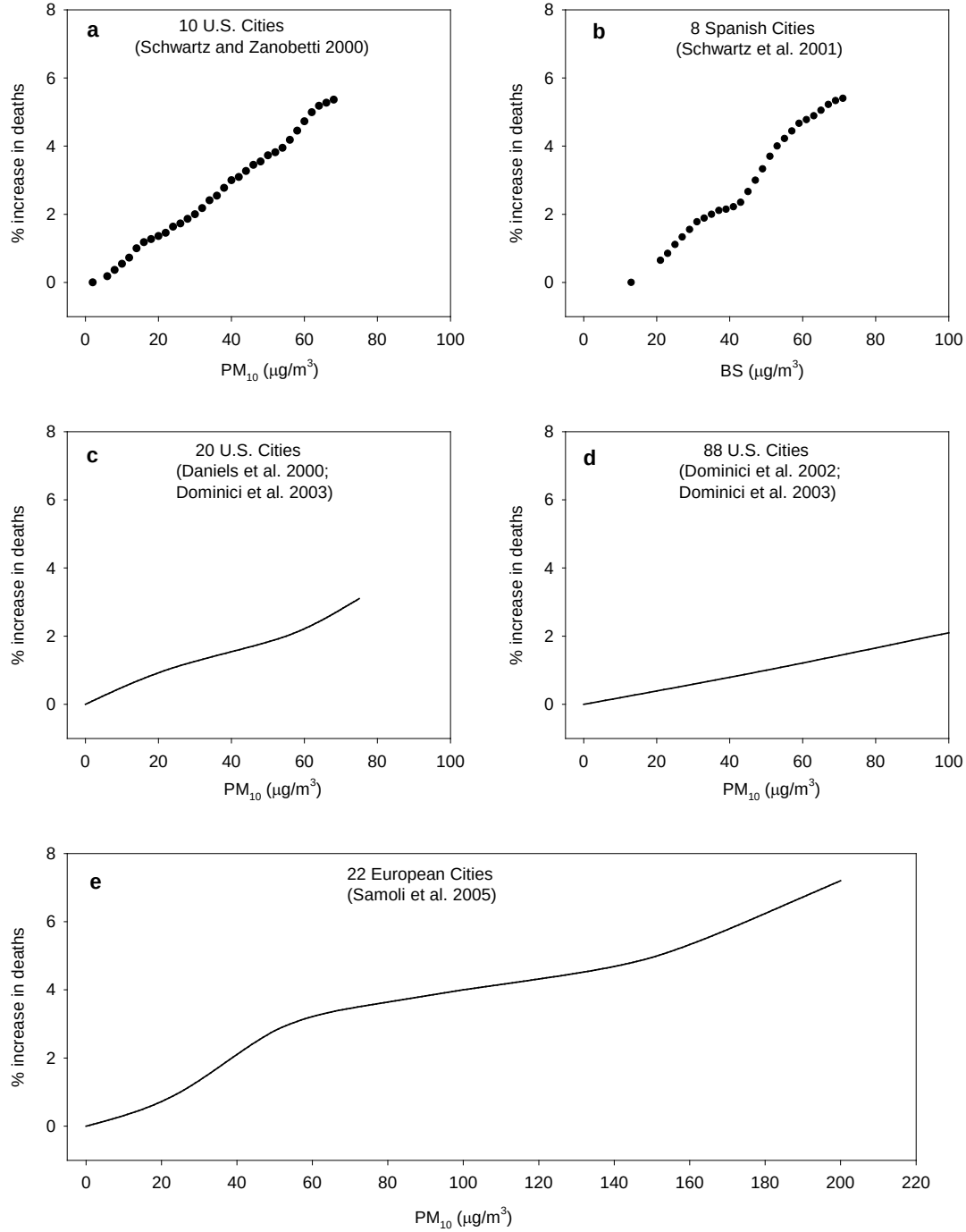




Early to mid 2000's

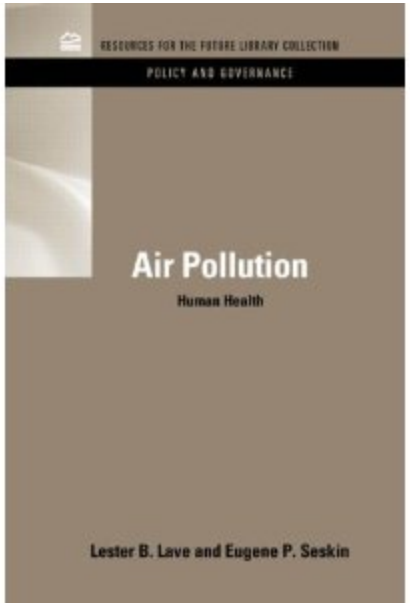
Combined or "meta-smoothed" C-R function estimated using multiple cities—enhancing statistical power and generalizability.

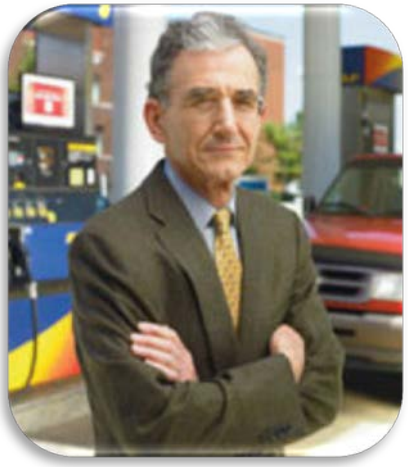
Examples:

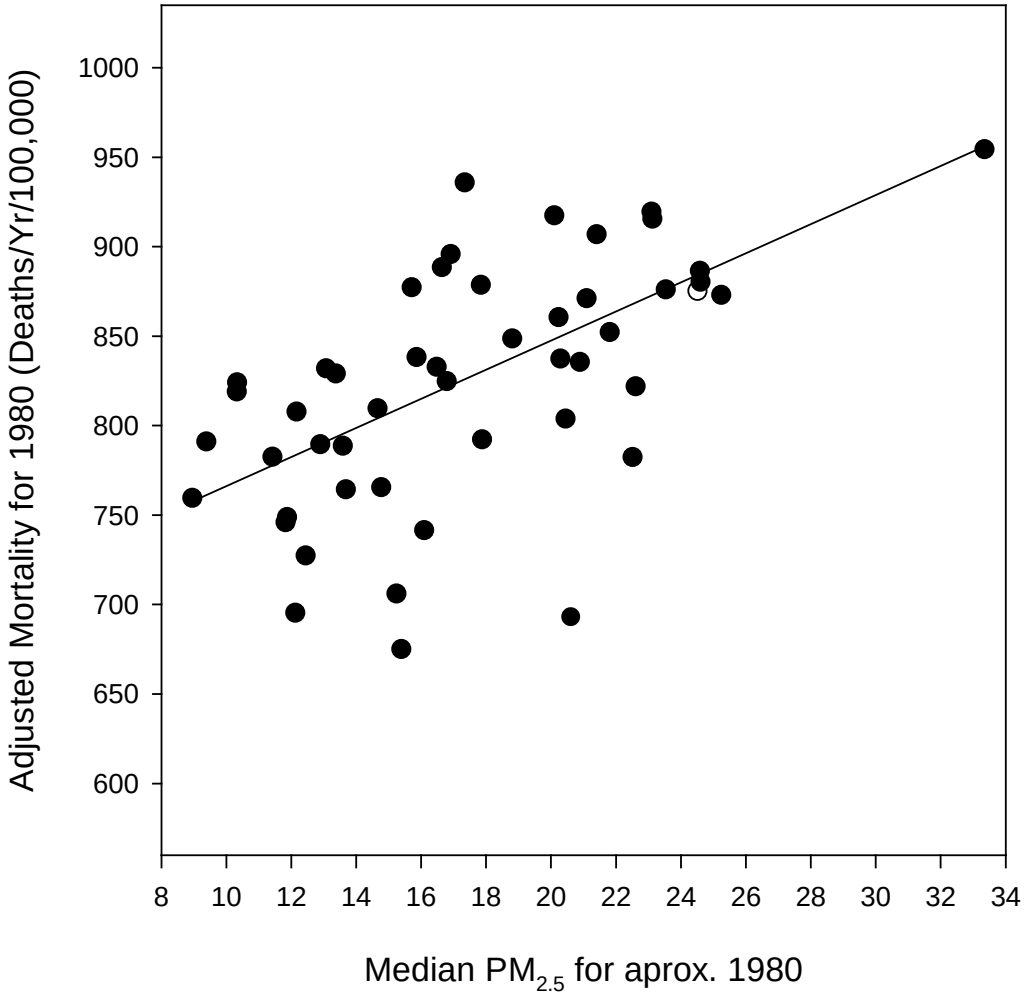


1970's and 1980s

Population-based mortality rates studies rates in U.S. cities.



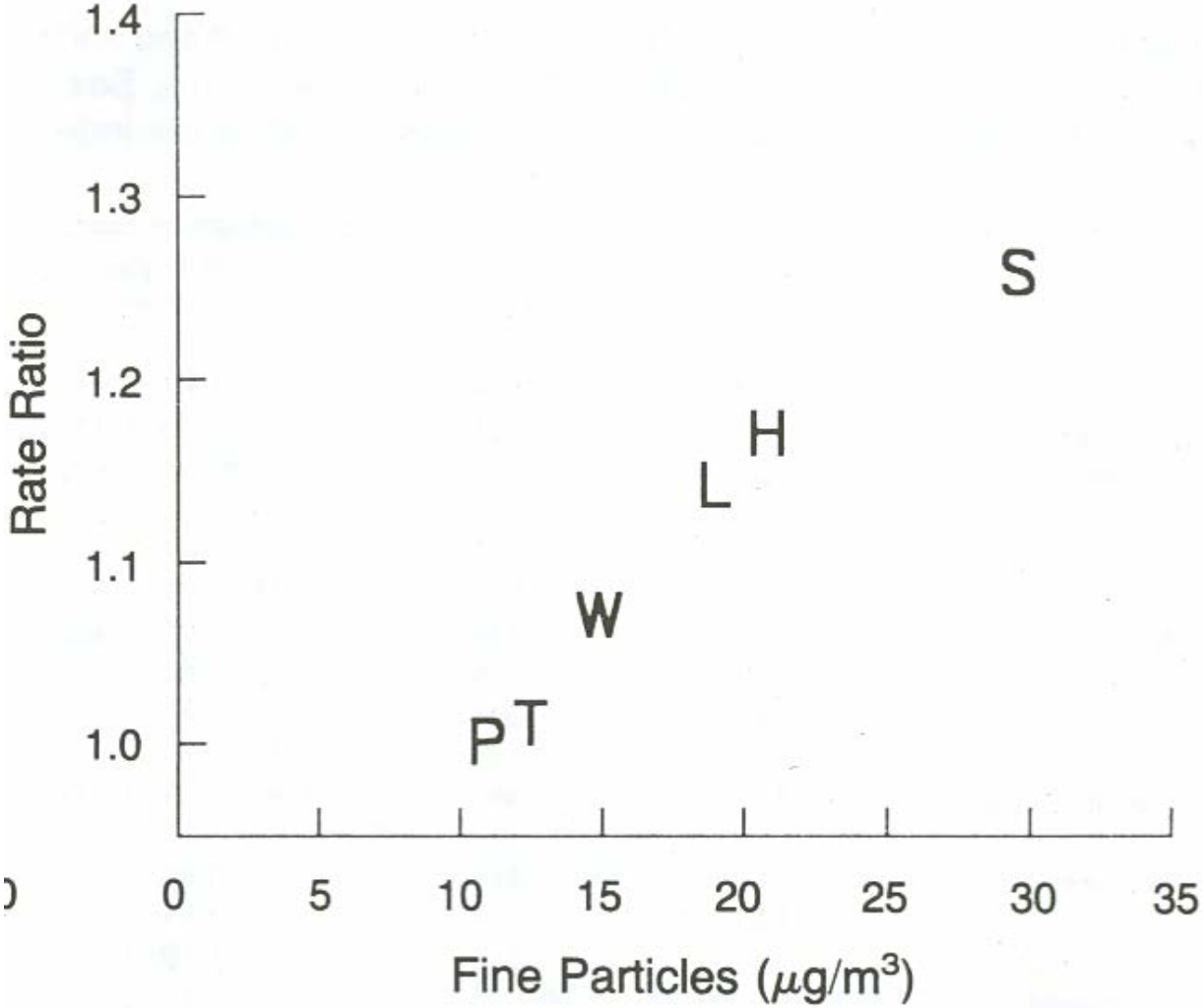


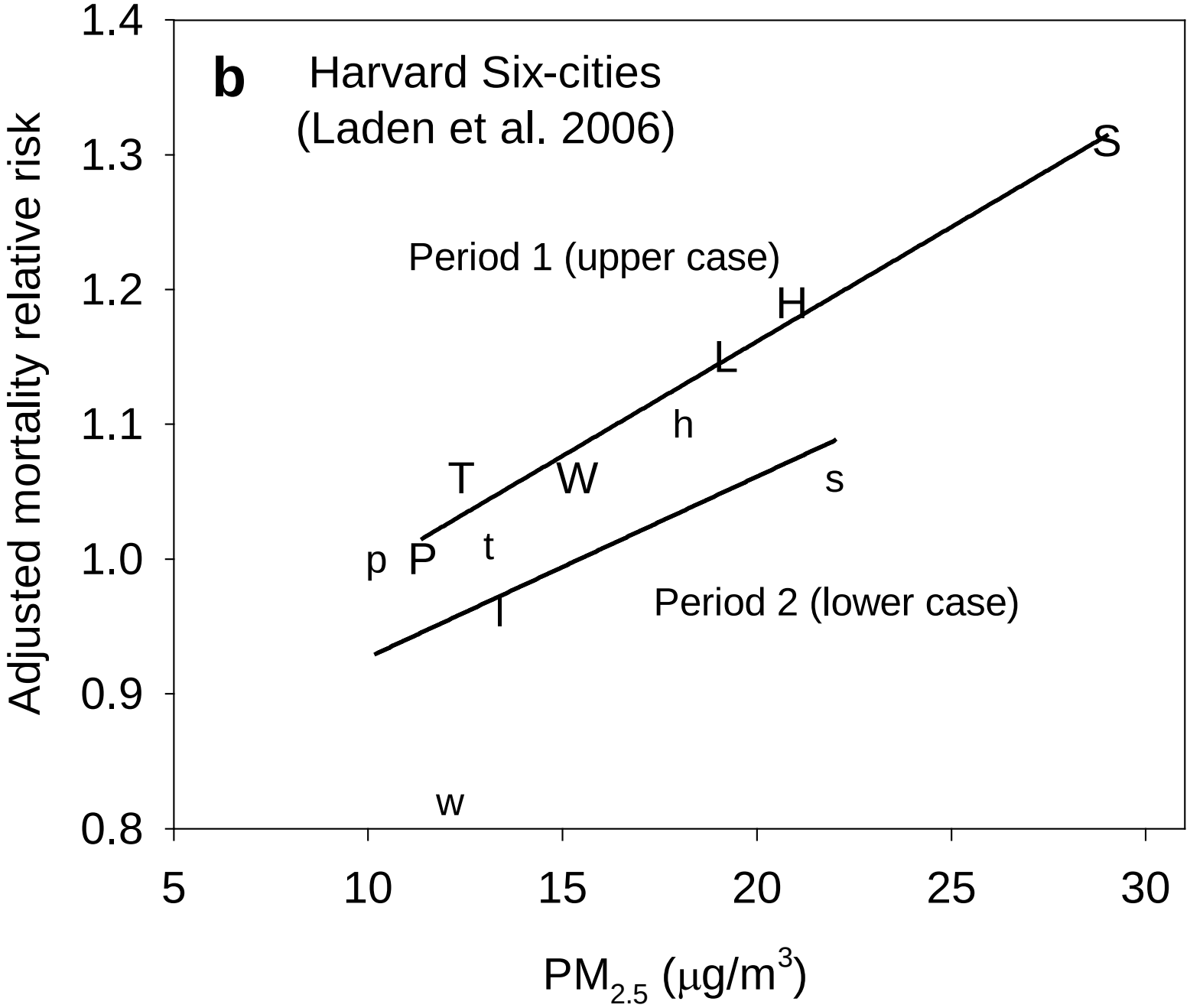


1993 + Cohort Mortality studies

The NEW ENGLAND JOURNAL of MEDICINE

Harvard Six Cities Study, Dockery et al. 1993.

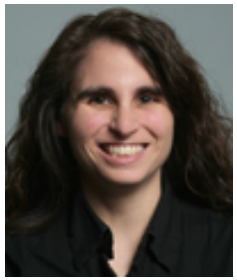



b
Harvard Six-cities
(Laden et al. 2006)
Period 1 (upper case)
Period 2 (lower case)
S
H
L
h
T
W
s
p
P
t
l
w
Adjusted mortality relative risk
1.4
1.3
1.2
1.1
1.0
0.9
0.8
5
10
15
20
25
30
PM2.5 (μg/m3)

Reduction in fine particulate air pollution:

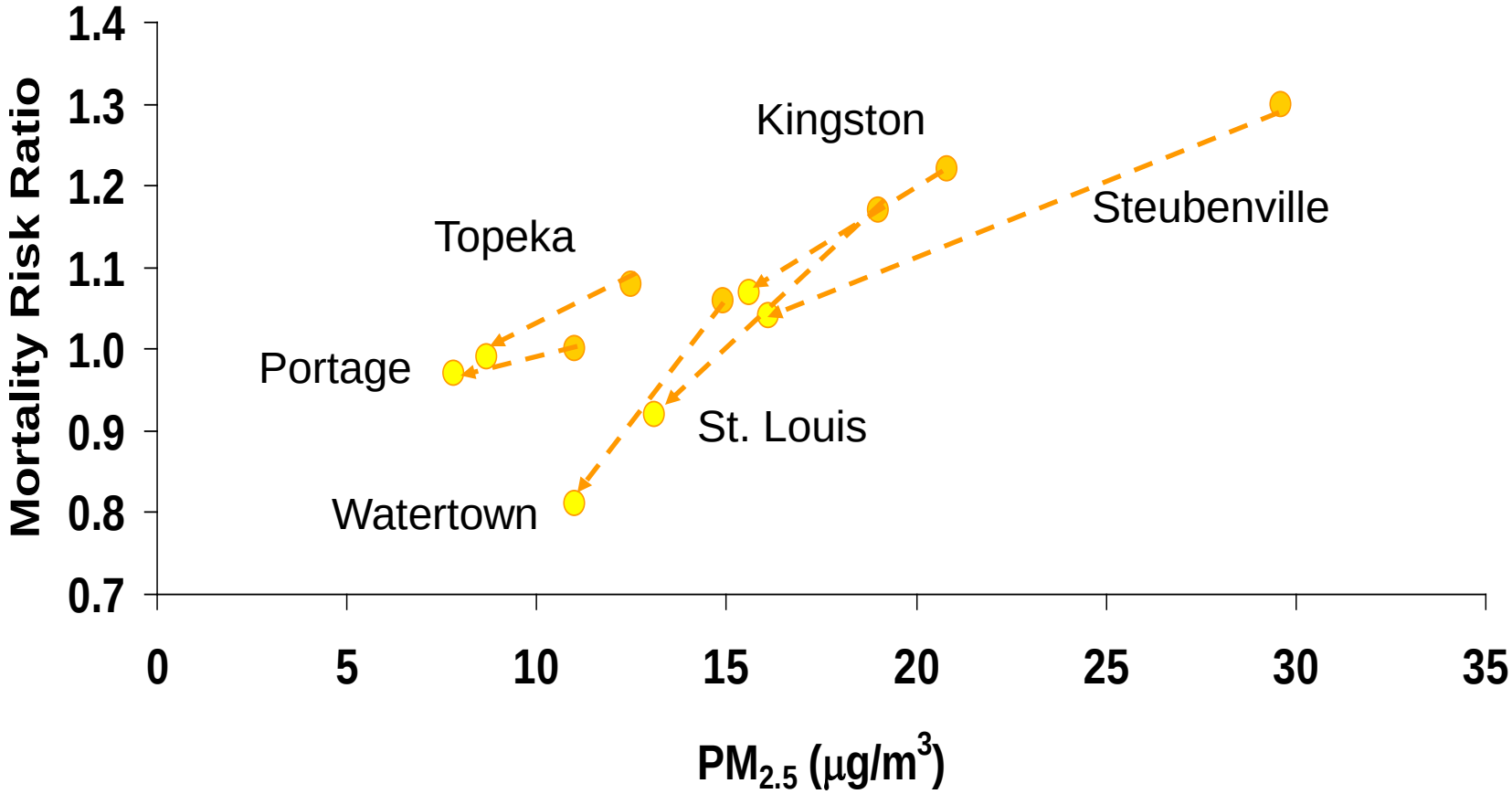
Extended follow-up of the Harvard Six Cities Study

(Laden, Schwartz, Speizer, Dockery. AJRCCM 2006)



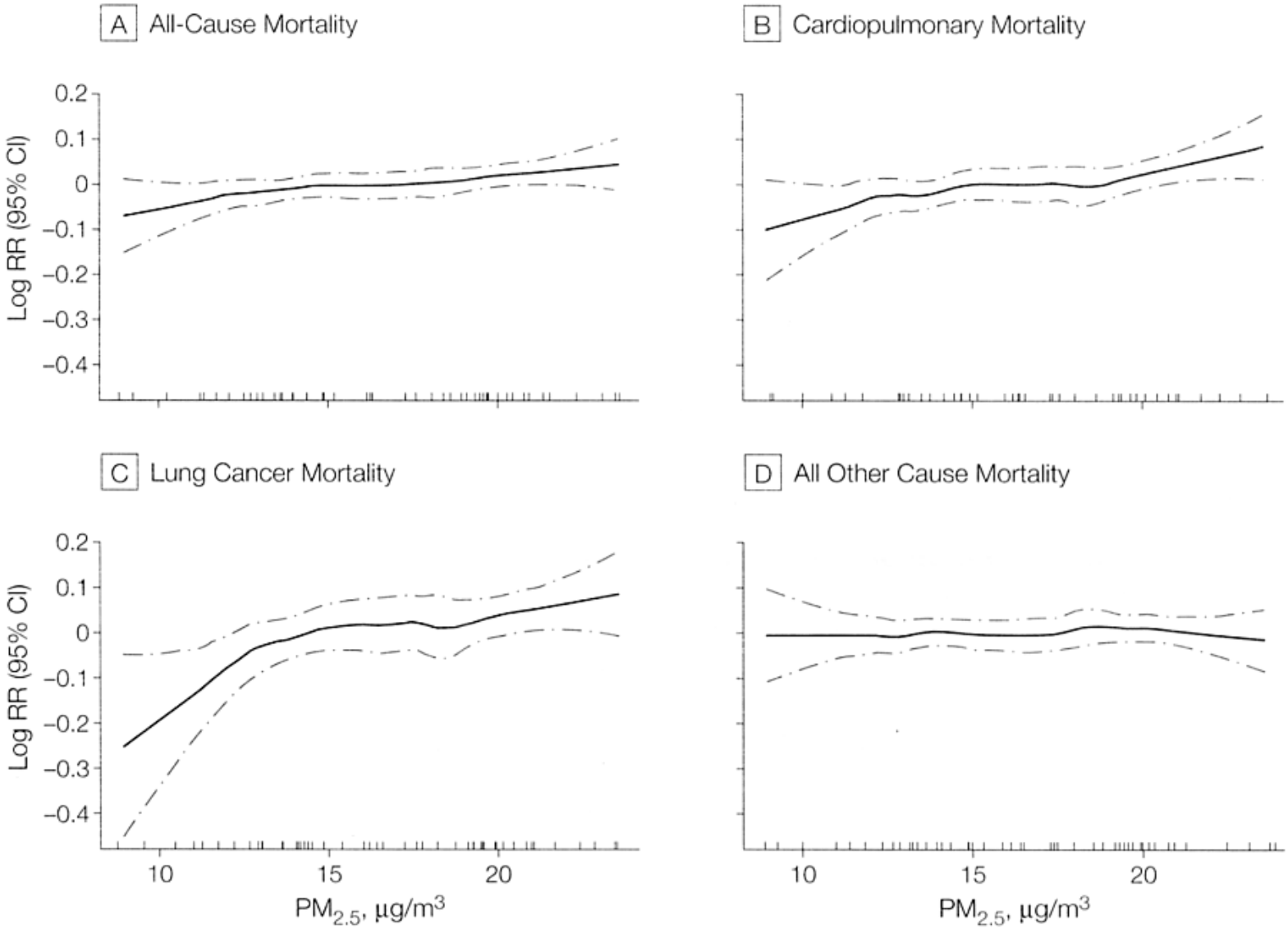
Francine Laden

Joel Schwartz



JAMA®
The Journal of the American Medical Association

ACS CPS-II Cohort Study, Pope et al. 1995, 2002



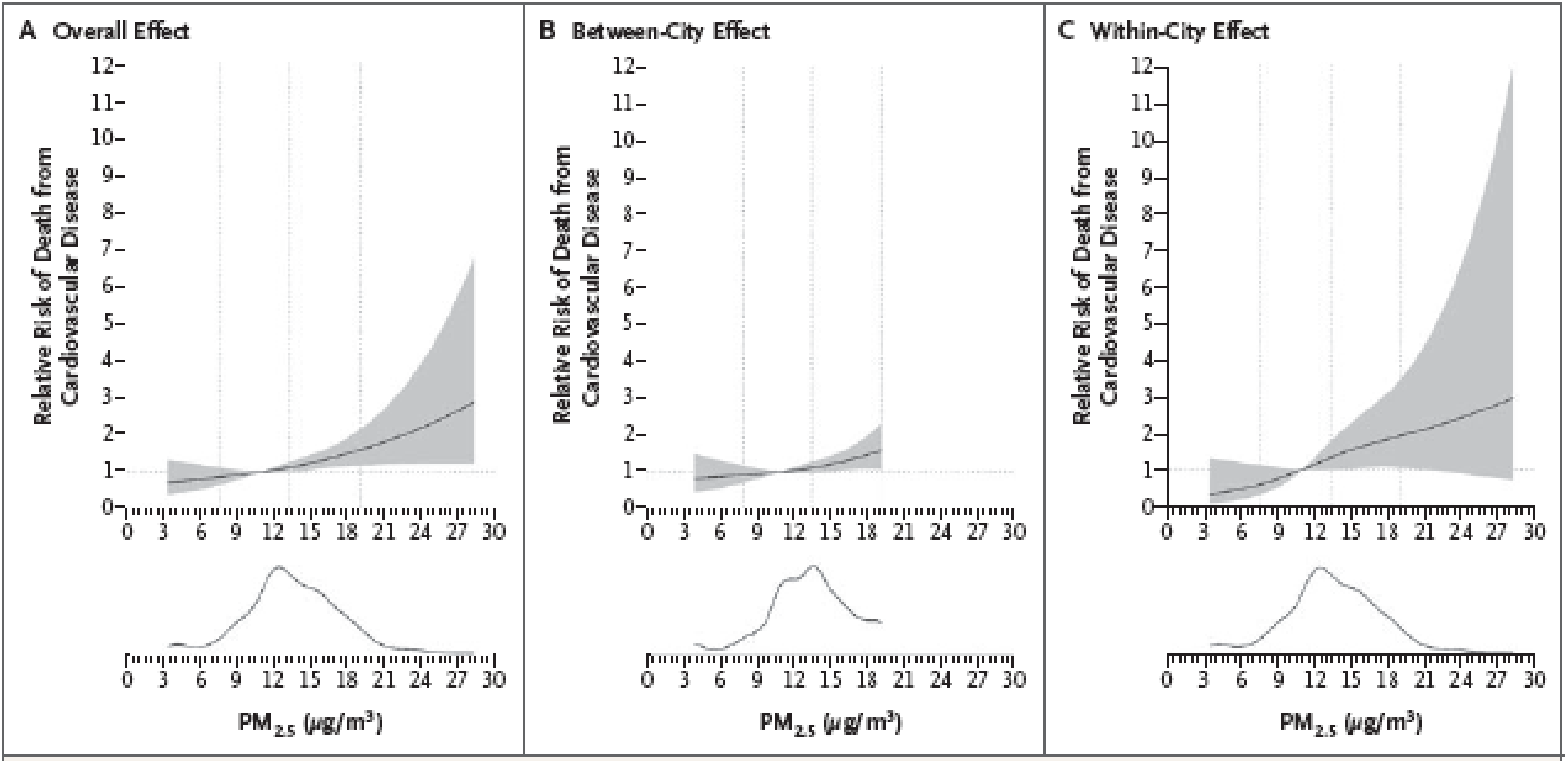


Figure 1. Level of Exposure to Fine Particulate Matter and the Risk of Death from Cardiovascular Causes in Women.

Miller et al. Long-Term exposure to Air Pollution and risk of Cardiovascular death Women. NEJM 2007

2012 EHP

Risk of Nonaccidental and Cardiovascular Mortality in Relation to Long-term Exposure to Low Concentrations of Fine Particulate Matter: A Canadian National-Level Cohort Study

Dan L. Crouse,[1] Paul A. Peters,[2] Aaron van Donkelaar,[3] Mark S. Goldberg,[4] Paul J. Villeneuve,[1,5] Orly Brion,[1] Saeeda Khan,[2] Dominic Odwa Atari,[2] Michael Jerrett,[6] C. Arden Pope III,[7] Michael Brauer,[8] Jeffrey R. Brook,[5,9] Randall V. Martin,[3,10] David Stieb,[1] and Richard T. Burnett[1]

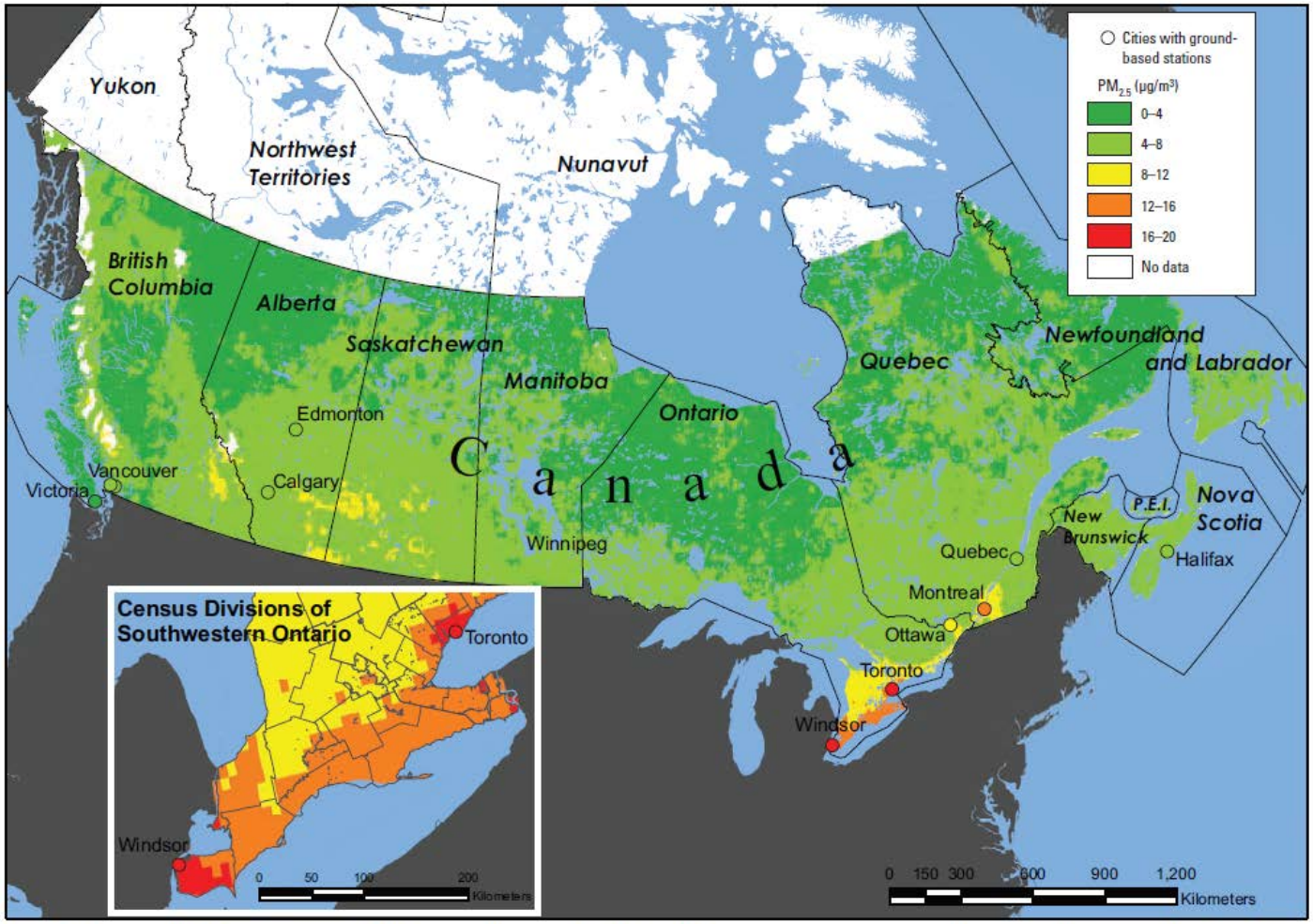


Figure 1. Mean satellite-derived estimates of $PM_{2.5}$ across Canada, 2001–2006, and the mean concentrations in the 11 cities included in our subcohort analysis. P.E.I., Prince Edward Island.

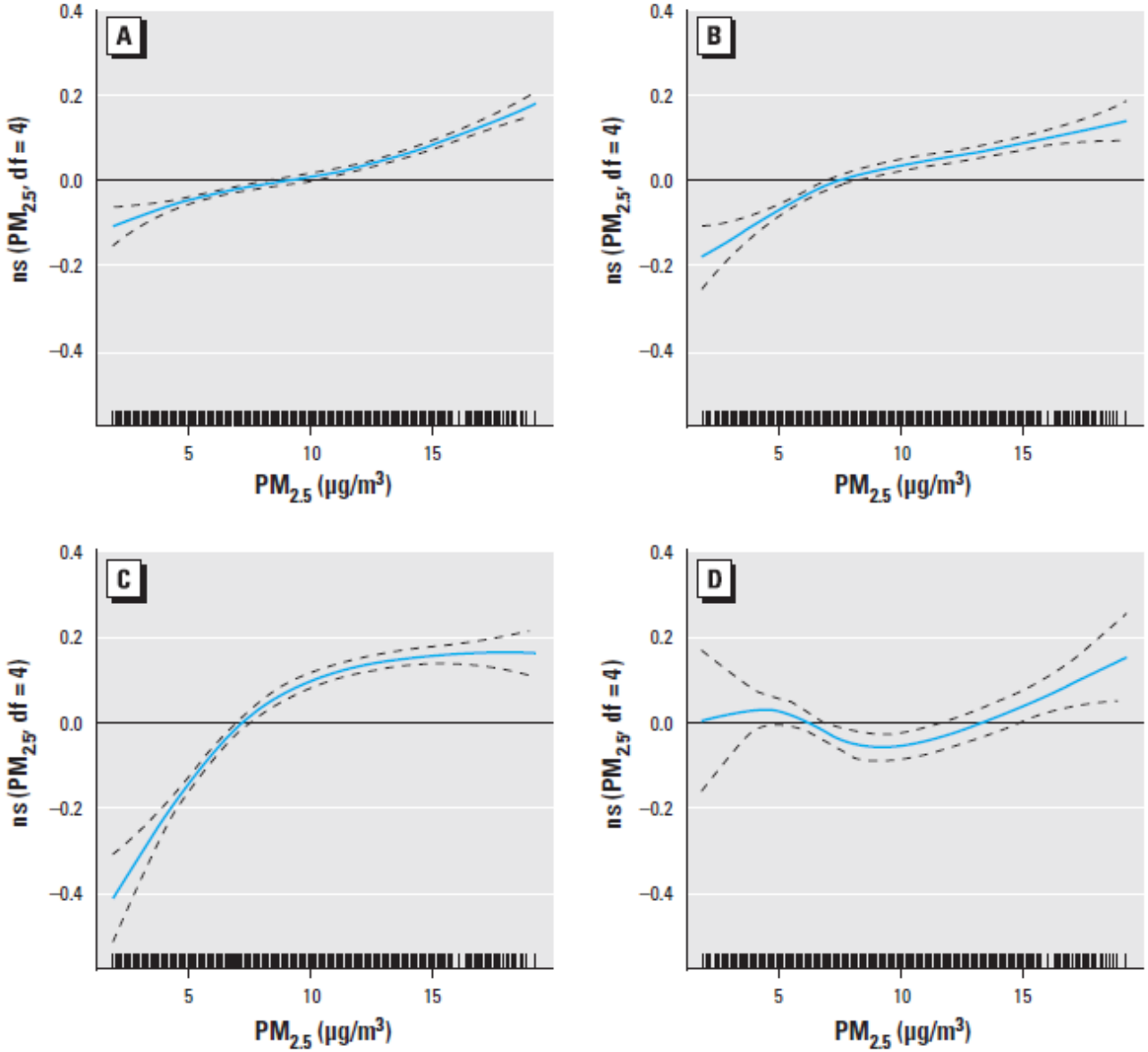
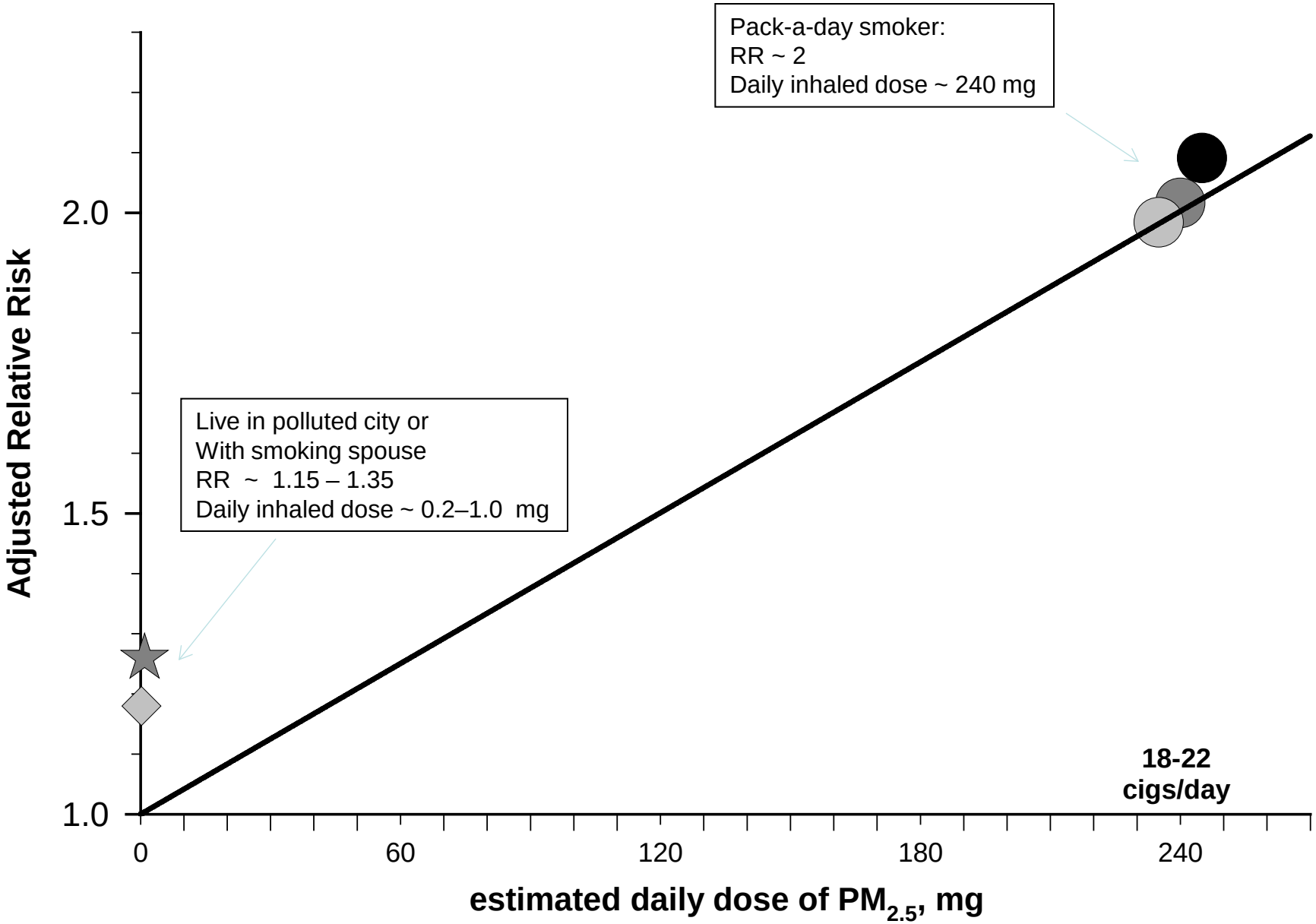


Figure 2. Concentration–response curves (solid lines) and 95% CIs (dashed lines) based on natural spline (ns) models with 4 df, standard Cox models stratified by age and sex, adjusted for all individual-level covariates, urban/rural indicator, and ecological covariates. (*A*) Nonaccidental causes. (*B*) Cardiovascular disease. (*C*) Ischemic heart disease. (*D*) Cerebrovascular disease. The tick marks on the *x*-axis identify the location of the $PM_{2.5}$ concentrations.


Pack-a-day smoker:
RR ~ 2
Daily inhaled dose ~ 240 mg
Live in polluted city or
With smoking spouse
RR ~ 1.15 – 1.35
Daily inhaled dose ~ 0.2–1.0 mg
18-22
cigs/day
Adjusted Relative Risk
2.0
1.5
1.0
0
60
120
180
240
estimated daily dose of PM2.5, mg

Circulation
JOURNAL OF THE AMERICAN HEART ASSOCIATION

Pope, Burnett, Krewski, et al. 2009.

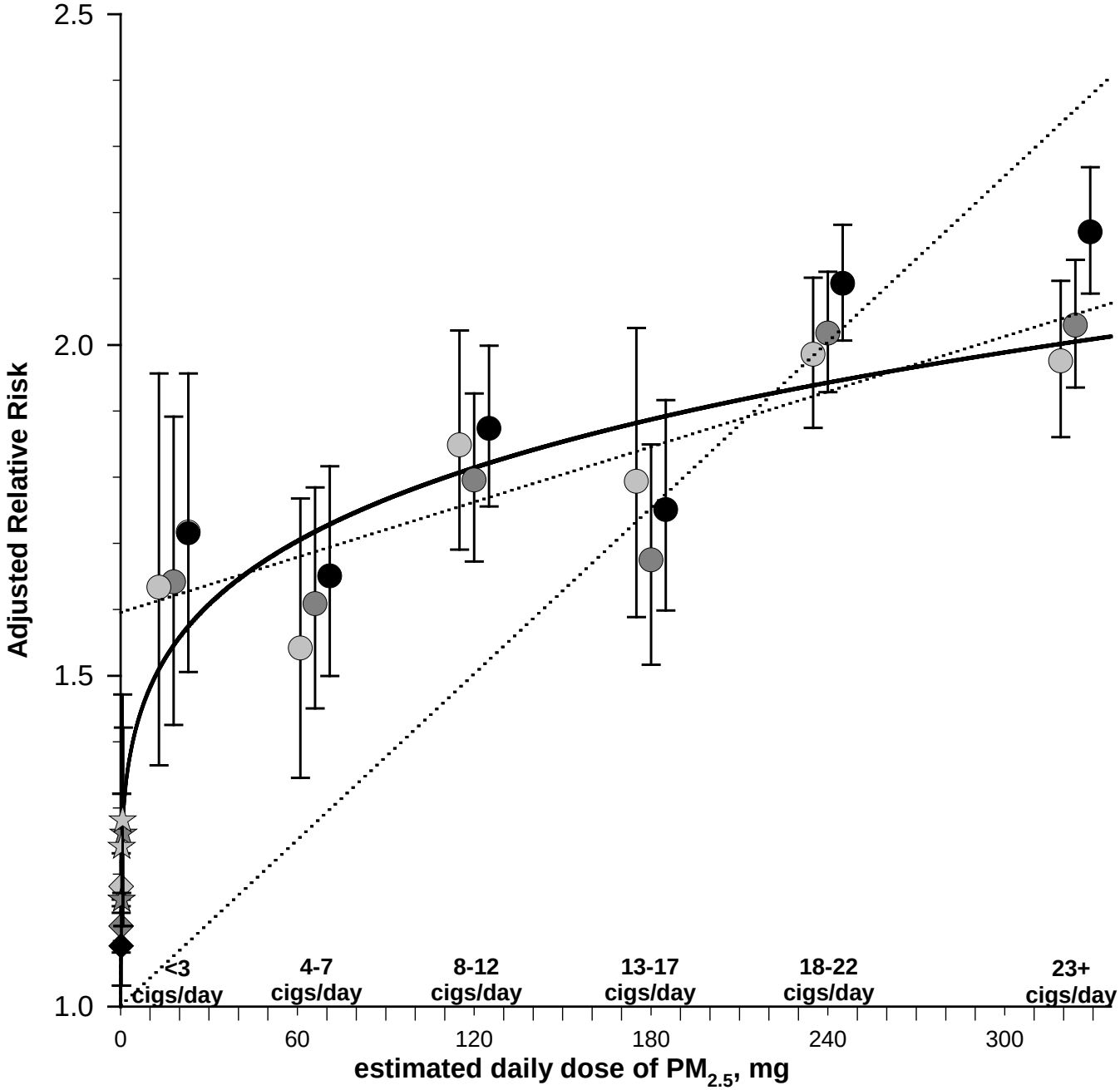


Figure 1. Adjusted relative risks (and 95% CIs) of IHD (light gray), CVD (dark gray), and CPD (black) mortality plotted over estimated daily dose of $PM_{2.5}$ from different increments of current cigarette smoking. Diamonds represent comparable mortality risk estimates for $PM_{2.5}$ from air pollution. Stars represent comparable pooled relative risk estimates associated with SHS exposure from the 2006 Surgeon General's report and from the INTERHEART study.

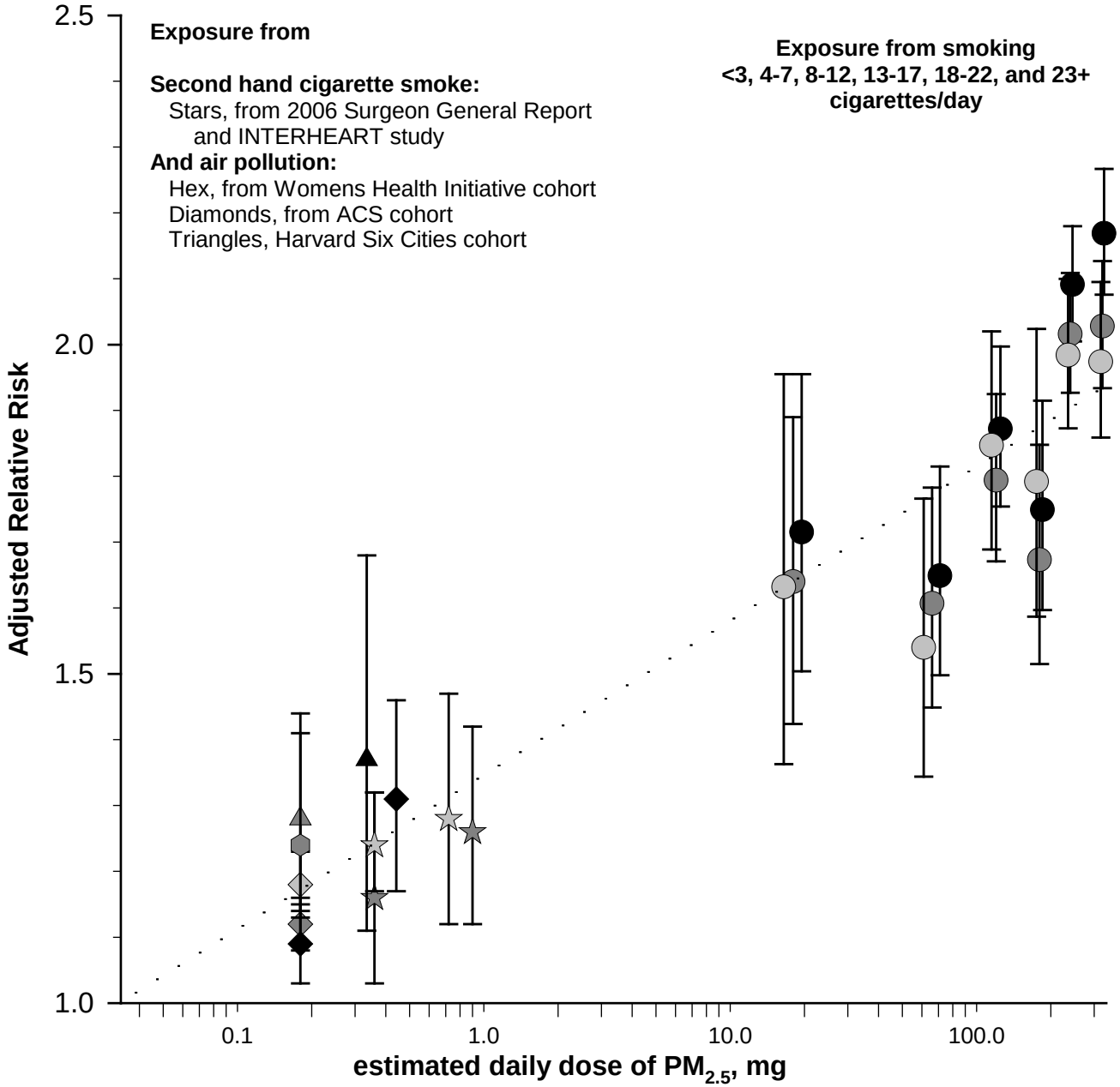
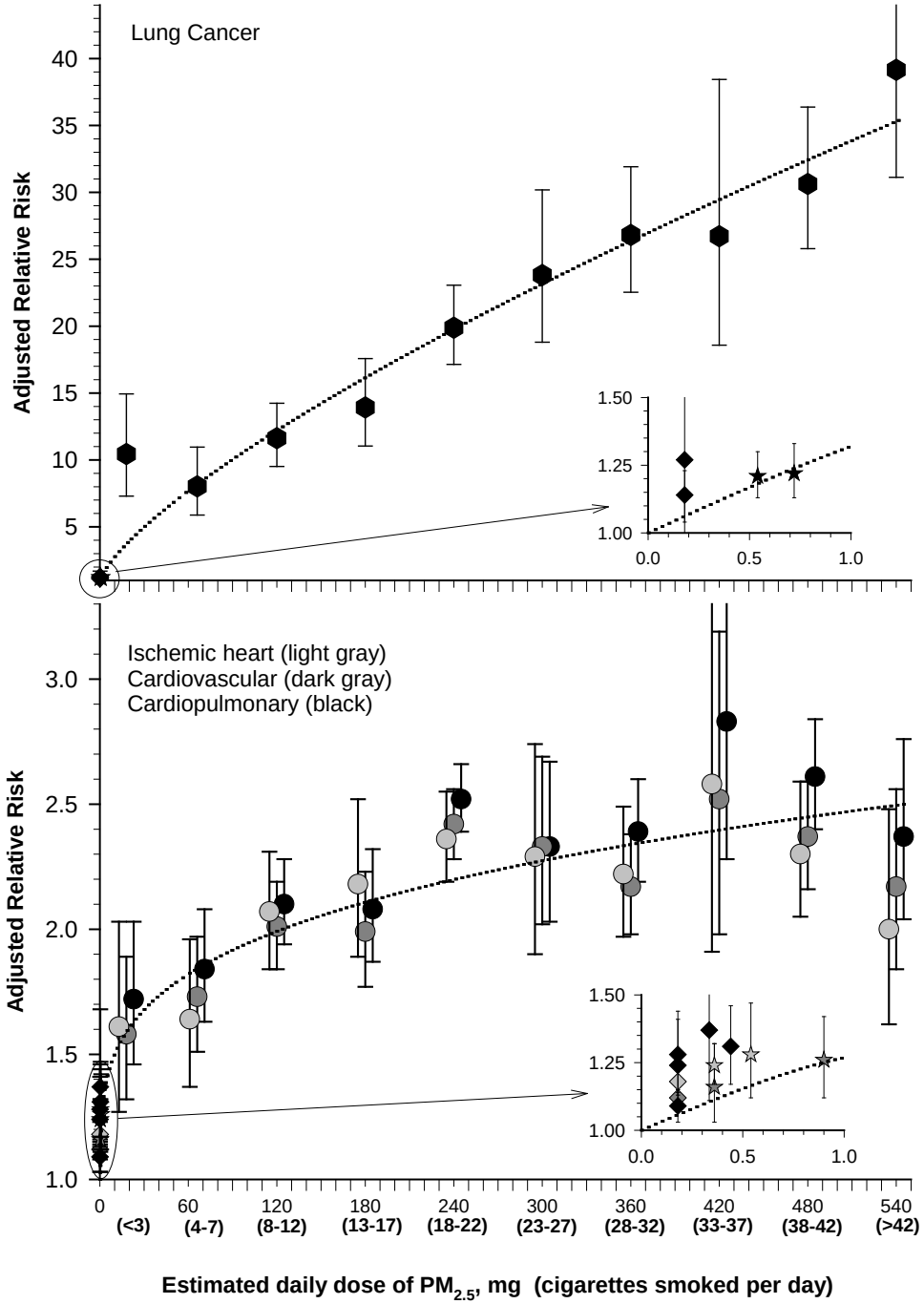


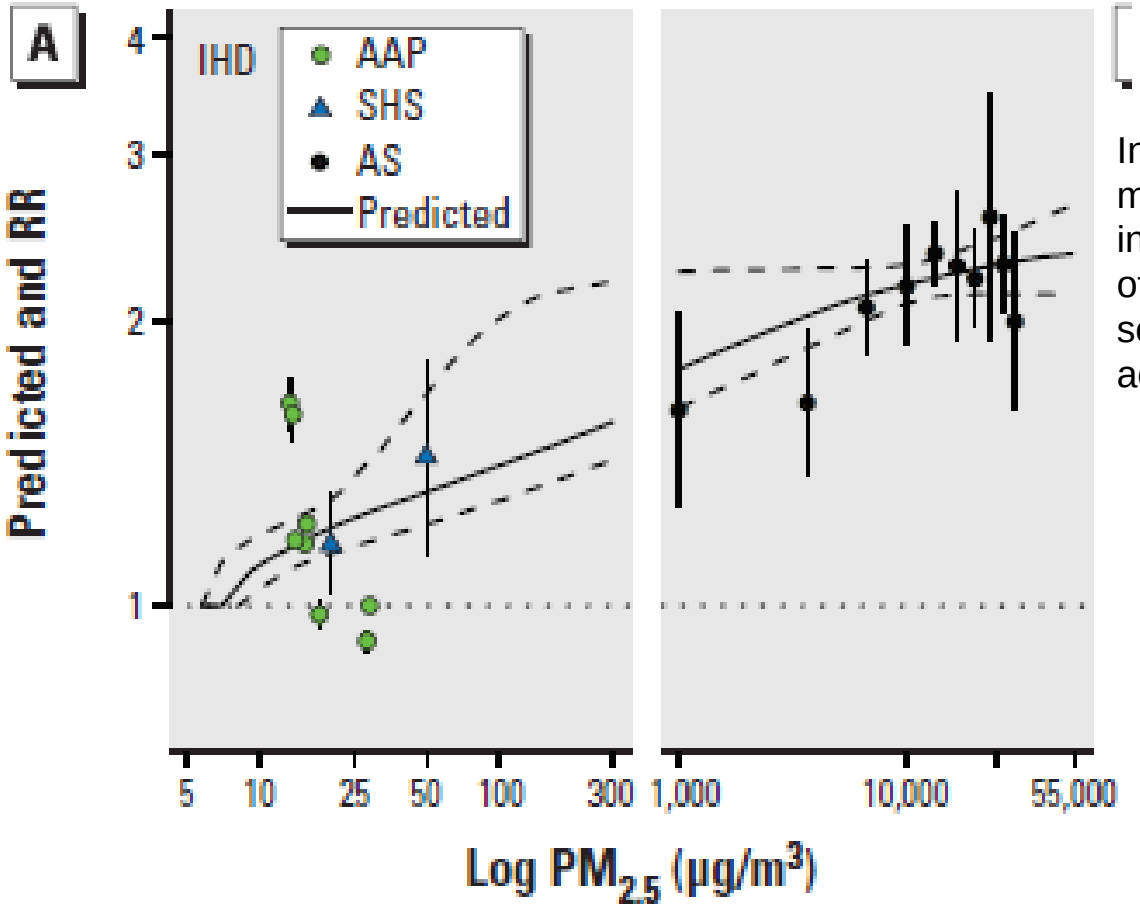
Figure 2. Adjusted relative risks (and 95% CIs) of ischemic heart disease (light gray), cardiovascular (dark gray), and cardiopulmonary (black) mortality plotted over baseline estimated daily dose (using a log scale) of $PM_{2.5}$ from current cigarette smoking (relative to never smokers), SHS, and air pollution.


Lung Cancer
Adjusted Relative Risk
40
35
30
25
20
15
10
5
1.50
1.25
1.00
0.0
0.5
1.0
Ischemic heart (light gray)
Cardiovascular (dark gray)
Cardiopulmonary (black)
Adjusted Relative Risk
3.0
2.5
2.0
1.5
1.0
1.50
1.25
1.00
0.0
0.5
1.0
0 (<3)
60 (4-7)
120 (8-12)
180 (13-17)
240 (18-22)
300 (23-27)
360 (28-32)
420 (33-37)
480 (38-42)
540 (>42)
Estimated daily dose of PM2.5, mg (cigarettes smoked per day)

2014--EHP

An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure

*Richard T. Burnett,[1] C. Arden Pope III,[2] Majid Ezzati,[3] Casey Olives,[4] Stephen S. Lim,[5] Sumi Mehta,[6] Hwashin H. Shin,[1] Gitanjali Singh,[7] Bryan Hubbell,[8] Michael Brauer,[9] H. Ross Anderson,[10] Kirk R. Smith,[11] John R. Balmes,[12,13] Nigel G. Bruce,[14] Haidong Kan,[15] Francine Laden,[16] Annette Prüss-Ustün,[17] Michelle C. Turner,[18] Susan M. Gapstur,[19] W. Ryan Diver,[19] and Aaron Cohen[20]**



Integrated Exposure-Response (IER) model for ischemic heart disease integrating information from studies of ambient air pollution (AAP), second hand smoke (SHS), and active smoking.

2014--EHP

An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure

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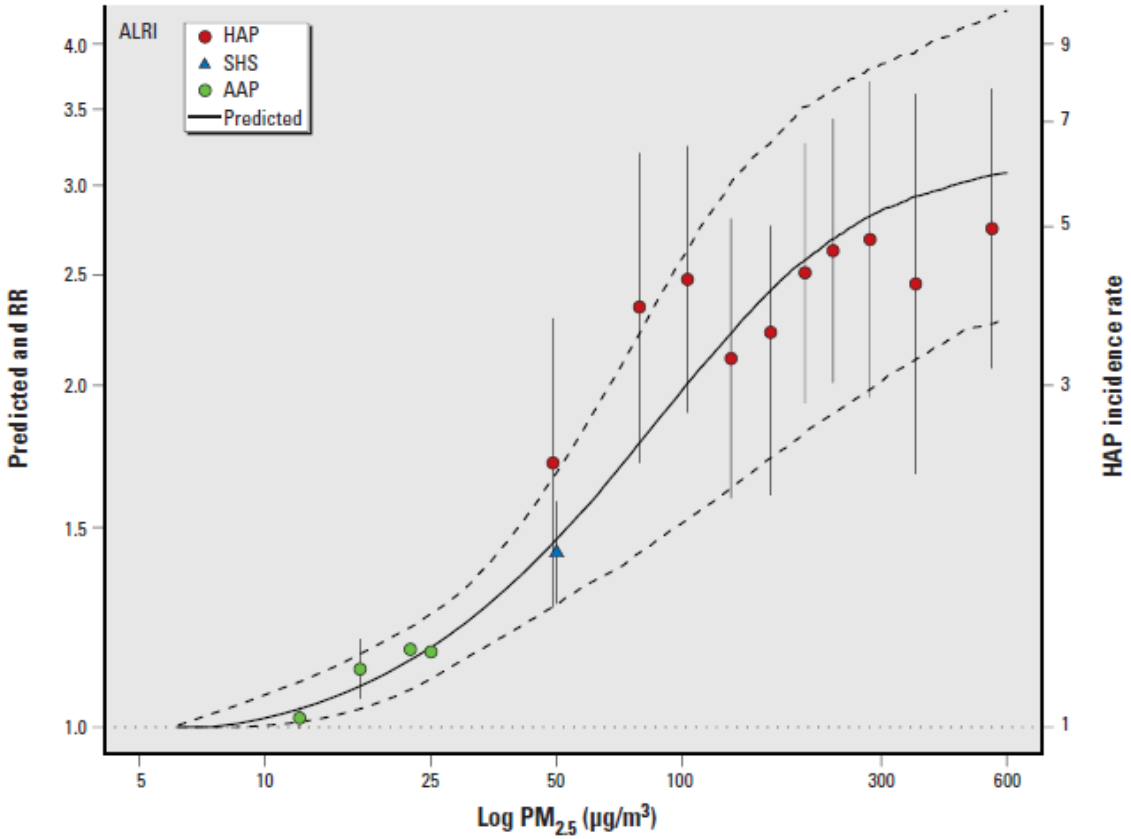


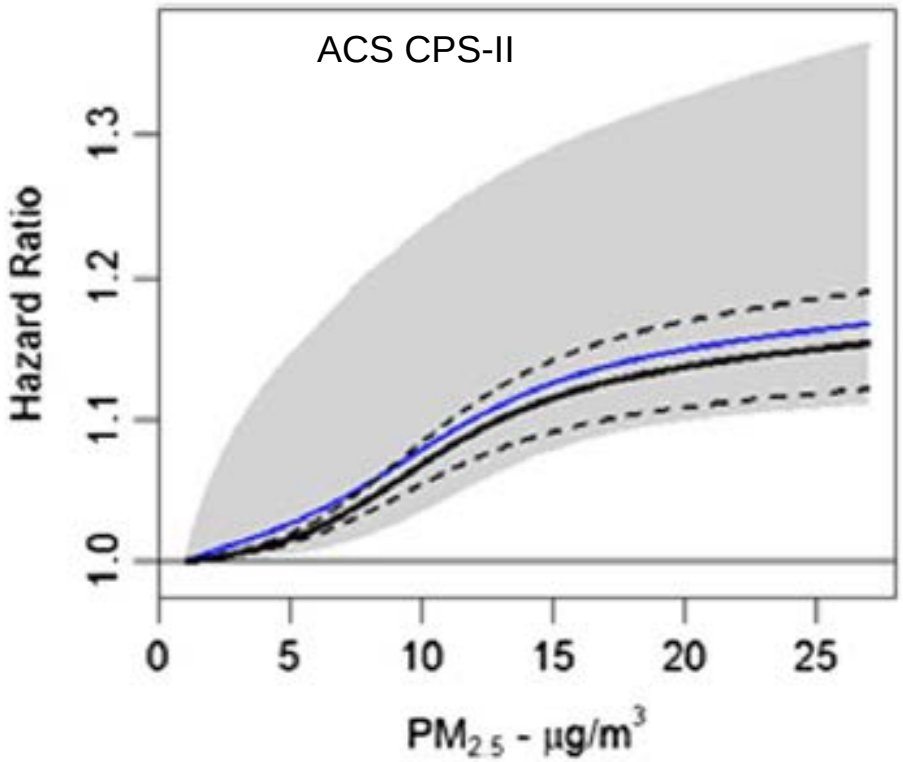
Figure 2. Predicted values of IER model (solid line) and 95% CIs (dashed line) and type-specific RRs (points) and 95% CIs (error bars) for ALRI in infants.

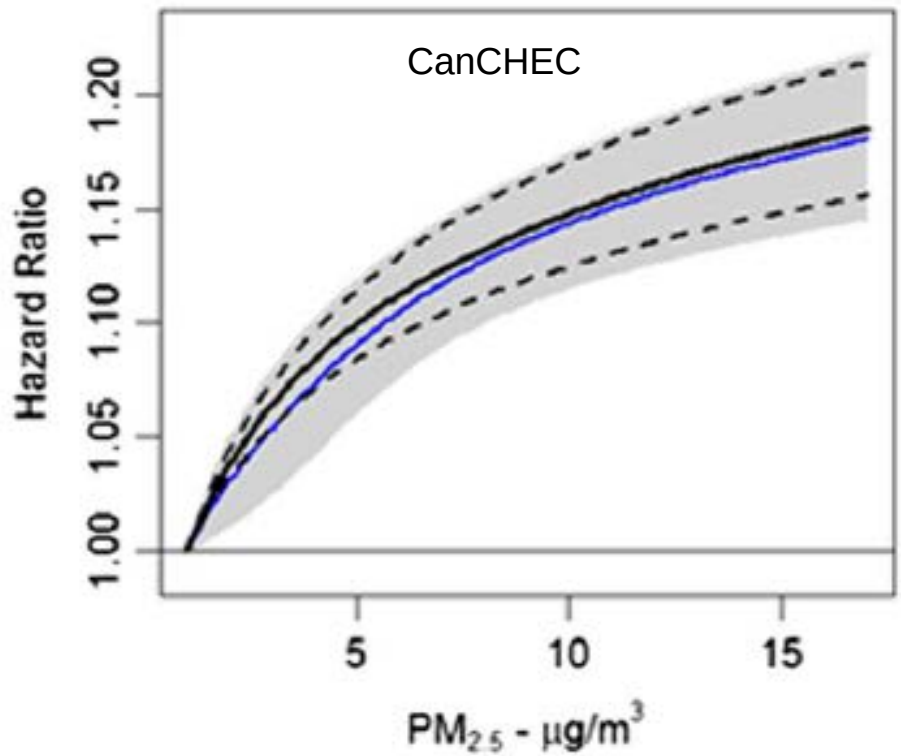
Integrated Exposure-Response (IER) model for acute lower respiratory Infection in infants integrating information from studies of household air pollution (HAP), ambient air pollution (AAP), and second hand smoke (SHS).

A class of non-linear exposure-response models suitable for health impact assessment applicable to large cohort studies of ambient air pollution

Air Qual Atmos Health 2016

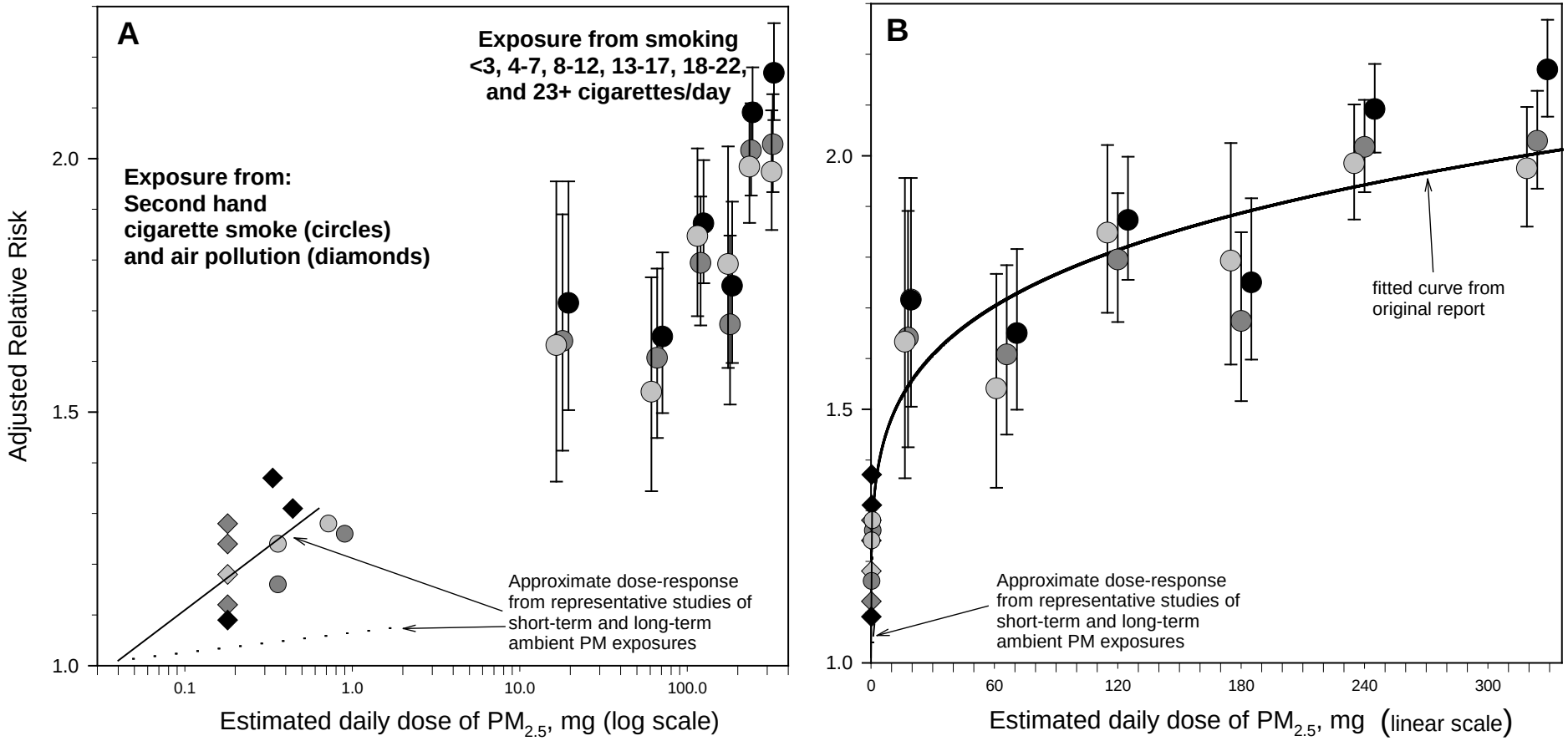
Masoud M. Nasari[1] · Mieczysław Szyszkowicz[1] · Hong Chen[2] · Daniel Crouse[1] · Michelle C. Turner[3,4,5,6] · Michael Jerrett[7] · C. Arden Pope III[8] · Bryan Hubbell[9] · Neal Fann[9] · Aaron Cohen[10] · Susan M. Gapstur[11] · W. Ryan Diver[11] · David Stieb[1] · Mohammad H. Forouzanfar[12] · Sun-Young Kim[13] · Casey Olives[14] · Daniel Krewski[3] · Richard T. Burnett[1]

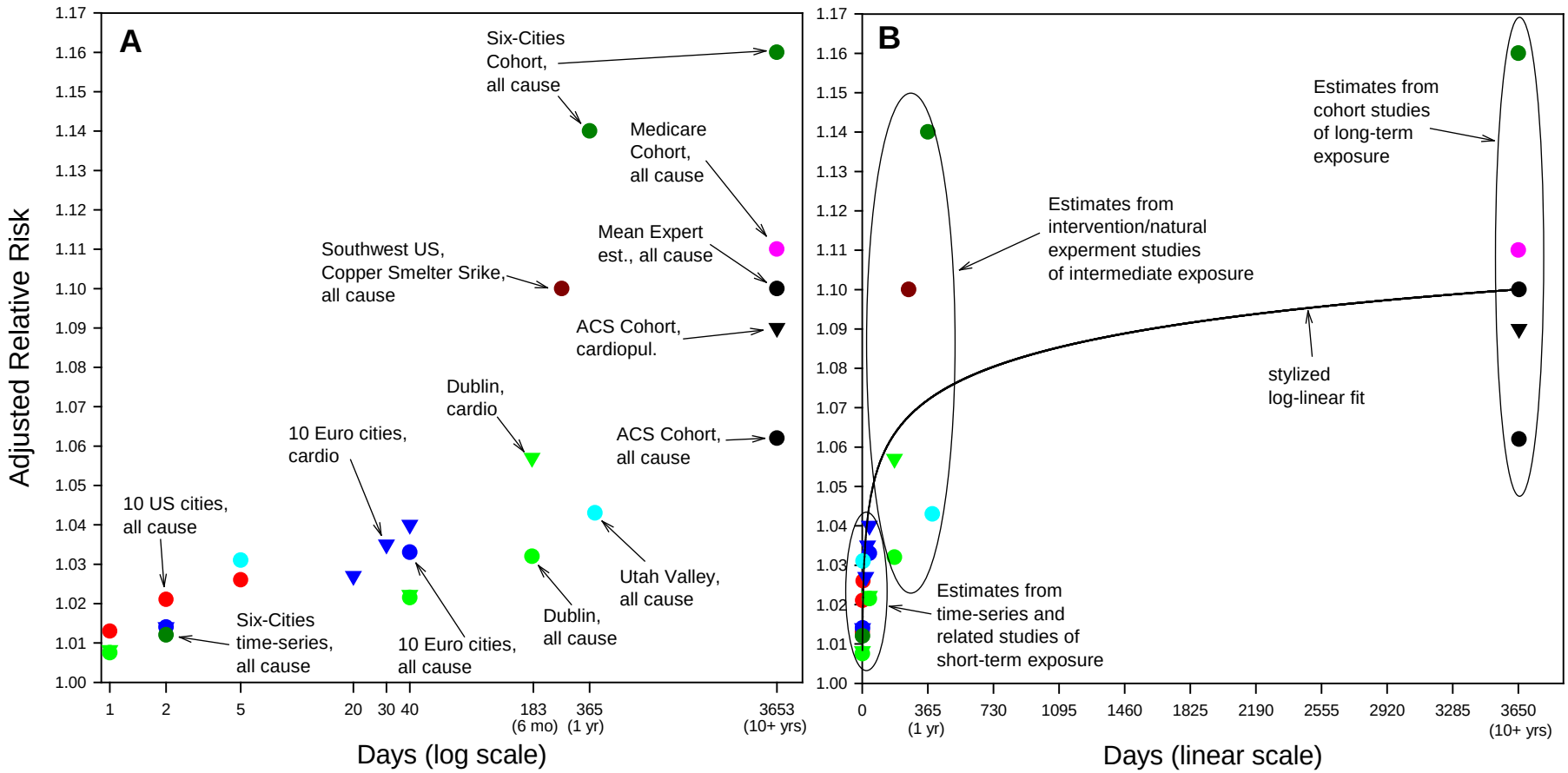




How is cardiovascular disease mortality risk affected by duration and intensity of fine particulate matter exposure? An integration of the epidemiologic evidence

C. Arden Pope III • Robert D. Brook •
Richard T. Burnett • Douglas W. Dockery




A
B
Adjusted Relative Risk
Days (log scale)
Days (linear scale)
Six-Cities Cohort, all cause
Medicare Cohort, all cause
Mean Expert est., all cause
Southwest US, Copper Smelter Srike, all cause
ACS Cohort, cardiopul.
Dublin, cardio
10 Euro cities, cardio
ACS Cohort, all cause
10 US cities, all cause
Utah Valley, all cause
Six-Cities time-series, all cause
10 Euro cities, all cause
Dublin, all cause
Estimates from cohort studies of long-term exposure
Estimates from intervention/natural experment studies of intermediate exposure
stylized log-linear fit
Estimates from time-series and related studies of short-term exposure
(6 mo)
(1 yr)
(10+ yrs)

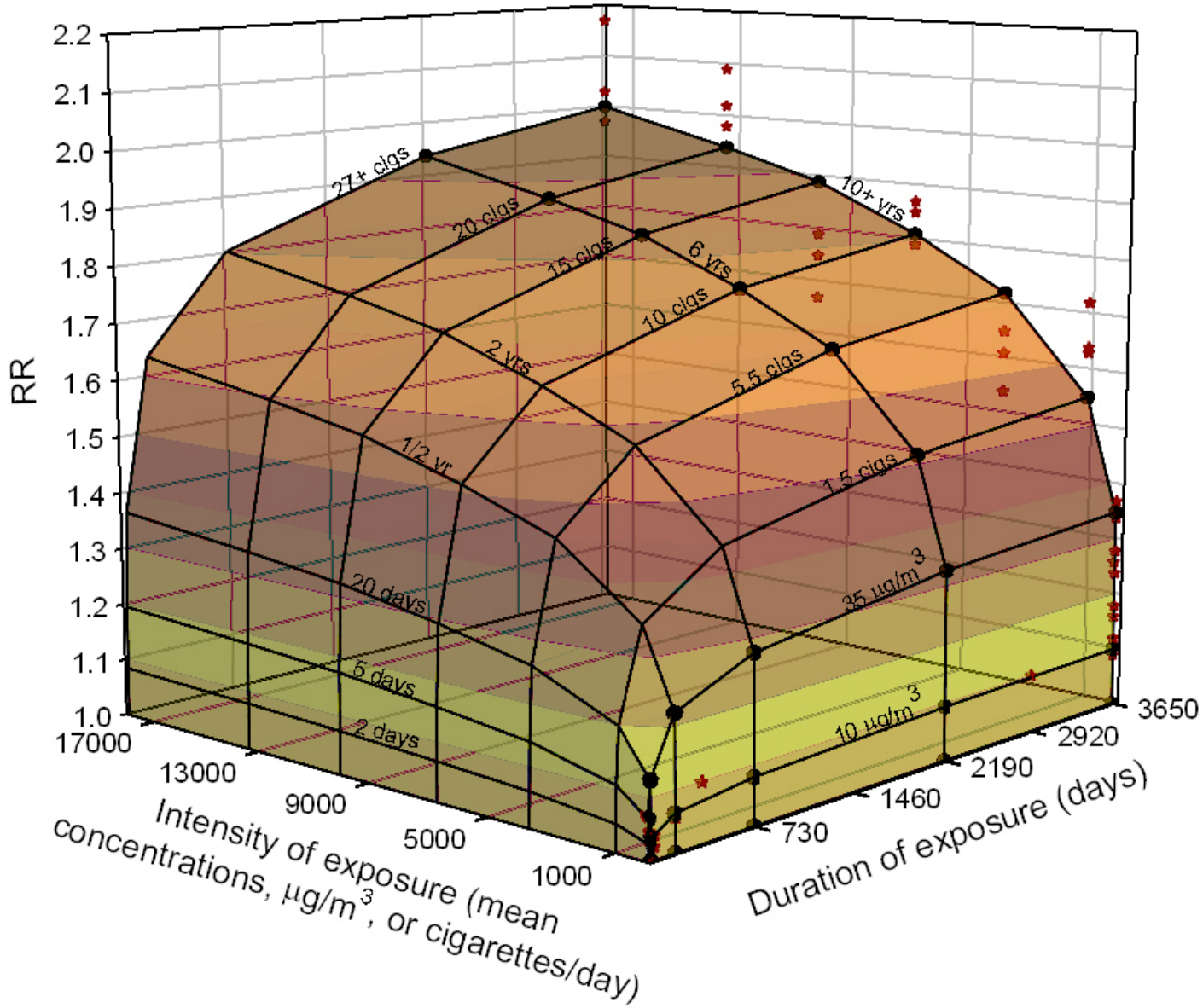
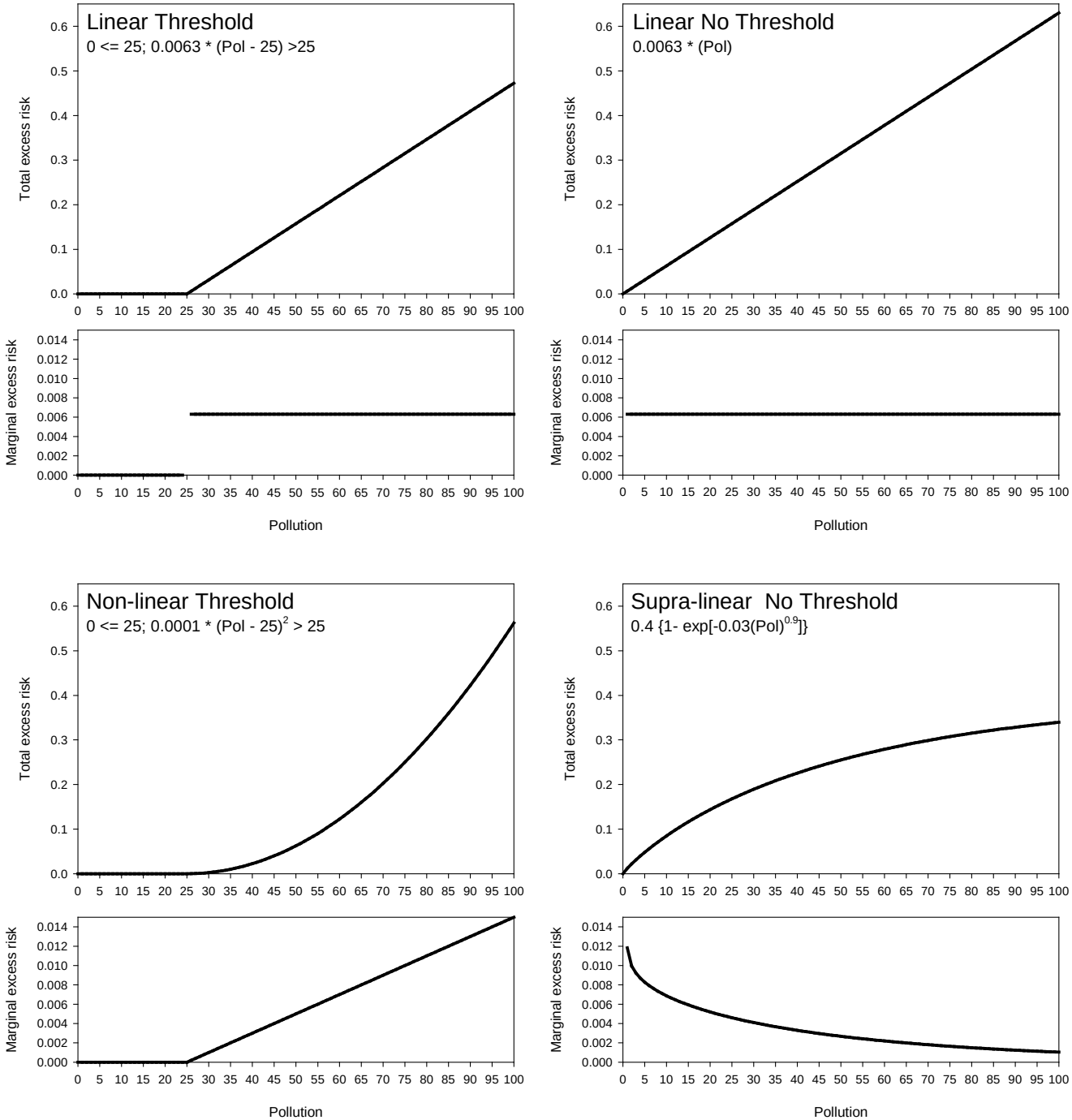
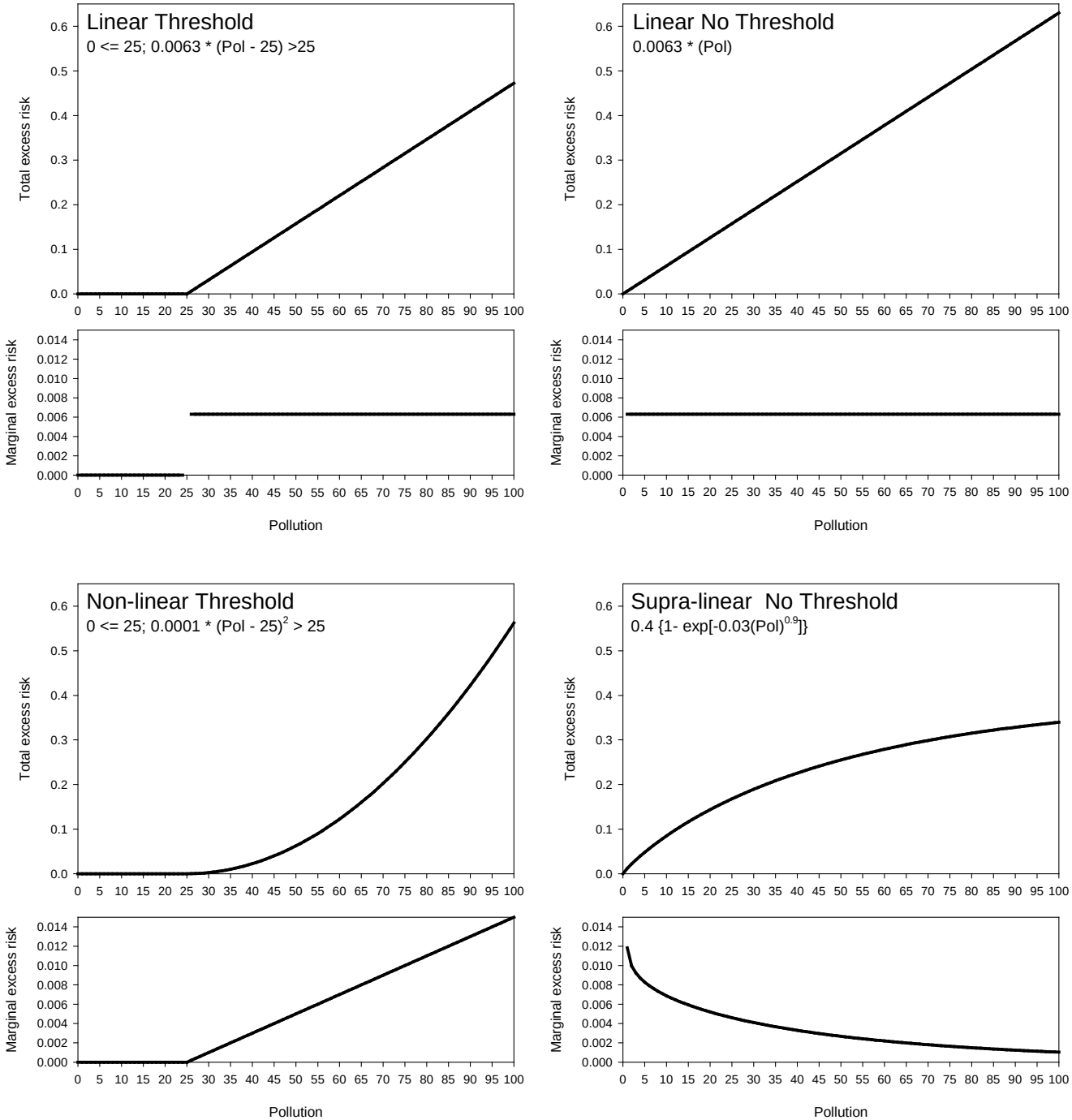
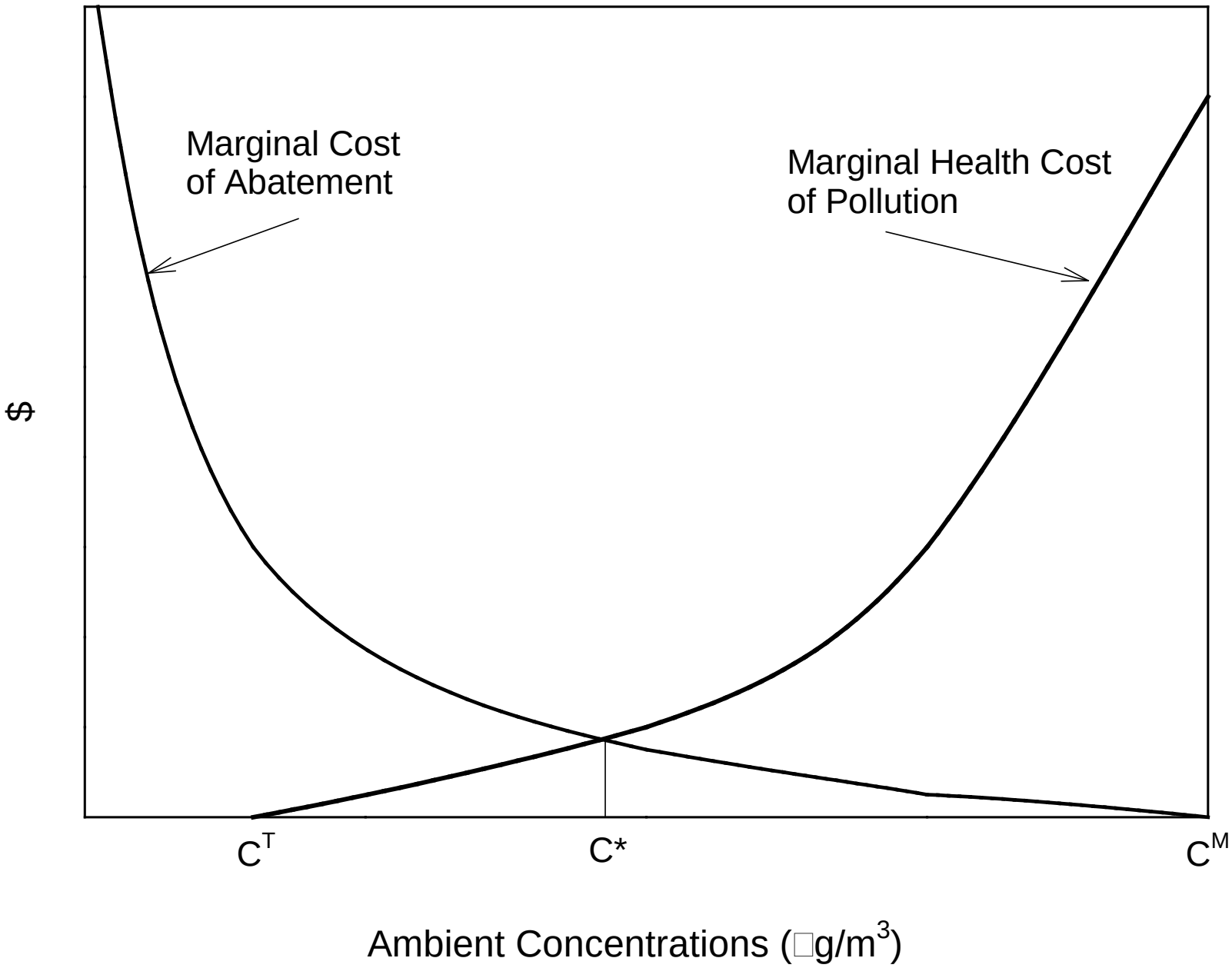
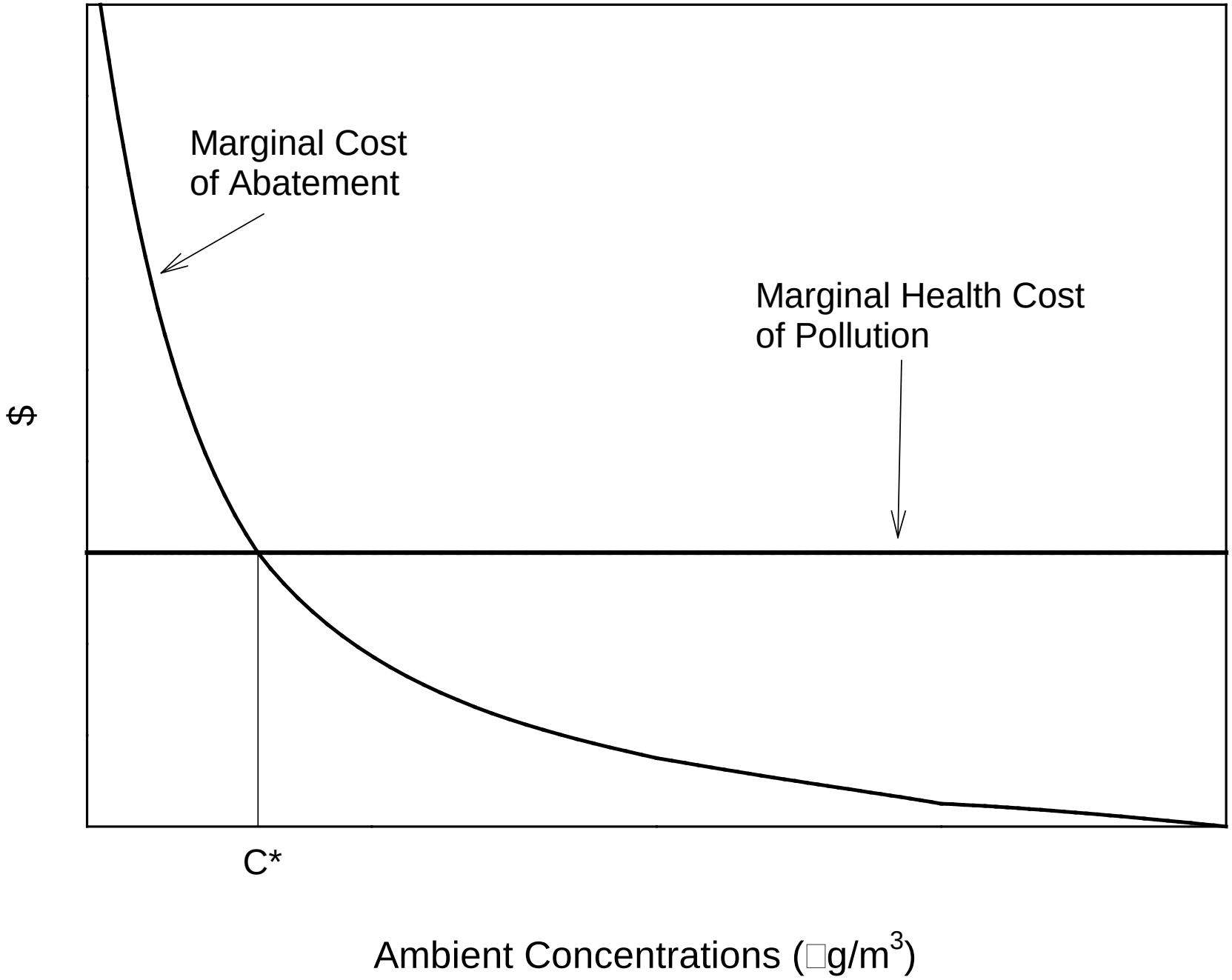


Figure 1. Stylized representation of the risk-response relationship between cardiopulmonary mortality and two primary dimensions of cumulative exposure to $PM_{2.5}$ (intensity and duration).

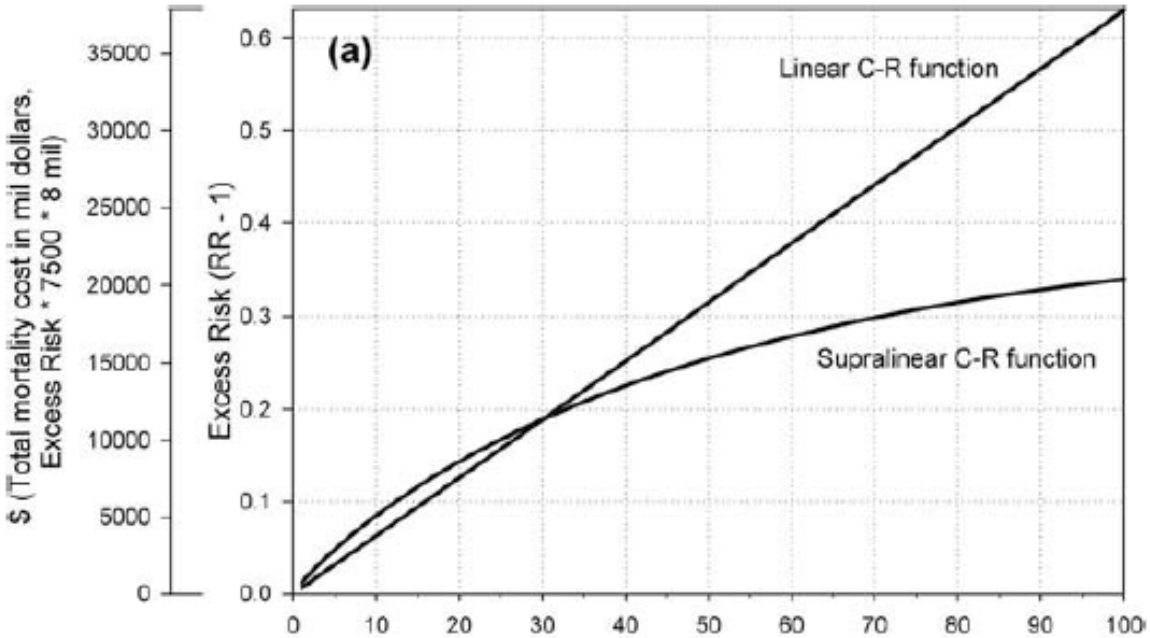

Linear Threshold
0 <= 25; 0.0063 * (Pol - 25) >25
Linear No Threshold
0.0063 * (Pol)
Non-linear Threshold
0 <= 25; 0.0001 * (Pol - 25)^2 > 25
Supra-linear No Threshold
0.4 {1- exp[-0.03(Pol)^0.9]}
Total excess risk
Marginal excess risk
Pollution

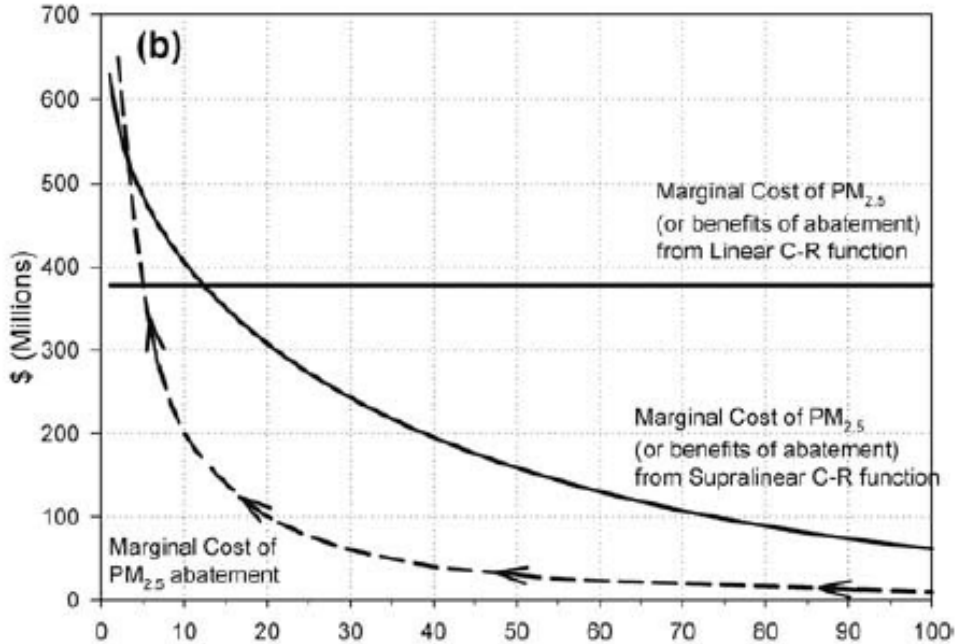

Linear Threshold
0 <= 25; 0.0063 * (Pol - 25) >25
Linear No Threshold
0.0063 * (Pol)
Non-linear Threshold
0 <= 25; 0.0001 * (Pol - 25)^2 > 25
Supra-linear No Threshold
0.4 {1- exp[-0.03(Pol)^0.9]}
Total excess risk
Marginal excess risk
Pollution


Marginal Cost
of Abatement
Marginal Health Cost
of Pollution
$
C^T
C*
C^M
Ambient Concentrations (□g/m^3)


Marginal Cost
of Abatement
Marginal Health Cost
of Pollution
$
C*
Ambient Concentrations (□g/m3)

2015


(a)
Linear C-R function
Supralinear C-R function
$ (Total mortality cost in mil dollars, Excess Risk * 7500 * 8 mil)
Excess Risk (RR - 1)
35000
30000
25000
20000
15000
10000
5000
0
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100


(b)
Marginal Cost of $PM_{2.5}$ (or benefits of abatement) from Linear C-R function
Marginal Cost of $PM_{2.5}$ (or benefits of abatement) from Supralinear C-R function
Marginal Cost of $PM_{2.5}$ abatement
$ (Millions)
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100

2017 and beyond—
or how low can we go?

Great HEI Initiative and Teams

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