Independent Science Advisors' Recommendations to EPA on the Ozone and PM NAAQS

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This talk

- Personal views only
  - Not representing or speaking for the EPA, the CASAC, the Society for Risk Analysis, the University of Colorado, or anyone else
- Presents my understanding of…
  - What we were asked to do
  - Current situation
  - What we did: consensus recommendations
  - Why it matters

The charge

- Review the science behind EPA's recommendations to the Administrator on PM2.5 and O3
  - Logically sound?
  - Correct inputs?
  - Correct calculations?
- Administrator Wheeler's emphasis
  - Sound science
  - Clear risk communication

Perspective on sound science to support risk-informed decisions

- Key question: What works to reduce risk?
  - Answer based on unambiguous *tested/validated generalizations* from data/experience ("laws")
    - Scientific method (tested predictive generalizations)
    - Focus *changes* in risks, not on attribution/blame
    - Discover and quantify reliable *dependence* relations
      - No untested assumptions, unverified models
- How do we know? How sure can we be?
  - *Test predictions with data*
  - Large, diverse samples increase confidence

CASAC recommendations

"The Draft PM PA depends on a Draft Particulate Matter (PM) Integrated Science Assessment (ISA) that, as noted in the April 11, 2019, CASAC Report on the Draft PM ISA, **does not provide a sufficiently comprehensive, systematic assessment of the available science** relevant to understanding the health impacts of exposure to PM,….

CASAC recommendations

"… due largely to a **lack of a comprehensive, systematic review** of relevant scientific literature; **inadequate evidence and rationale for altered causal determinations**; and a **need for clearer discussion of causality** and causal biological mechanisms and pathways."

Testable predictions

- For longitudinal data (changes): Are risk reductions greater where exposure has decreased than where it hasn't?
  - *Quasi-experiment* design and analysis
  - Use appropriate comparison groups
- For cross-sectional data (levels): Does risk depend on exposure, given other variables?
  - Test null hypothesis of conditional independence
  - Control for confounders (e.g., hot/cold days)

Example: Dublin intervention study

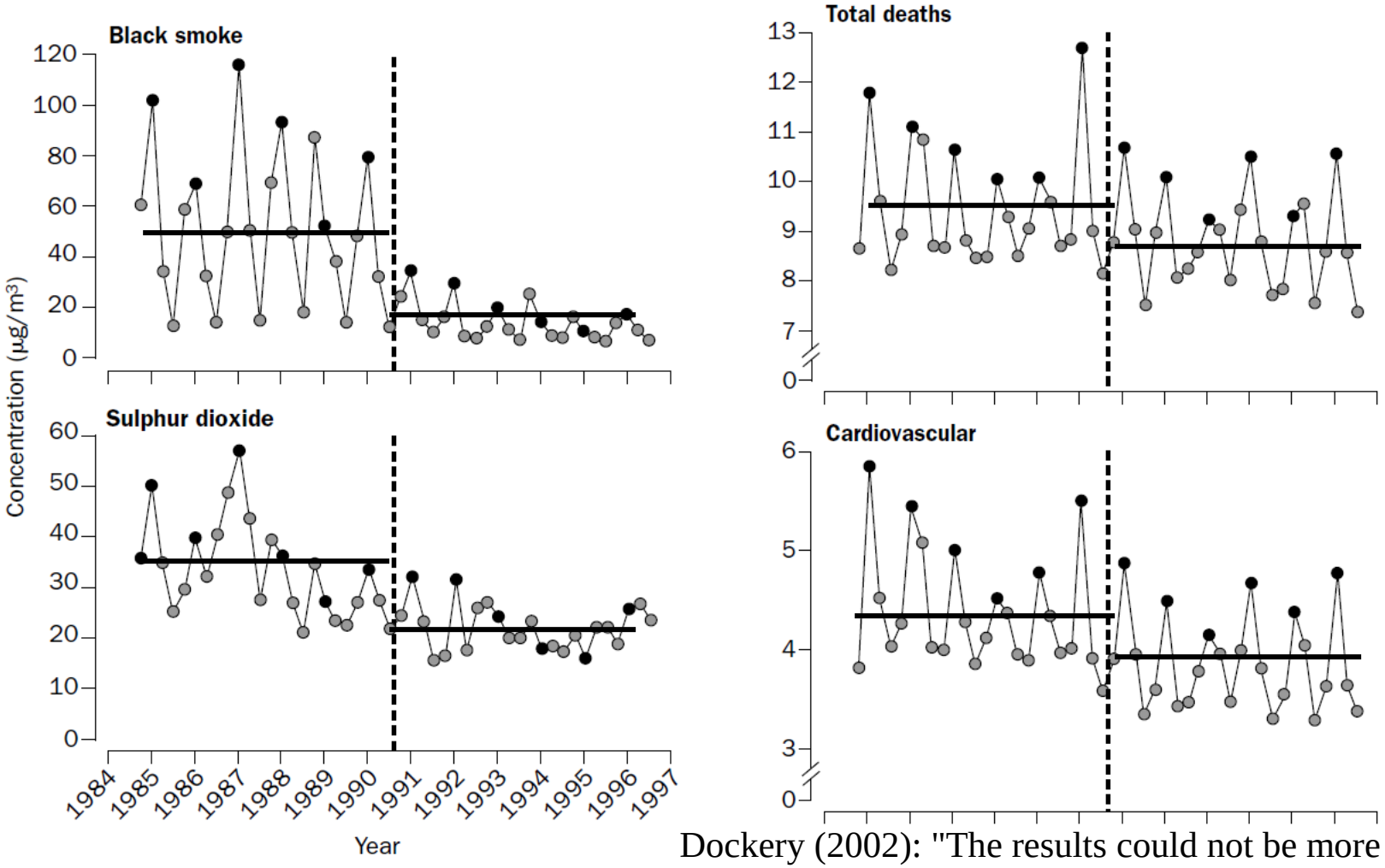

Figure 1: **Seasonal mean black smoke (upper) and sulphur dioxide (lower) concentrations, September 1984–96**
Vertical line shows date sale of coal was banned in Dublin County Borough. Black circles represent winter data.

Dockery (2002): "The results could not be more clear: Reducing particulate air pollution reduces the number of respiratory and cardiovascular-related deaths immediately."
www.news.harvard.edu/gazette/2002/10.24/14-coal.html

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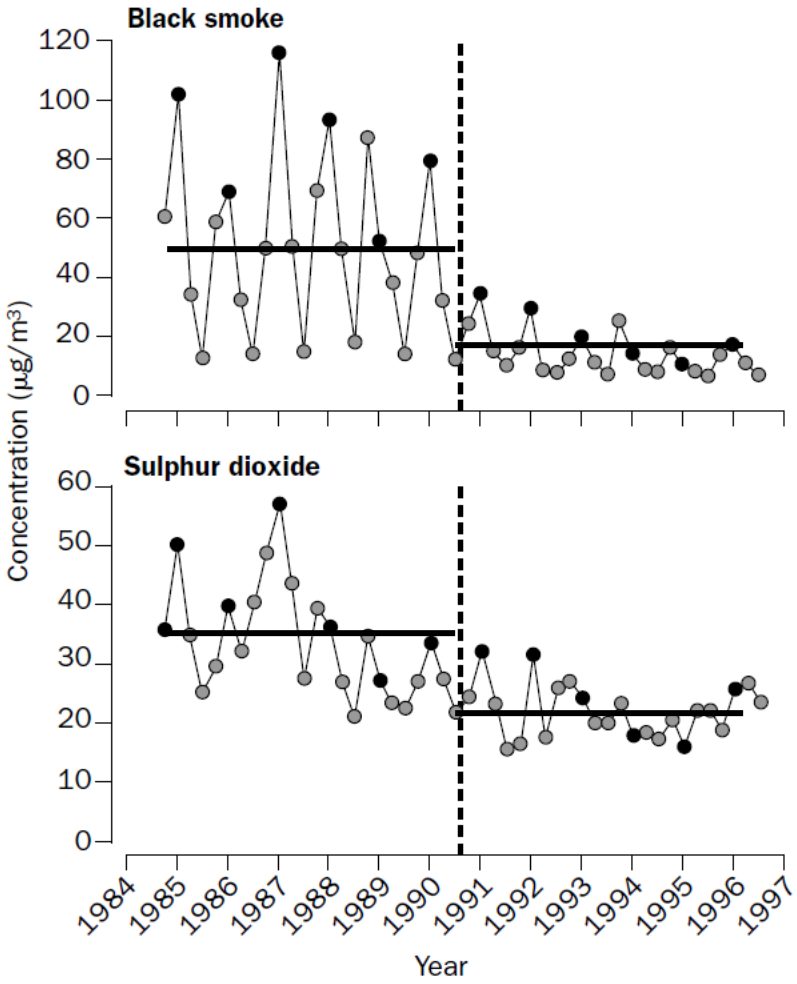

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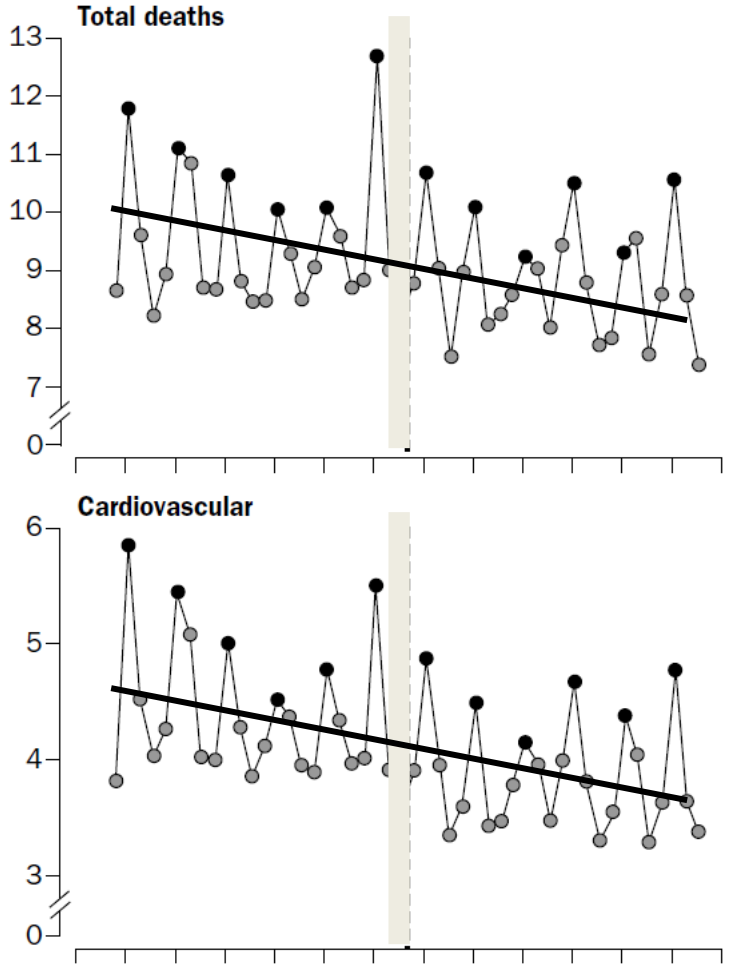


Wittmaack 2007, Pelucchi et al.: Air pollution reduction has no detectable effect on mortality rate trend
www.ncbi.nlm.nih.gov/pubmed/17365039

Dockery et al. (2013) update

- “We compared these results with similar analyses in Midlands counties also presumably unaffected by the bans. In comparisons with the pre-ban periods, no significant reduction was found in total death rates… **Detecting changes in public health indicators associated even with clear improvements in air quality, as in this case, remains difficult.**”

Res Rep Health Eff Inst. 2013 Jul;(176):3-109. Effect of air pollution control on mortality and hospital admissions in Ireland. Dockery DW1, Rich DQ, Goodman PG, Clancy L, Ohman-Strickland P, George P, Kotlov T; HEI Health Review Committee.

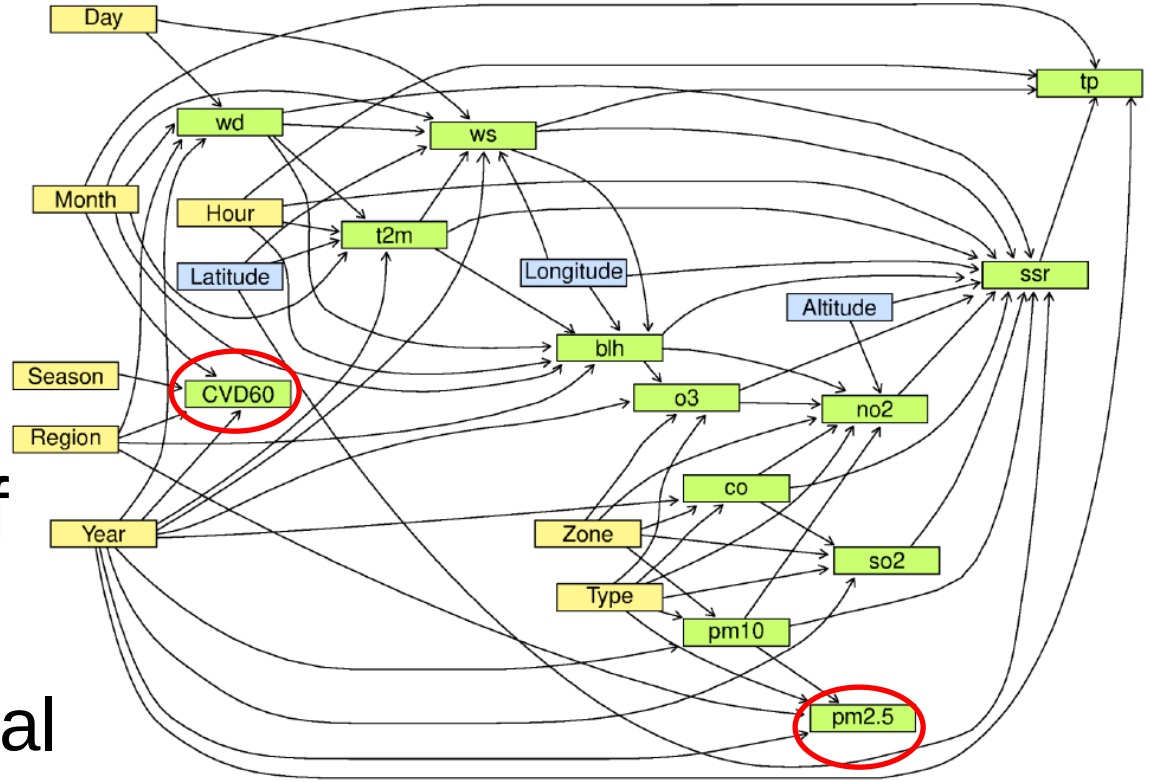
Dublin is not alone…

- “We included 42 studies assessing 38 unique interventions. … Evidence for effectiveness was mixed. Most included studies observed either no significant association or an association favoring the intervention… it was **difficult to derive overall conclusions regarding the effectiveness of interventions**…The evidence base highlights the challenges related to establishing the effectiveness of specific air pollution interventions on outcomes.” (Burns et al. 2020)

Interventions to reduce ambient air pollution and their effects on health: An abridged Cochrane systematic review. Burns J et al. Environ Int. 2020 Feb;135:105400.

Modern causal analysis: 50 million observations in UK

- Assume effects depend on their causes
- Use data to test null hypothesis of no dependence
  - Test for conditional independence
  - “Causal discovery”



Example: Cardiovascular mortality (CVD60) is conditionally independent of PM2.5. Both depend on Year and Region (confounders).

https://climate.copernicus.eu/sites/default/files/2019-11/Scutari.pdf

CASAC recommendations

"**Given these limitations** in the underlying science basis for policy recommendations, and diverse opinions about what quantitative uncertainty analysis and further analysis of all relevant data using the best available scientific methods would show, **some CASAC members conclude that the Draft PM PA does not establish that new scientific evidence and data reasonably call into question the public health protection afforded by the current 2012 PM2.5 annual standard**."

CASAC recommendations

"**Other members of CASAC conclude that the weight of the evidence, particularly reflecting recent epidemiology studies showing positive associations** between PM2.5 and health effects at estimated annual average PM2.5 concentrations below the current standard, **does reasonably call into question the adequacy of the 2012 annual PM2.5 National Ambient Air Quality Standards (NAAQS) to protect public health with an adequate margin of safety.**"

- Confounded associations might still be causal

CASAC recommendations

"Some members of the CASAC are concerned that **the risk assessment approach in Chapter 3 treats regression concentration-response (C-R) functions** (that is, functions describing associations between past estimated exposure concentration levels and mortality rates) **as if they were causal C-R functions** (that is, functions describing how changing future exposure concentrations would change future mortality rates)."

- Confounded C-R associations are not necessarily predictive or valid for risk assessment

CASAC recommendations

"Because **this is technically unsound**, these **CASAC members recommend that the PM PA explicitly state the implicit assumption** that regression coefficients can be used to quantify causality, noting that it is not necessarily a valid assumption, and **provide information about whether the assumption has been tested and what the results were.**"

- Untested modeling assumptions ≠ scientific evidence

CASAC recommendations

"**Future changes in public health risks that might be caused by reducing PM2.5 exposures are currently highly uncertain. The CASAC recommends that the PM PA better characterize this uncertainty** using quantitative uncertainty analysis. Such an analysis should account for model uncertainty, exposure estimation errors, and both inference (internal validity) and generalization (external validity) uncertainties."

- How would reducing exposure affect risk?

CASAC O3 PA recommendations

"The **CASAC recommends** that the final ISA should provide a **more balanced report of relevant epidemiology**, to be reflected in the Final PA, as discussed further for the Draft Ozone ISA; **causality determinations for metabolic effects should be updated** to reflect the Final Ozone ISA; that **FEV1 decrements are not the only relevant health effect** from ozone exposure should be more fully discussed, along with its implications for interpretation and application of the risk assessment results; and **lack of empirical validation for risk modeling assumptions and predictions should be acknowledged** and its implications for uncertainty about public health effects of changes in ozone exposures should be discussed. The CASAC recommends that a t**horough quantitative uncertainty and variability analysis** should be added and its **implications for policy-relevant** conclusions discussed."

- How would reducing exposure affect risk?

CASAC O3 PA recommendations

"**On overarching process issues, the CASAC strongly recommends that the EPA consider restoring a traditional interactive discussion process** in which the CASAC can interact directly with external expert panels, **while also keeping the option of obtaining written responses from external experts to specific questions. The CASAC strongly recommends that the EPA work with experts in causal analysis, biological causation, management science, decision analysis, and risk analysis to improve the causal determination framework**. Experts from outside the air pollution health effects area should be included. **The CASAC recommends that the EPA work with the National Academies** to critically review and improve the logical and conceptual foundations for its causal analyses and the clarity with which its causal conclusions are expressed and communicated…"

- How would changing exposure change risk?

Current situation

- Causal determination framework
  - Judgment-based, association-based
    - No calculations to review for causal impacts
    - No clear definitions: Does “cause” refer to necessary, sufficient, contributing, other?
- Quantitative risk assessment (QRA)
  - Simulation/assumption-based, no validation
    - Key part is assumed “impact function” (C-R)
    - Based on confounded associations (regression), unverified assumptions. No predictive validity.

Causal determination: Details

- "Causal" determination definition: "Evidence is sufficient to conclude that there is a **causal relationship** with relevant pollutant exposures (e.g., doses or exposures generally within one to two orders of magnitude of recent concentrations). That is, the pollutant has been shown to result in health effects in studies in which **chance, confounding, and other biases could be ruled out with reasonable confidence**. For example: (1) controlled human exposure studies that demonstrate consistent effects, or (2) **observational studies** that cannot be explained by plausible alternatives or that are **supported by other lines of evidence (e.g., animal studies or mode of action information)**. Generally, the determination is based on multiple high-quality studies conducted by multiple research groups."
- *Q: Does "causal" mean necessary. sufficient, both, or neither?*
- *Q: Rates of false positives, false negatives?*

CASAC O3 PA recommendations

- Restore traditional interactive discussion process
  - Keep asking: What do statements mean? How well supported are they
- Keep written responses from external experts to specific questions.
- EPA should work with external experts (NAS) in causal analysis, biological causation, management science, decision analysis, and risk analysis to improve the causal determination framework.

Conclusions

- Protecting public heath effectively requires successfully using causal relationships between actions and their consequences
- NAAQS review process has focused on attribution, association, and causal determination, not on predicting/validating changes in health from changed exposures
- Big opportunity to improve scientific basis for future regulations

Thank you!

Q&A

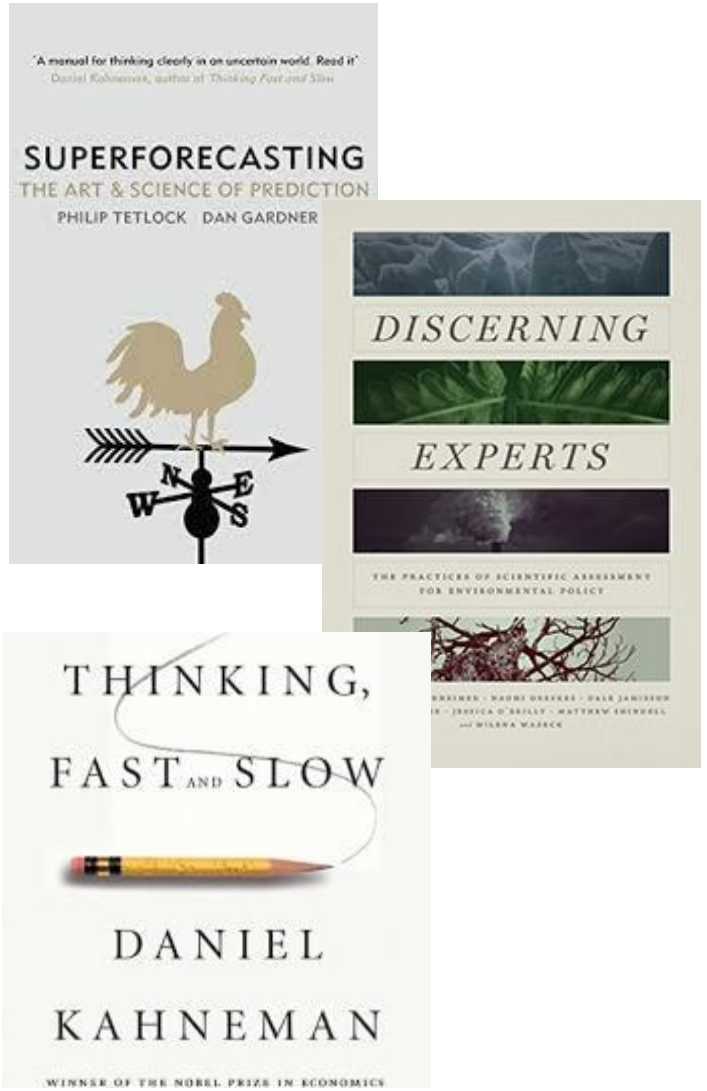
Backup Materials

Causal determination judgments

- “In the evaluation of the evidence **determinations are made about causation**, not just association, and are **based on judgments** of aspects such as the consistency of evidence within a discipline, coherence of effects across disciplines, and biological plausibility of observed effects as well as related uncertainties.” (EPA 2018, Draft PM2.5 ISA)

Q: What's wrong with judgment?

- A: Often doesn't work well
  - Often/usually wrong
  - Not a sound, reliable basis for regulation, litigation, or risk management decisions
  - Slightly less good than random guessing
  - Open to heuristics and biases
    - Overconfidence, confirmation, framing, overgeneralization, etc.
  - Not open to correction/learning from data



Lack of clear definitions undermines informed regulation

- Example: US EPA uses “causal determination” categories with no clear meanings
  - No distinction between necessary, sufficient, contributing, other types of causation
- No clear implications for effects of interventions
  - But treated as if they implied that reducing exposure would reduced risk

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- Q: Does "causal" mean necessary cause, sufficient cause, both, or neither?

Problem: “Causal” criteria do not actually address causation

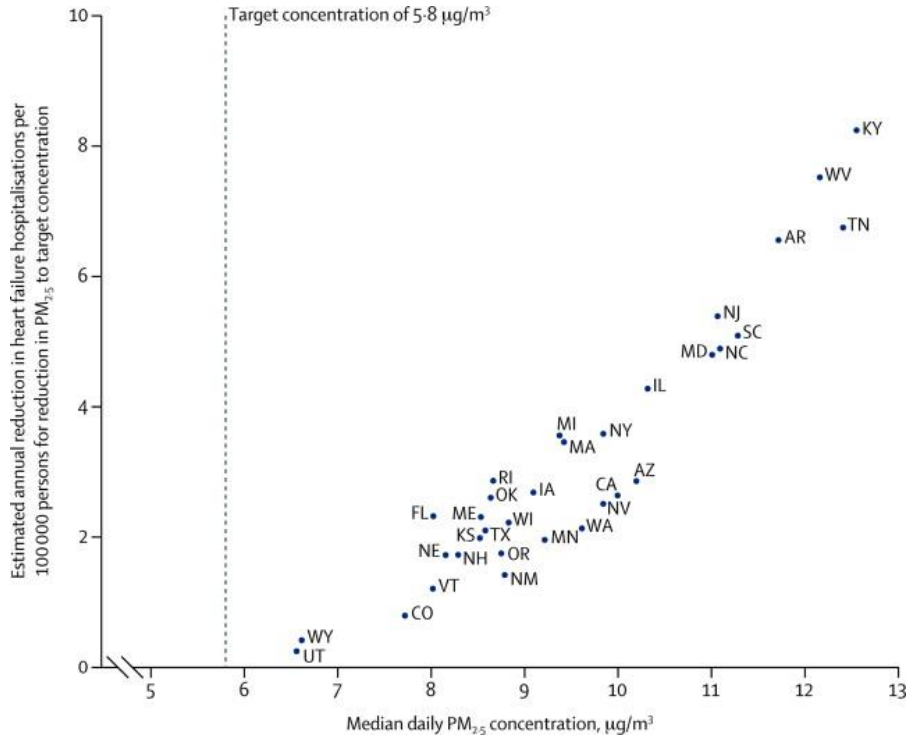
- Example: Suppose rising college tuitions accompany warmer global temperatures.
  - Significant association (chance unlikely)
  - No common causes (confounding unlikely)
  - No obvious biases (bias unlikely)
- “Causal determination” logic: Therefore, college tuition costs cause global warming
- Moral: Excluding chance, confounding, bias does *not* imply or suggest causation!

Current regulatory risk assessment

- *Worry* that exposure to X might cause harm Y
- *Predict* that reducing X will reduce Y
  - Develop a slope factor or ratio said to “link” them
    - “link” almost always means association, not causation
  - Ask anti-X advocates to judge whether link is “causal”
  - Quantify: Present to Congress estimates of reduction in harm Y *per unit* of reduction in exposure X
- Examples:
  - Air pollution and mortality
  - Animal antibiotics and resistance
  - Any exposure and any effect

Interpreting associations as causal leads to dramatic predictions and calls for action

Estimated benefit (decreased heart failure hospitalizations) from tighter PM2.5 regulation)



Example: Shah et al., 2013, *Lancet* meta-analysis

"Findings: Increases in particulate matter concentration were associated with heart failure hospitalisation or death (PM2·5 2·12% per 10 µg/m3, 95% CI 1·42–2·82… In the USA, we estimate that a mean reduction in PM2·5 of 3·9 µg/m3 **would prevent 7978 heart failure hospitalisations and save a third of a billion US dollars a year**."

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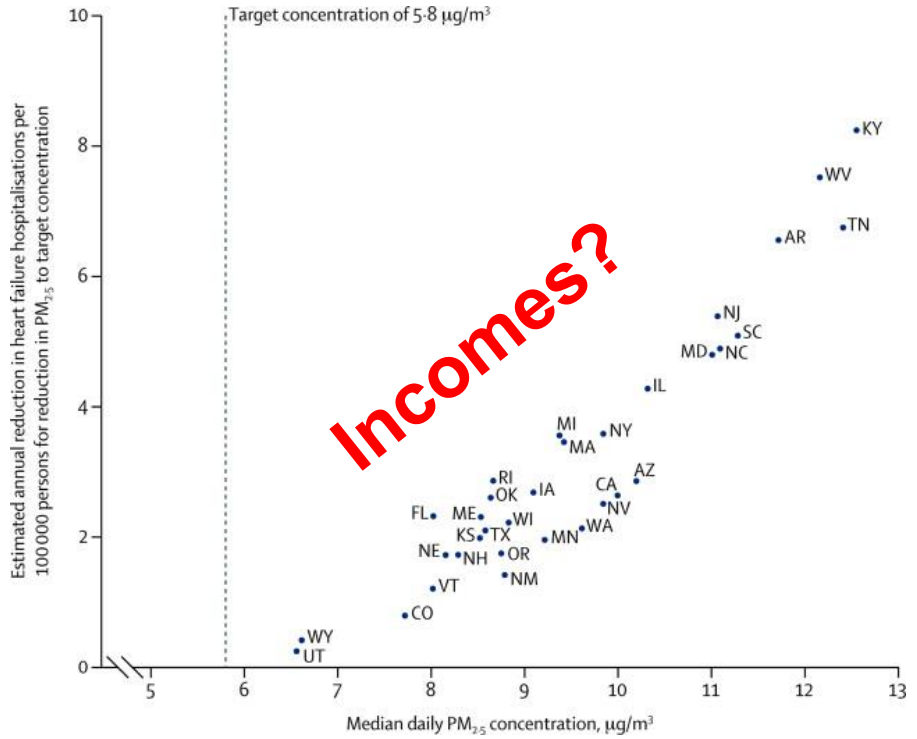

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“Increases” in exposure ≠ differences in exposure

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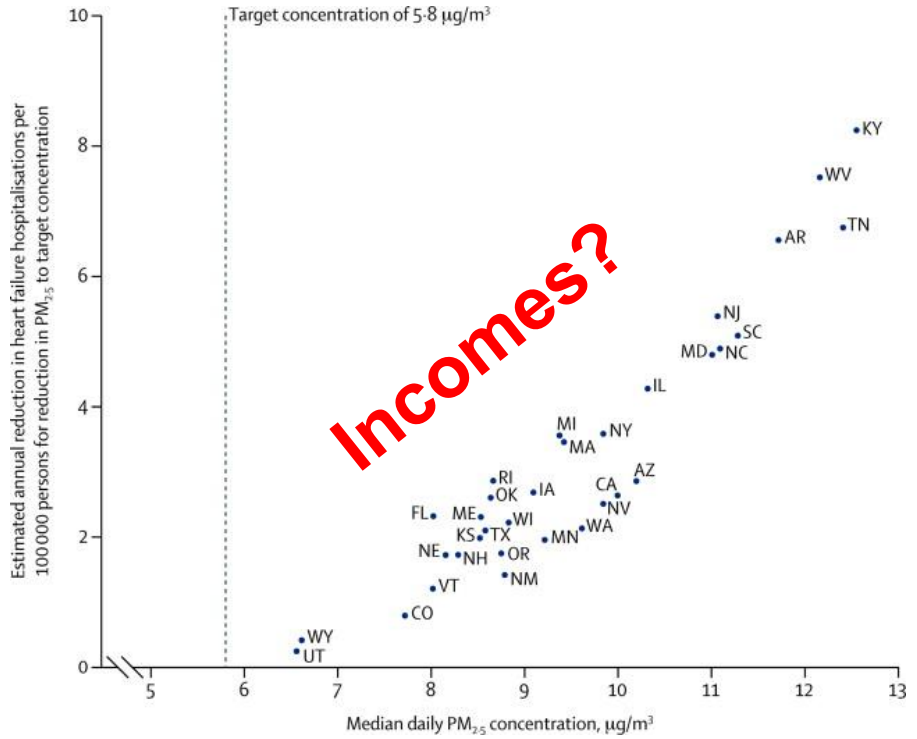

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Association ≠ causation

- How would cutting exposure concentration C in half affect future response rate R?

Community	Concentration , C	Income, I	Mortality rate, R
A	4	100	8
B	8	60	16
C	12	20	24

Association depends on model

- How would cutting exposure concentration C in half affect future response rate R?

Community	Concentration , C	Income, I	Mortality rate, R
A	4	100	8
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Model 1: R = 2C, (I = 140 – 10C) $I \leftarrow C \rightarrow R$

Model 2: R = 35 – 0.5C – 0.25*I, $C \rightarrow R \leftarrow I$

Model 3: R = 28 – 0.2*I, (C = 14 – 0.1*I) $C \leftarrow I \rightarrow R$

So, decreasing C could decrease R, increase it, or leave it unchanged.

Associations have many possible non-causal explanations

Explanation	Model
• X causes Y	$X \rightarrow Y$
• Confounder	$X \leftarrow Z \rightarrow Y$
• Selection bias	$X \rightarrow Z \leftarrow Y$
– If Z = Y – X, then Y = X + Z, though X does not cause Y	
• Trends	X, Y both decreasing
• Measurement error	$X \leftarrow Z \rightarrow Y$
• Model misspecification	E(Y) = aX + bZ

Science-policy-law questions

- Should judicial deference extend to letting agencies base policies on predictions from any association model that fits the data?
  - Is it arbitrary and capricious to select a model to drive policy if equally good models give opposite results?
- Should it let agencies choose models that don't fit the data? (Example: EPA, PM2.5)
- Who should have standing to challenge, using models with opposite predictions?

Key points

- Regulation (and litigation) commonly (mis)interpret association as causation
- Association is not causation.
  - Associations between past *levels* of exposure and risk do not describe how future *changes* in exposure would change future risks
  - Associations are often model-dependent
  - Many non-causal sources of association
  - Bradford Hill considerations don’t reveal causation
- How can we fix this?

Current risk communication: Exciting headlines!

- February 13, 2016: “Polluted air causes 5.5 million deaths a year new research says – BBC.” www.bbc.com/news/science-environment-35568249
- April 18, 2018: “Air Pollution Contributed to More Than 6 Million Deaths In 2016” www.forbes.com/.../air-pollution-contributed-to-more-than-6-million-deaths-in…
- May 1, 2018 “Air Pollution Kills 7 Million People a Year, WHO Reports – Bloomberg.” www.bloomberg.com/news/articles/2018-05-01/air-pollution-kills-7-million-people-a-year-who-reports
- May 7, 2018: “How air pollution contributes to 8 million deaths each year - CBS News.” www.cbsnews.com/news/how-air-pollution-makes-people-sick-8-million-early-deaths-each-year/
- November 16, 2018: “Air pollution causes 4 million deaths per year and restricts children's lung growth.” www.technology.org/2018/11/16/air-pollution-causes-4-million-deaths-per-year-and-restricts-childrens-lung-growth/
- March 12, 2019: “Air Pollution Causes 8.8 Million Extra Deaths a Year.” www.usnews.com/news/national-news/articles/2019-03-12/air-pollution-causes-88-million-extra-deaths-worldwide-each-year-study-says

What the headlines don't communicate

- "Air pollution causes X million extra deaths per year" does *not* necessarily imply that there would be fewer deaths per year if air pollution were eliminated. (!)
  - No necessary relation between deaths "caused by" or *attributed* to air pollution and deaths *preventable* by removing air pollution
- The same deaths may also be "caused by" hot weather, cold weather, poverty, old age, malnutrition, illnesses, other pollutants, etc.

How attributable risks work

- *Assume* that difference in risks is due to (i.e., caused by, attributable to, preventable by removing) difference in exposure of interest
- Can attribute up to 100% of excess risk to each of many factors associated with it
  - If risk = 0 for rich, young, healthy, unexposed
  - And risk = 0.1 for old, poor, sick, exposed, etc.
  - Then attributable fraction = 100% “from exposure” (and from age, poverty, illness, etc.)

Risk communication in the US

U.S.News & WORLD REPORT

100,000 Americans Die from Air Pollution, Study Finds

A report puts a human and financial price on air pollution as a government panel looks to dismiss its costs.

By **Alan Neuhauser**, Staff Writer April 8, 2019, at 3:05 p.m.

MORE THAN 100,000 Americans each year die of heart attacks, strokes and other illnesses caused by air pollution spewed from factories, motor vehicles and even bucolic-seeming farmland, according to a new report that contradicts an EPA panel whose members downplayed the risks during a public meeting last month.

Can it be true?

Iron laws of arithmetic:

- Everyone dies just once
- Therefore, pollution cannot increase number of deaths "*each year*" (unless it increases number of births per year)
- Shortening lives does *not* change deaths per year (!)
- Headlines imply nothing about how to *reduce* risk

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The findings, in a new study published Monday in the Proceedings of the National Academy of Sciences, put a human toll and a price tag – some $886 billion a year – on the health impacts caused by air pollution, especially from fine particulate matter known as PM 2.5.

"The link between fine particulate matter pollution and decreased health impacts is well-established in the literature from epidemiological studies, and our work builds on that," says study co-author Jason Hill, an associate professor of engineering at the University of Minnesota. "This is a substantial cost to human health, both in terms of lives lost and economic impact."

Members of a powerful EPA committee, however, all but dismissed such connections during a meeting March 28, with some stating they did not even agree inhaling air pollution – including soot – could lead to an early death.

There are "varying opinions on the adequacy of the evidence supporting the EPA's conclusion that there is a causal relationship between [particulate matter] exposure and mortality," Tony Cox, chairman of the agency's Clean Air Scientific Advisory Committee, said in prepared remarks, adding that he was "actually appalled" by what he claimed was a lack of evidence connecting air pollution to health consequences.

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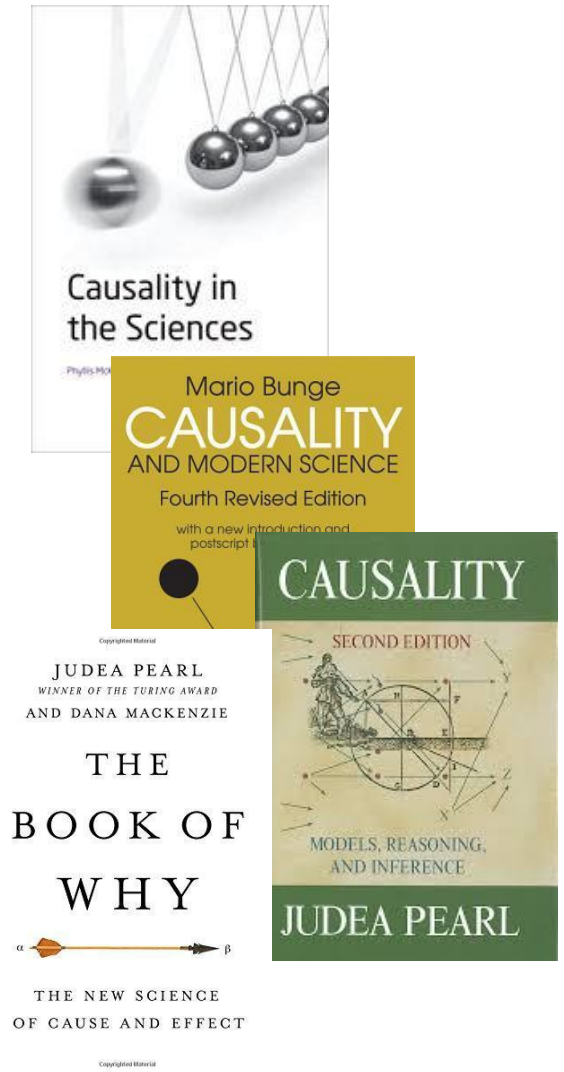
Doing better

- What works to prevent/reduce risk?
- How do we know?
- How sure can we be?

Conclusions: Science & causality



Science is a process for discovering, validating, and refining general, causal laws, mechanisms, and explanations using reproducible data

- Causal laws: Predictive generalizations
- Causal mechanisms: How things work
- Causal explanations/theories: Networks of mechanisms
- Causal predictions: Theories imply predictions for new situations
  - "Invariant causal prediction" property

What can science do for us?

- Use data to test/challenge/replace assumptions and preconceptions, correct mistakes and…
- Discover how reality works
  - Reveal unexpected findings (causal networks)
  - Explain, attribute given assumptions
  - Predict consequences of interventions
- Identify causal laws that enable trustworthy predictions, plausible explanations, and effects estimates given assumptions

What can science *not* do?

- Prescribe: Tell us what we should do
  - "Sound science" does not imply policies
- Attribute/blame: Tell us who or what to blame how much for undesired events
- Reveal "the" probability of an event or outcome with and without different actions
- Make expert judgments trustworthy
- Manufacture useful certainty from ambiguous data
- Predict effects of policy changes from associations

Fixing what's broken

- Start clearly defining what we care about
  - How much reduction in risk from a reduction in exposure, given levels of other variables?
- Use causal methods for causal questions
  - Conditional independence tests, analysis of changes in time series, quasi-experiments
- Stop treating association as causation
- Stop treating judgments as science
  - Hill considerations are inadequate, obsolete