Methodological Perspectives on Evaluating Health Effects of Policies

Corwin M. Zigler

Department of Biostatistics, Harvard School T.H. Chan School of Public Health

March 15, 2017

Background

Accountability

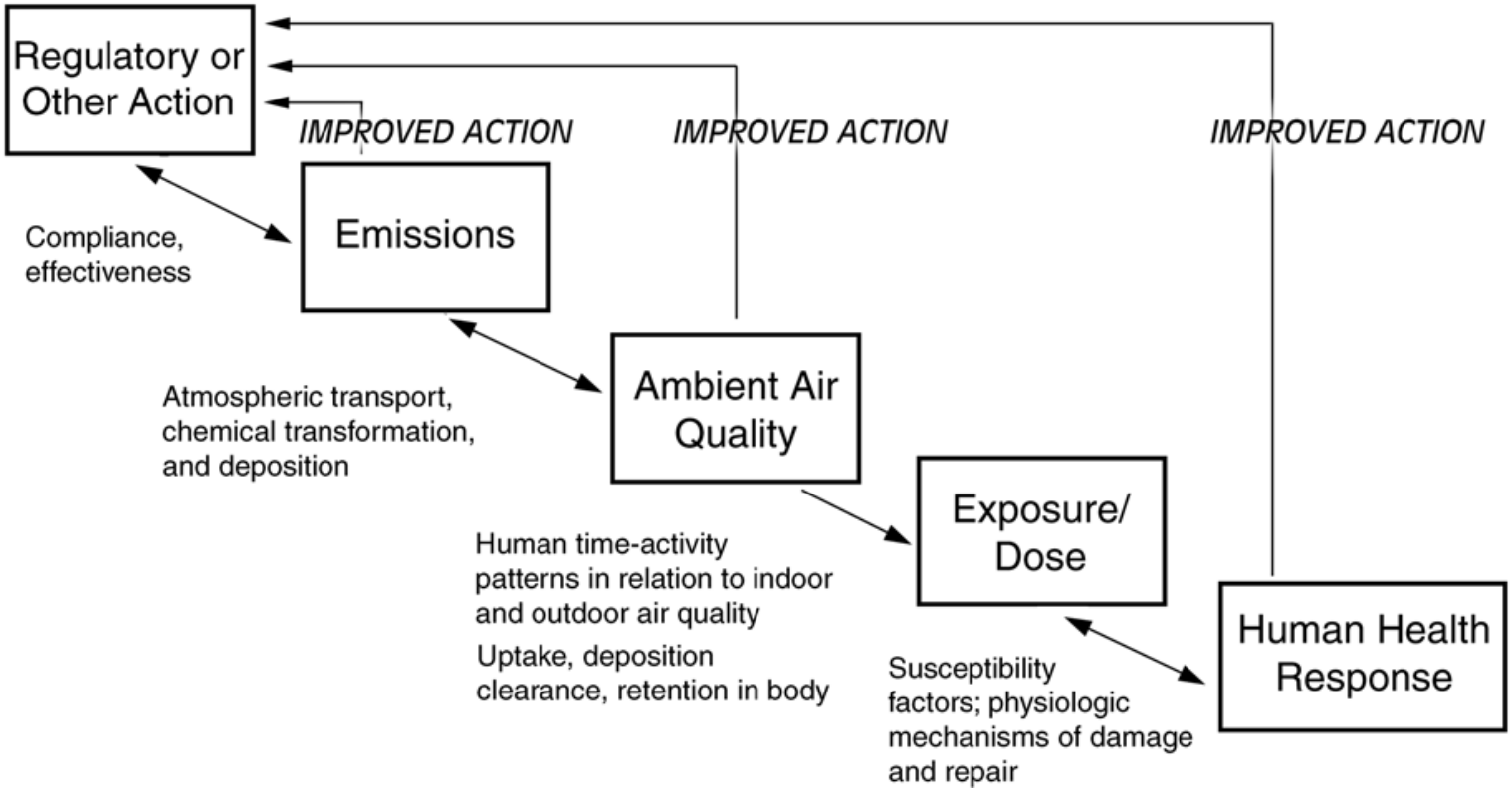
Accountability Assessment
(Health Effects Institute (2003))

"Evaluating the extent to which **air quality regulations** improve public health is part of a broad effort–termed **accountability**–to assess the performance of all environmental **regulatory policies**."

- "... taking **regulatory and other actions**... tracking their consequences so that efforts can be redirected as indicated by subsequent evidence."

AKA Health impact analysis, health outcomes analysis, policy evaluation, intervention analysis, ...

Chain of Accountability
(from the Health Effects Institute)



Background

Two Relevant Questions

Question # 1
Effects of *pollution*

What are the “health effects” of exposure to air pollution?

Question # 1
Effects of *pollution*

What are the "health effects" of exposure to air pollution?

- What is the concentration-response (C-R) relationship
- Is the relationship *causal*?
- A central question to epidemiology for decades

Question # 1
Effects of *pollution*

What are the "health effects" of exposure to air pollution?

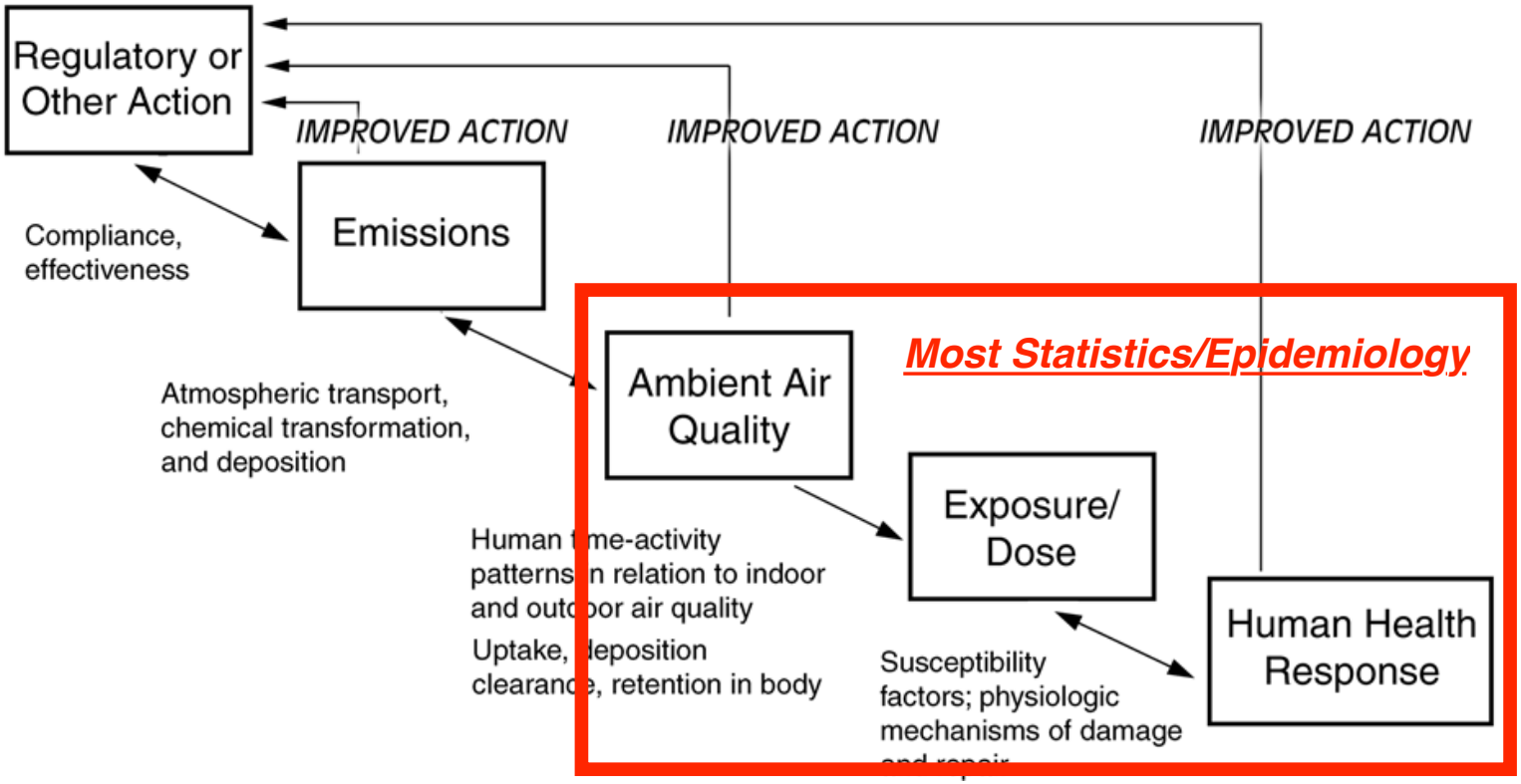
- What is the concentration-response (C-R) relationship
- Is the relationship *causal*?
- A central question to epidemiology for decades

Relevance for Evaluating Policies

- Question is not about any policy *per se*
- Motivates policies
- Answer can imply health benefits of polices

Question #1 on the Accountability Chain

Most statistics/epidemiology/toxicology lies at the end of the chain:



Question #2
Effects of *policies*

What are the "health effects" of a policy (or intervention or action)?

Question #2
Effects of *policies*

What are the "health effects" of a policy (or intervention or action)?

- To what extent did a policy *cause* health improvements?
- Which effects can be attributed to which policies?
- Which policies are most effective?

Question #2
Effects of *policies*

What are the "health effects" of a policy (or intervention or action)?

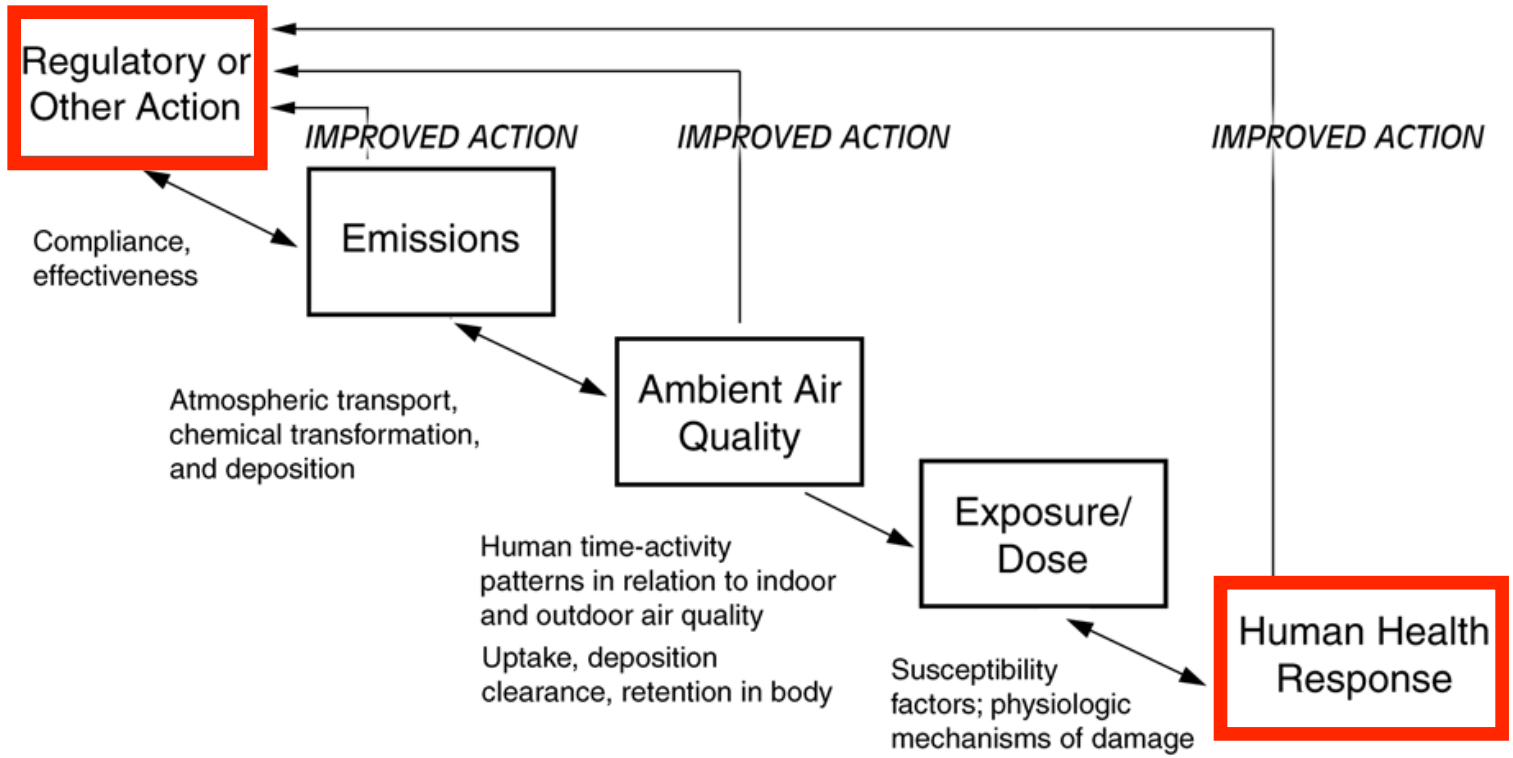
- To what extent did a policy *cause* health improvements?
- Which effects can be attributed to which policies?
- Which policies are most effective?

Relevance for Evaluating Policies

- Explicitly addresses effectiveness of policies

Question #2 on the Accountability Chain

Directly evaluate the health impact of the policy:



Highlight the Distinction

between two different (but good!) questions

Question #1

What are the "health effects" of pollution exposure?

- Most epidemiology focuses here
- Many remaining challenges!

Question #2

What are the "health effects" of a specific policy or intervention?

- Less focus here
- Many remaining challenges!

Highlight the Distinction

between two different (but good!) questions

Question #1

What are the "health effects" of pollution exposure?

- Most epidemiology focuses here
- Many remaining challenges!

Question #2

What are the "health effects" of a specific policy or intervention?

- Less focus here
- Many remaining challenges!

Different questions $\leftrightarrow$ Different challenges $\leftrightarrow$ Different methods

Methods

Paradigms of Causality

The "Classical" Paradigm of Causality
(e.g., Bradford Hill Criteria)

Is the pollution $\leftrightarrow$ health relationship causal?

- Synthesize available evidence of association
- Place along a **continuum of causality**
  - E.g., EPA Integrated Science Assessments classify evidence as: causal, *likely* causal, *suggestive* of causal, *inadequate* to infer causal, *not likely* causal
- More rigor $\leftrightarrow$ more likely "causal"
- More confidence in a causal relationship $\Rightarrow$ more useful for characterizing policy impacts

The "Potential-Outcomes" Paradigm of Causality

- Causal effects defined as **consequences of specific actions**
  - "Cause" $\equiv$ something that either happens or does not
  - "Effect" $\equiv$ consequence of that cause
- Typically relies on estimating *would have happened* without the policy
  - "Counterfactual scenarios"
- Knowing "the counterfactual" characterizes the effect of the policy
- More appropriate for direct policy evaluation

Methods

Predicting the Counterfactual

"Counterfactual Scenario"

Familiar Idea:

Attributing changes in air quality and health to a policy requires knowledge of:

(1) What *did* happen following the intervention
- Or what is expected to happen

(2) What *would have* happened without the intervention
- Or under some alternative action
- "The Counterfactual"

$$(1) + (2) \Rightarrow \text{Policy Impact}$$

"Counterfactual Scenario"

Familiar Idea:

Attributing changes in air quality and health to a policy requires knowledge of:

(1) What *did* happen following the intervention
- Or what is expected to happen

(2) What *would have* happened without the intervention
- Or under some alternative action
- "The Counterfactual"

$$(1) + (2) \Rightarrow \text{Policy Impact}$$

The most fundamental differences among methods for accountability assessment pertain to how the "counterfactual" is obtained

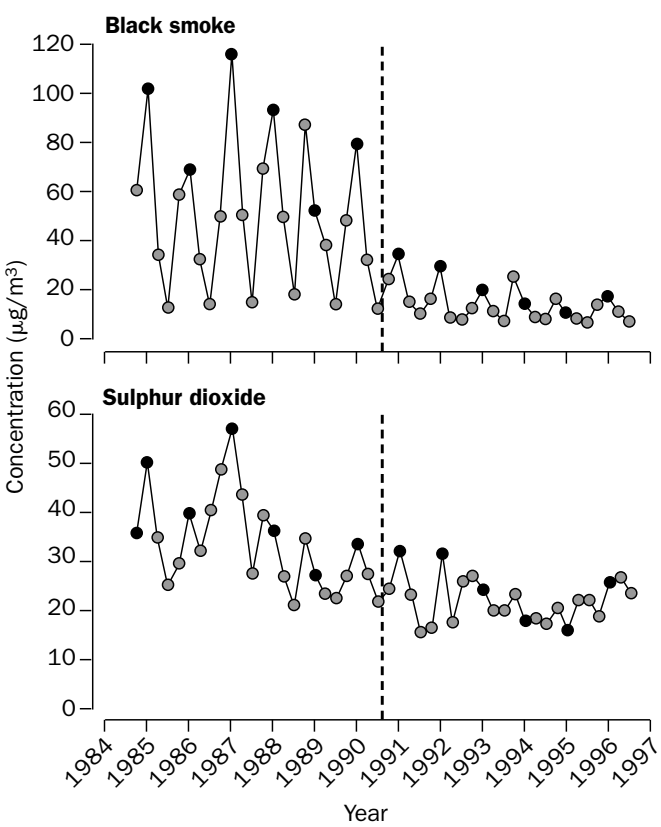
How to Obtain the Counterfactual

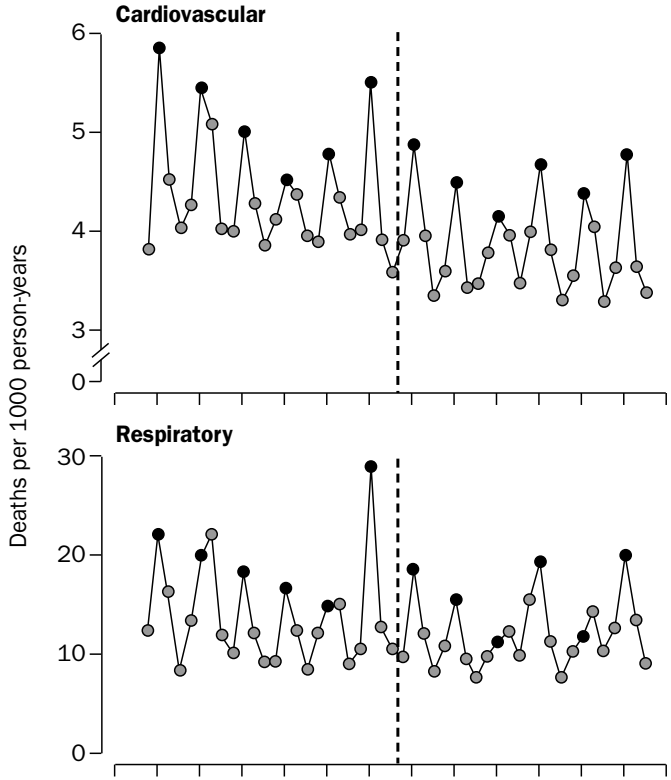
The task of learning about what *would have* happened depends on:

- Which links in the chain are of interest
- Type of policy or intervention
- Time-frame of interest
- Spatial/temporal features of the policy
- What data are available
- Prospective vs. retrospective evaluation

Short-Term, Localized Policy

Think: Dublin Coal Ban, Clancy et al 2002





Clear, abrupt change $\rightarrow$ easier to predict "the counterfactual"
(not much else changing pre/post intervention)

"Temporal Stability"

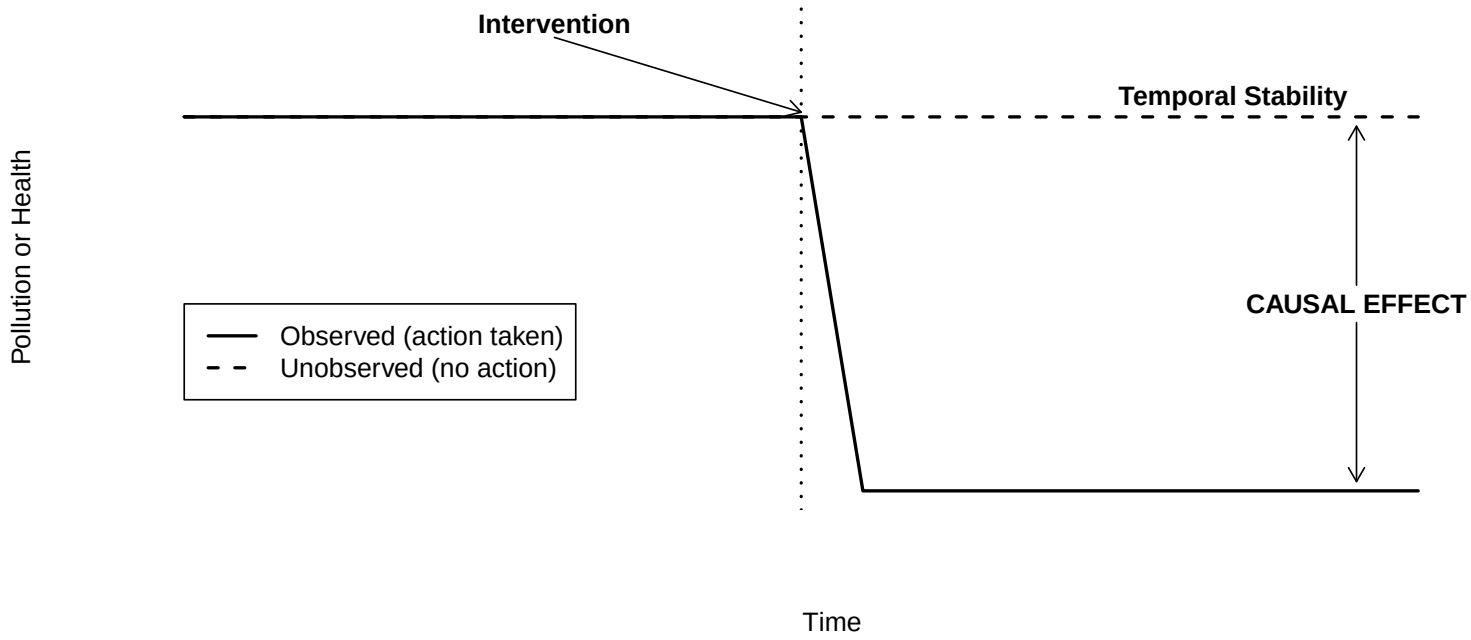
Clear intervention point + abrupt, short-term change + not much else changes

"Temporal Stability"

Clear intervention point + abrupt, short-term change + not much else changes
$\Rightarrow$ (relatively) easy to predict the counterfactual
(assume pre-intervention trends would have continued)

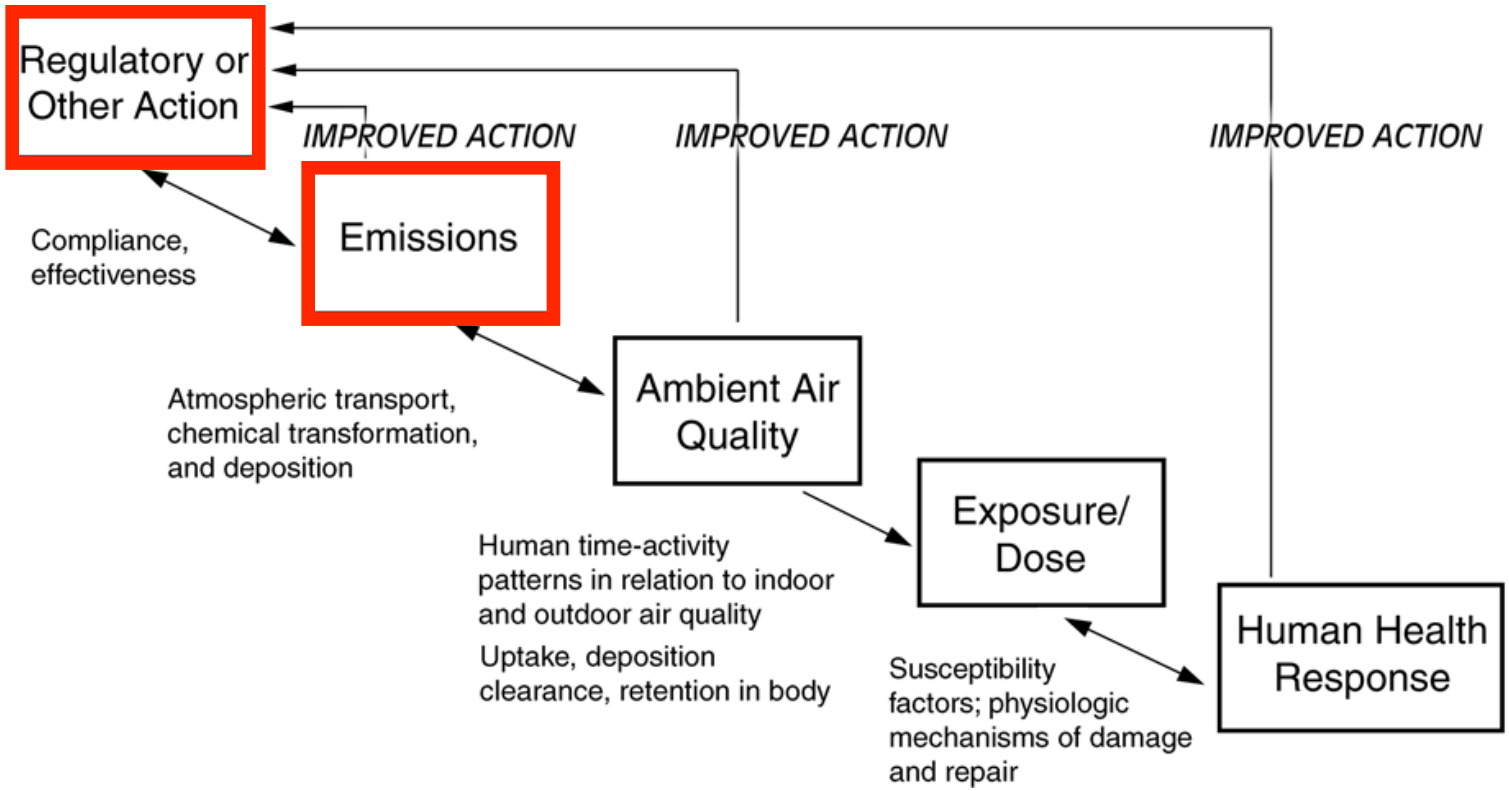
"Temporal Stability"

Clear intervention point + abrupt, short-term change + not much else changes
$\Rightarrow$ (relatively) easy to predict the counterfactual
(assume pre-intervention trends would have continued)



Short-Term, Localized Policy

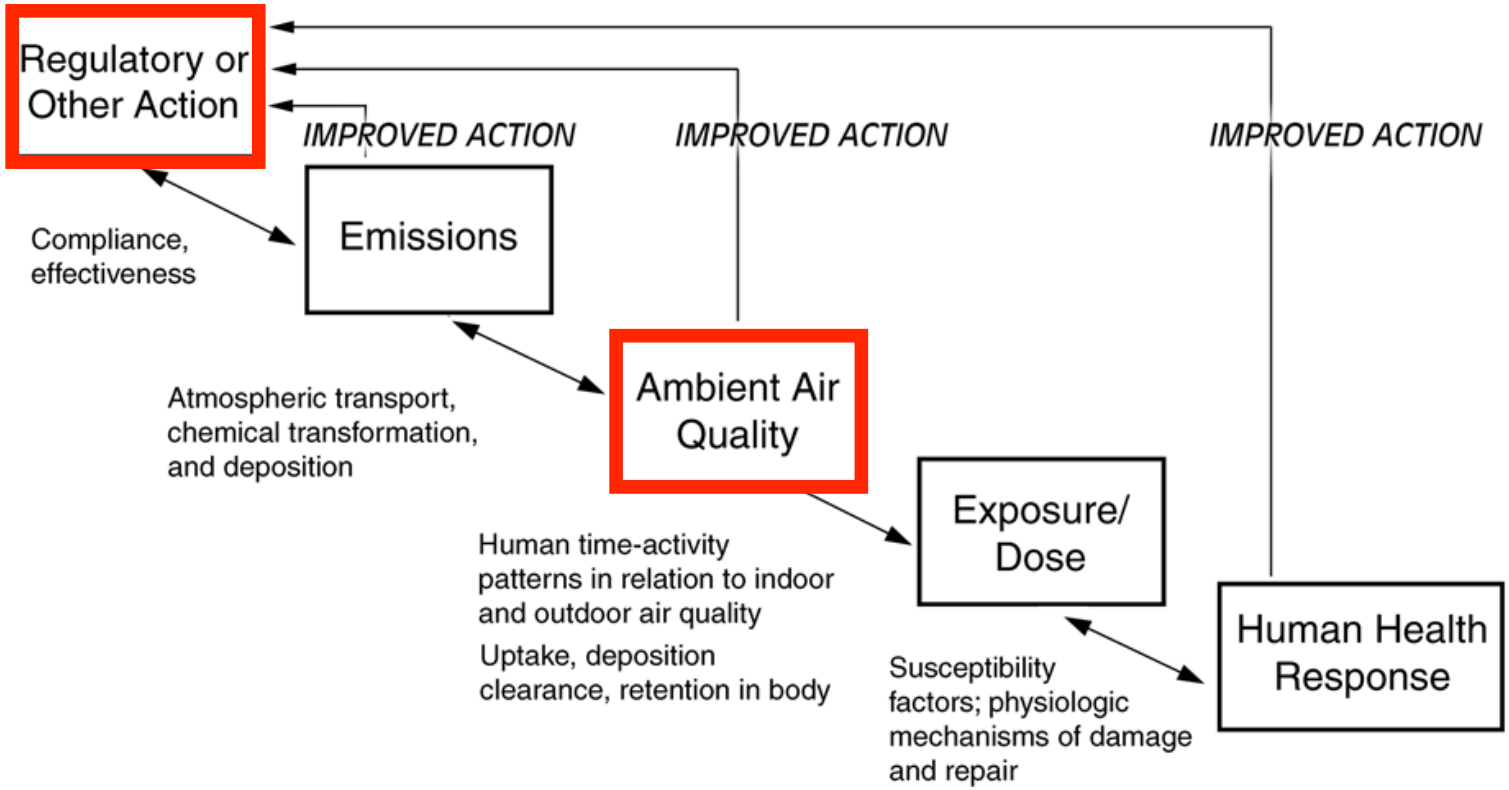
Think: Dublin Coal Ban



What would **emissions** have been without the ban?

Short-Term, Localized Policy

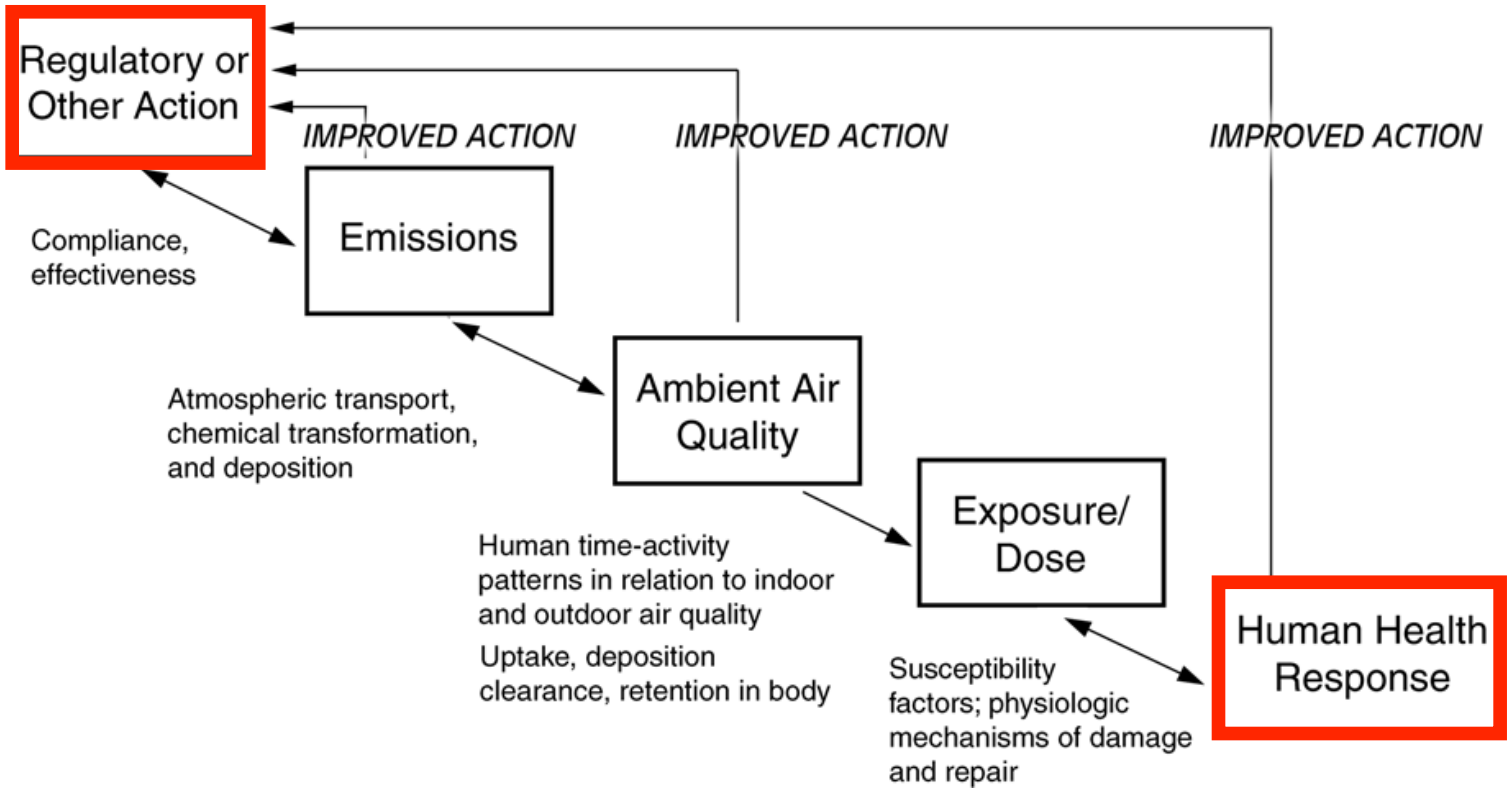
Think: Dublin Coal Ban



What would **AQ** have been without the ban?

Short-Term, Localized Policy

Think: Dublin Coal Ban

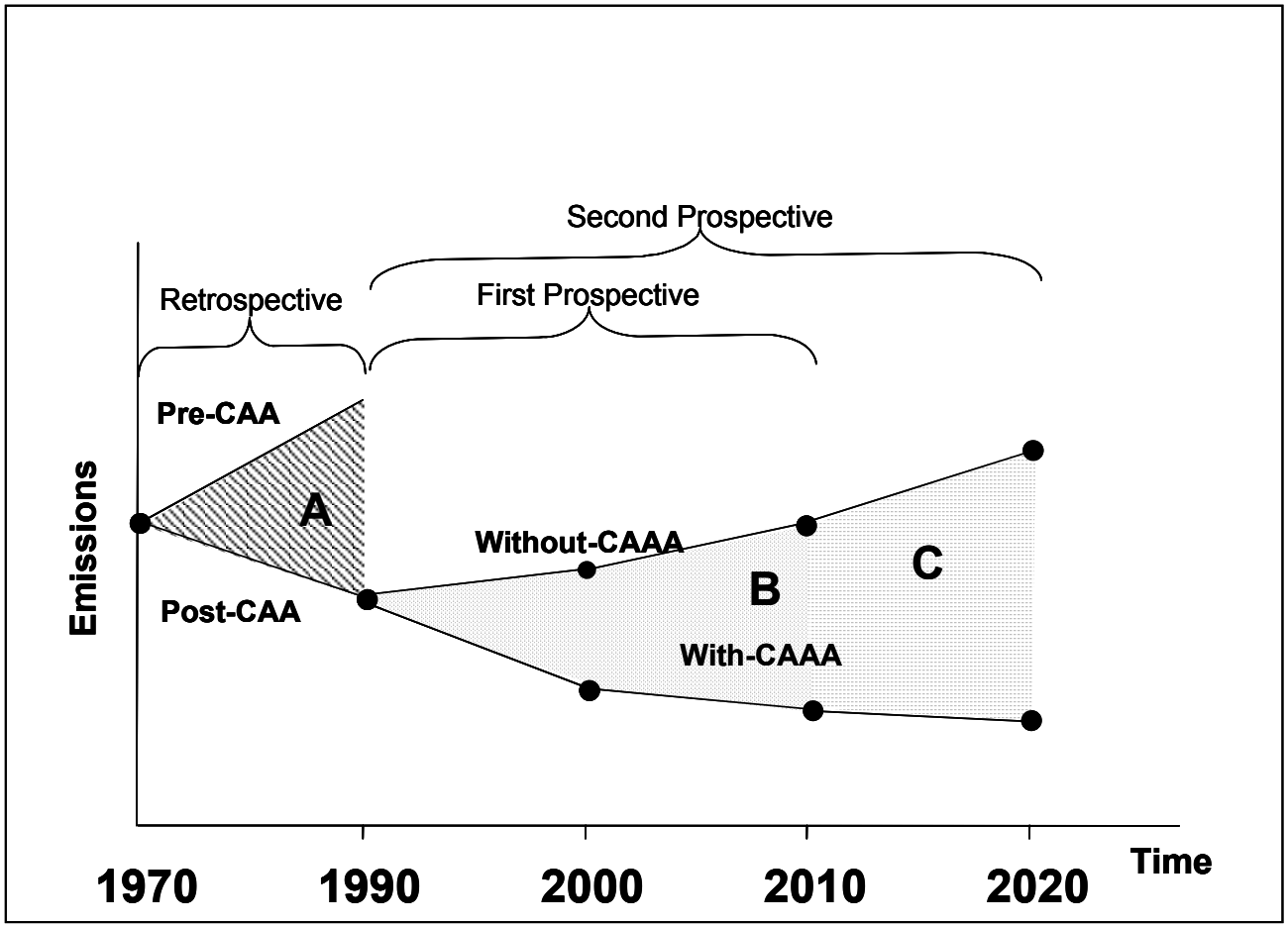


What would **health** have been without the ban?

Long-Term, Regional Policy

Think: Evaluating the Clean Air Act

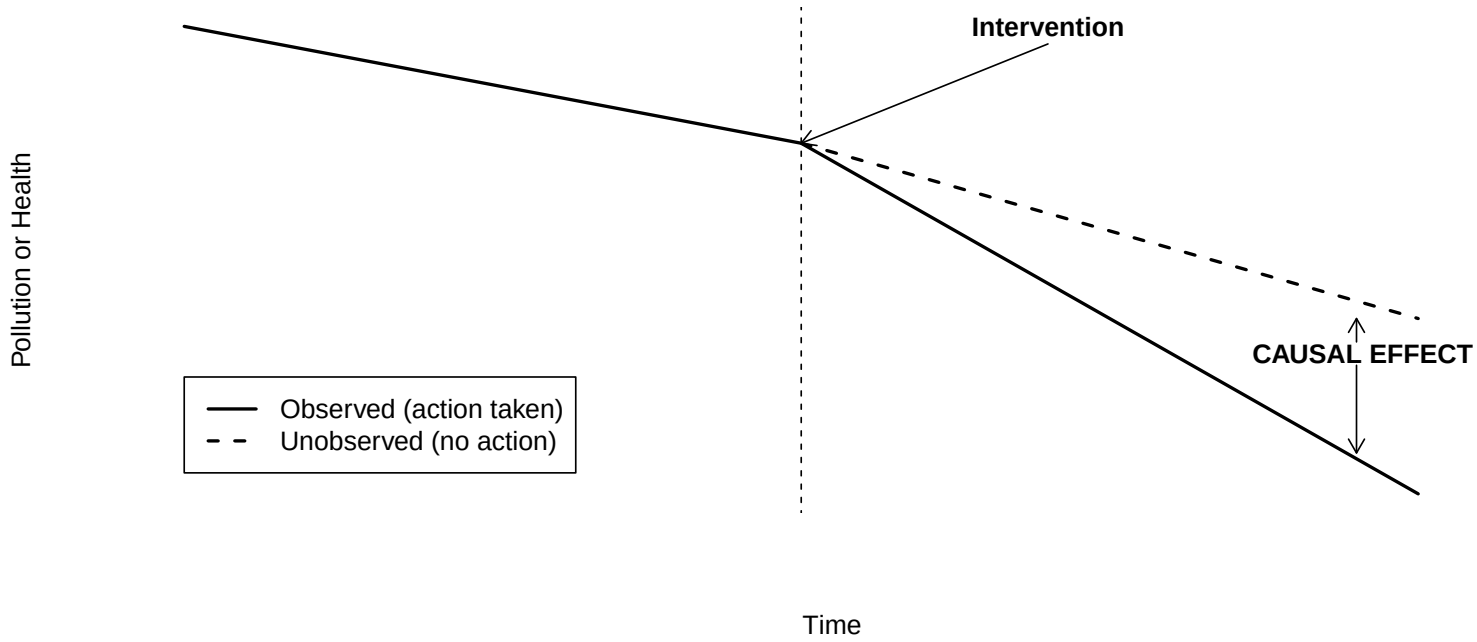
FIGURE 1-1. CLEAN AIR ACT SECTION 812 SCENARIOS: CONCEPTUAL SCHEMATIC



From EPA (2011) *The benefits and costs of the Clean Air Act from 1990 to 2020*

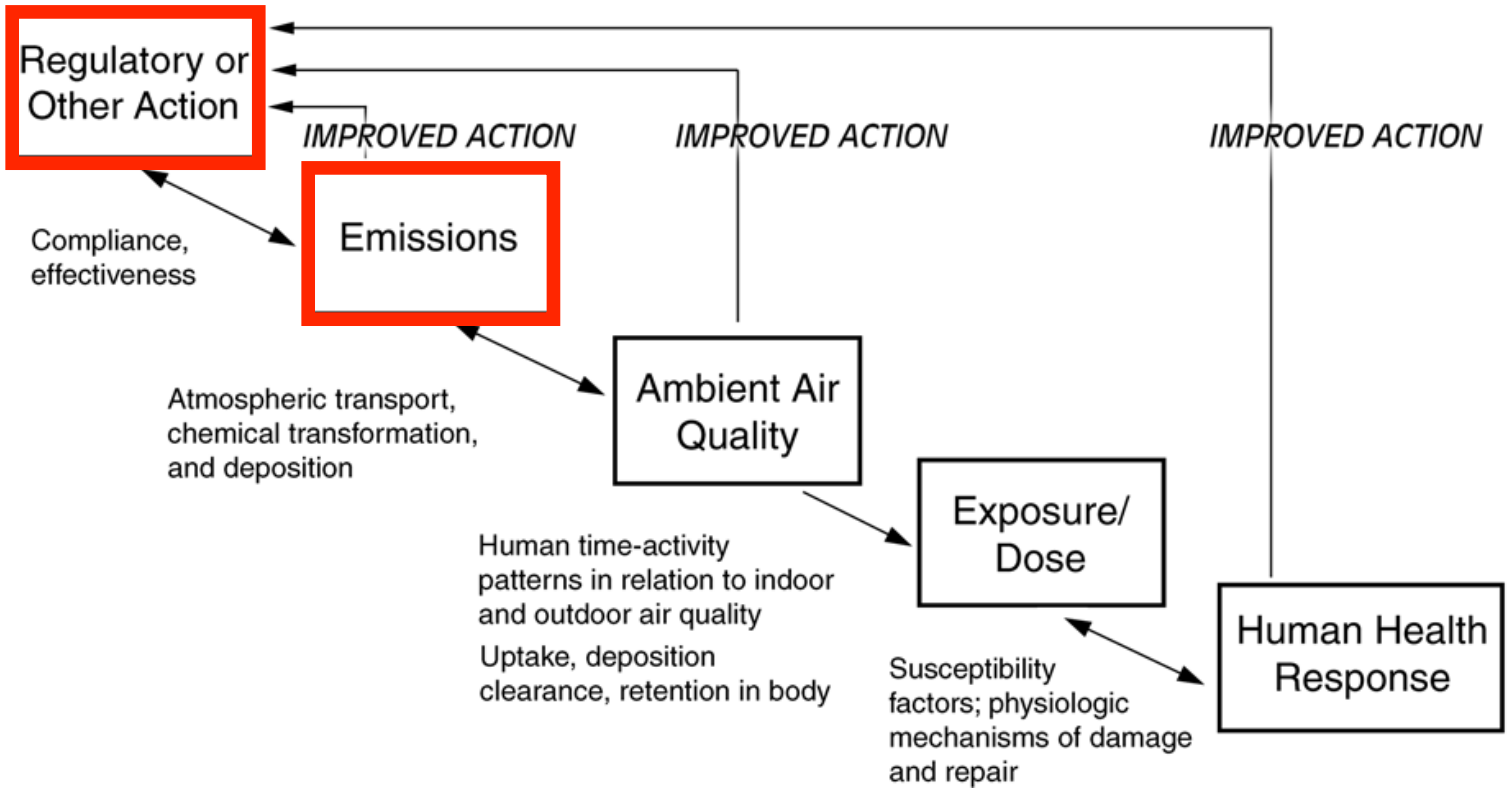
Temporal Stability?

probably not . . .



Long-Term, Regional Policy

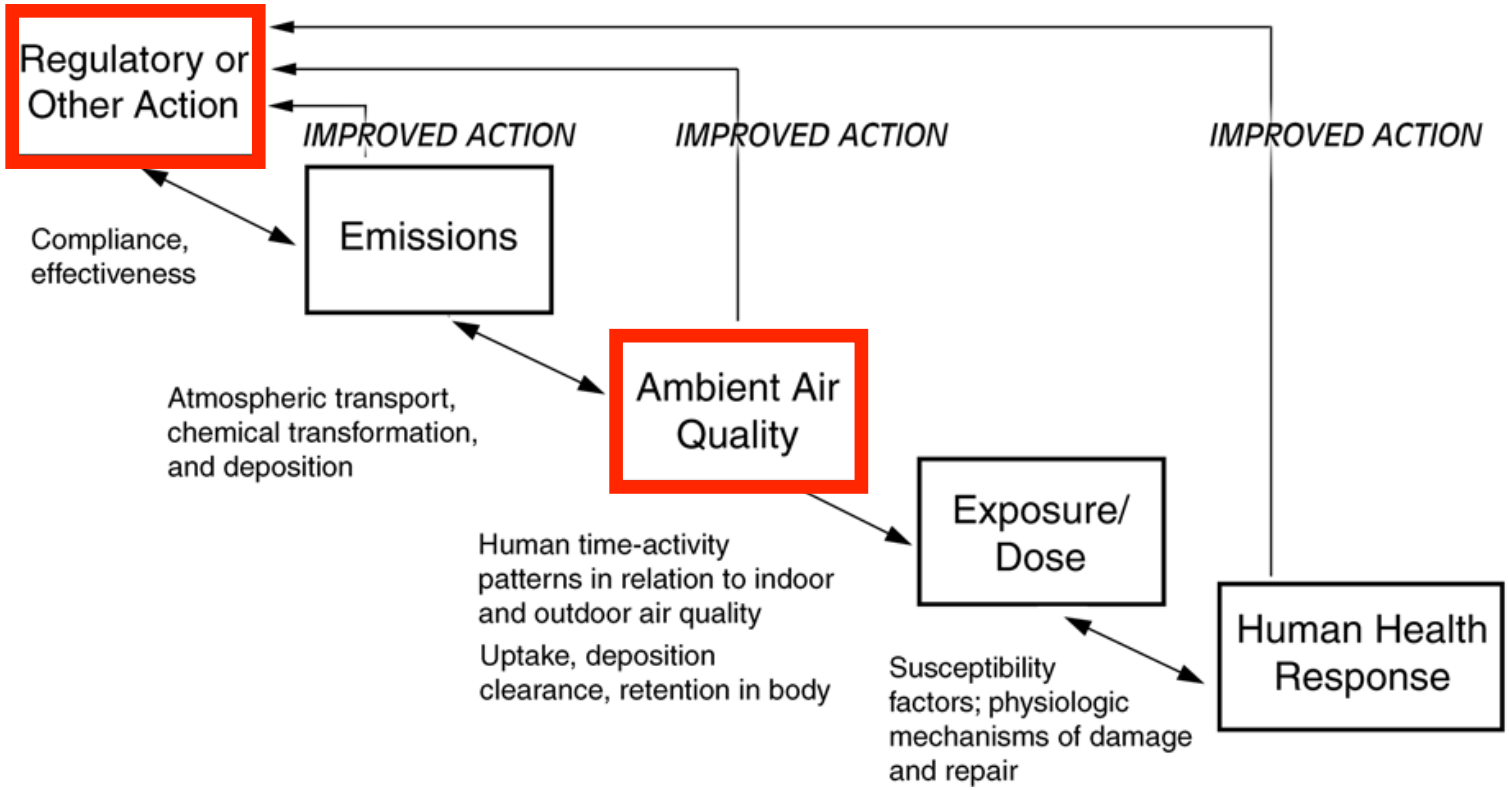
Think: Evaluating the Clean Air Act



What would **emissions** have been without the amendments?

Long-Term, Regional Policy

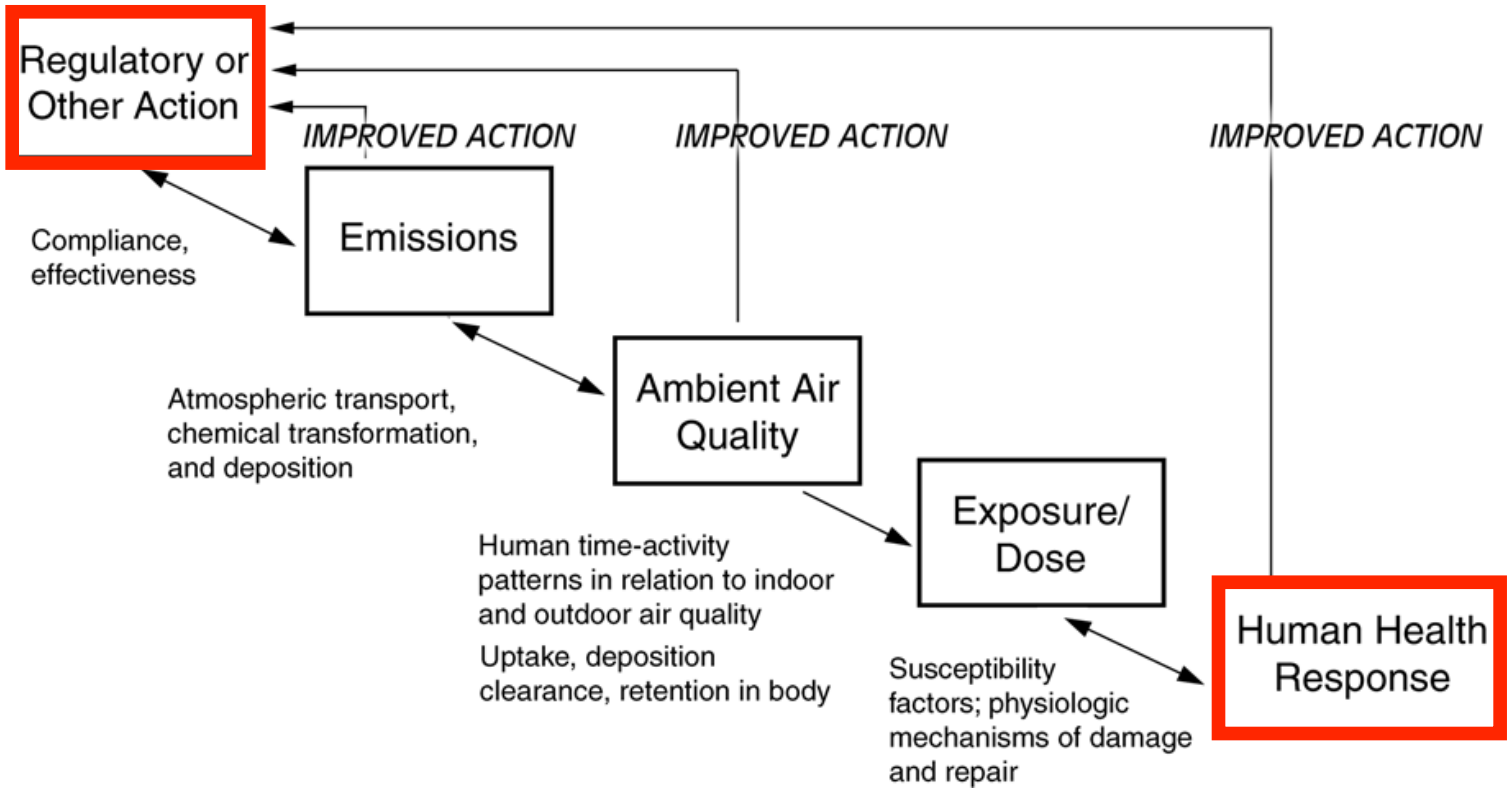
Think: Evaluating the Clean Air Act



What would **AQ** have been without the amendments?

Long-Term, Regional Policy

Think: Evaluating the Clean Air Act



What would **health** have been without the amendments?

Long-Term, Regional Policies Particularly Challenging

Parsing effects of the intervention from:

- Long-term improvements in health (e.g., due to improvements in medical care)
- Long-term trends in AQ
- Impacts of oncurrent policies
- Weather/climate patterns
- Economic changes
- . . .

Counterfactual scenario must reflect other changes that were *not* due to the policy

Methods

Use of Air Quality Models

The Role of Air Quality Models

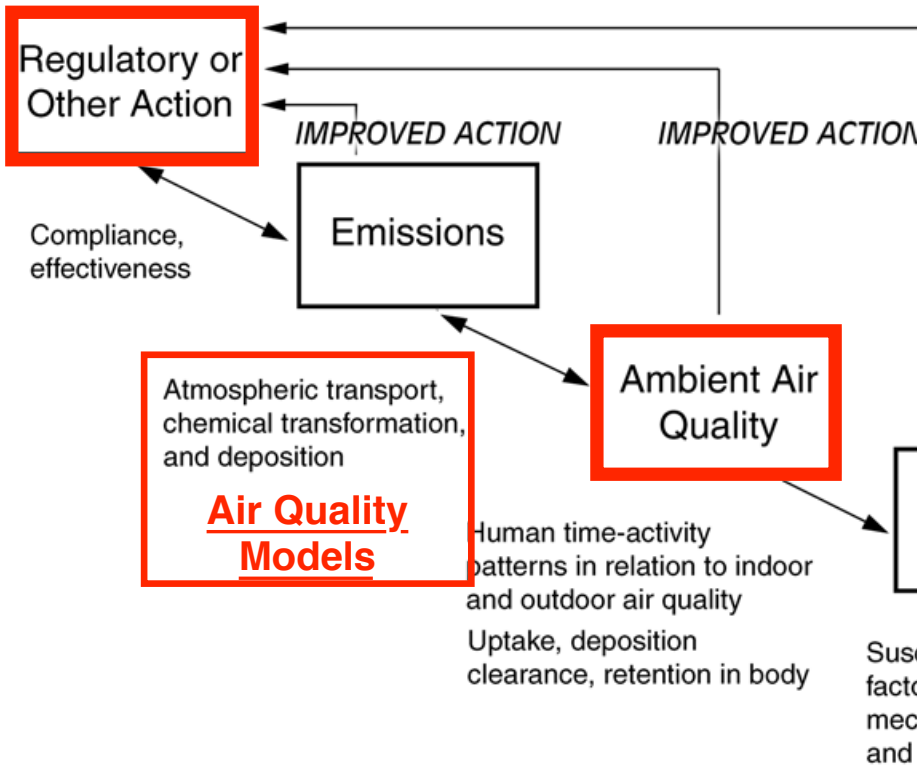
CMAQ, GEOS-Chem, etc.

The Intervention $\leftrightarrow$ AQ link is particularly complex

AQ Models leverage...

- Chemistry
- Physics
- Climate/weather
- Pollution transport
- Atmospheric science

...to deterministically predict various *observed* and *counterfactual* pollution scenarios



Accountability using AQ Models

E.g., as in EPA Cost-Benefits Analysis

1. AQ $\leftrightarrow$ Health Link

Use epidemiological studies to model:

- Question # 1
- "Health Effect" of any hypothetical shift in AQ

2. Intervention $\leftrightarrow$ AQ Link

Use CMAQ to model:

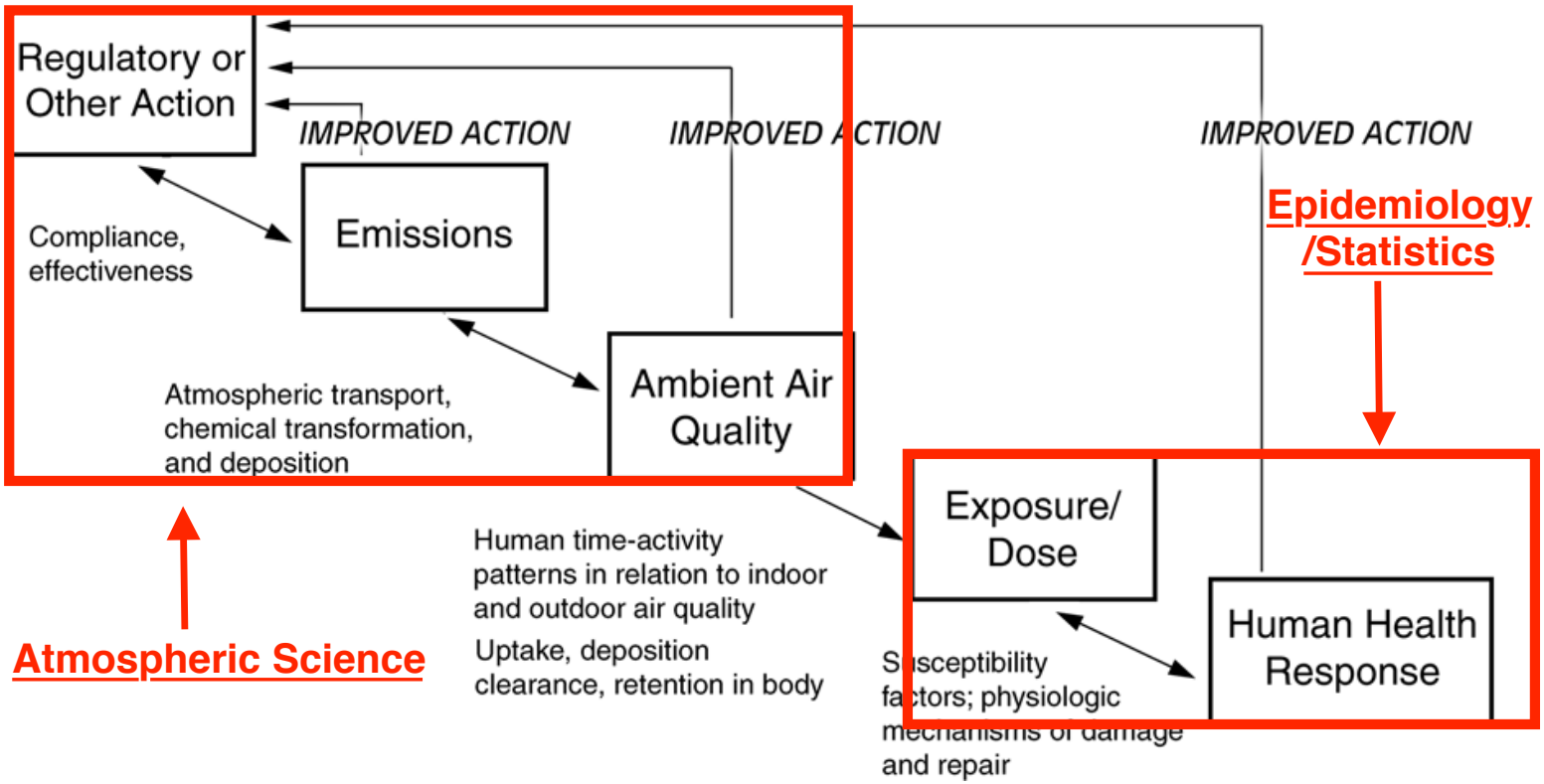
- Pollution under the observed regulatory scenario
- Counterfactual pollution without the 1990 Clean Air Act Amendments

$\Rightarrow$ Intervention effect on AQ

$$1 + 2 \Rightarrow \text{Health Impact of Policy}$$

Accountability using AQ Models

separates two fields



Notes on Combining AQ Models + C-R

Health impact is *indirectly* inferred by combining knowledge of air quality impacts with knowledge of C-R function:

- Prospective or retrospective $(+)$
- Leverages sophisticated account of chemistry/physics/atmospheric science $(+)$
- Relies on "literal" interpretation of C-R function $(-)$
  - Success hinges on causal interpretation of C-R function
- Hard to acknowledge co-benefits $(-)$
  - Including co-benefits would require knowledge of "multipollutant" C-R function
- Assumes the C-R relationship would persist amid the complex realities of actual regulatory implementation $(-)$

Methods

Use of Statistics

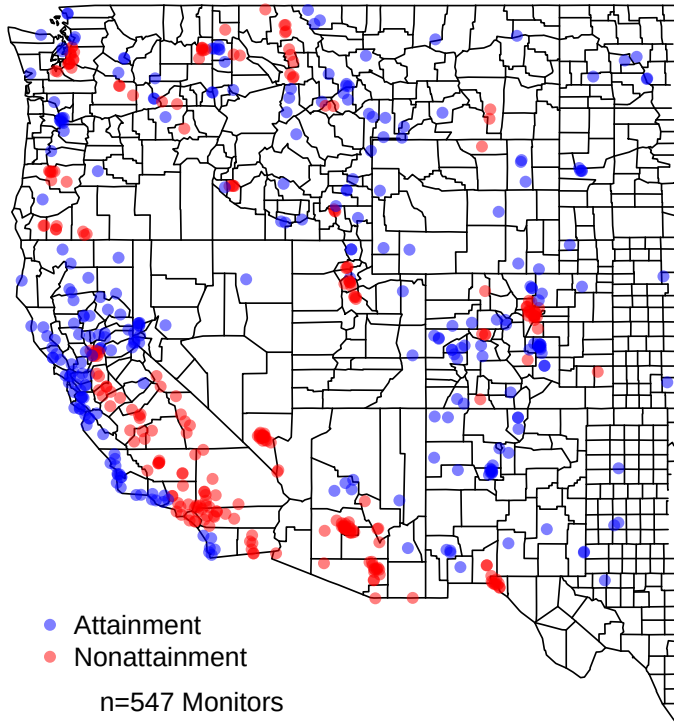
Observed Data instead of Modeled Predictions

- Direct accountability assessment can use observed data on interventions, emissions, air quality, and health outcomes
- Generally rely on statistical methods for causal inference
  - Difference-in-difference (-in difference) Analysis
  - "Quasi-randomized" policies
  - Propensity scores
  - Marginal structural models
  - Causal inference with interference

Accountability Using Observed Data and Statistics

Zigler et al. (2016) estimate the health impacts of enforcing designations of areas as "nonattainment" of the NAAQS for PM over a $\sim$ 10 year period

- View attainment areas as a "control group" for the nonattainment areas
- Use propensity scores + statistical models to compare outcomes in nonattainment and attainment areas
- Evaluate effects of nonattainemnt on AQ and health



Notes on Direct Evaluation with Observed Data/Statistics

- Don't necessarily rely on knowledge of intermediate steps in the chain $(+)$
- Don't need a perfect C-R function $(+)$
- Co-benefits/unexpected consequences can be "baked in" $(+)$
- Easy to evaluate multiple outcomes $(+)$
- Requires detailed observed data $(-)$
- "Ignores" physics/chemistry/atmospheric science $(-)$
- Hard to incorporate pollution transport $(-)$
- Often relies on opportunistic study designs $(-)$

Methods

The Role of Data

Different Disciplines, Different Data

1. "Data"

- Not *measurements* per se
- Modeled predictions (e.g., from AQ models)

2. Data

- Actual measurements of emissions, AQ, health, etc.

Many policy evaluations rely on (1), in part because (2) can sometimes struggle to capture relevant complexities

Available Data Not Always Used

From the EPA Report *The Benefits and Costs of the Clean Air Act from 1990 to 2020* (2011):

"Air pollutant emissions for...EGUs, were **estimated**...through an optimization procedure that considers costs of electricity generation, costs of pollution control, and external projections of electricity demand to forecast the fuel choice, pollution control method, and generation for each unit considered in the model."

Available Data Not Always Used

From the EPA Report *The Benefits and Costs of the Clean Air Act from 1990 to 2020* (2011):

"Air pollutant emissions for...EGUs, were **estimated**...through an optimization procedure that considers costs of electricity generation, costs of pollution control, and external projections of electricity demand to forecast the fuel choice, pollution control method, and generation for each unit considered in the model."

EPA Air Markets Program maintains **Continuous Emissions Monitors** that actually *measure* emissions from power plants!

Data Sources Constantly Improving

Increasingly able to capture complexity

- Emissions
  - Continuous emissions monitors for power plants
  - Remote sensing based emissions inventories
- Air Quality
  - Ambient monitoring data
  - Remote sensing measurements
  - Data "fusion"
- Health outcomes
  - Administrative data (e.g., hospital billing data)
  - Health registries

Actual observed measurements can increasingly capture the complexity of regulations, emissions, AQ, weather, etc.

Conclusions

Policy Implications

Increased Focus on Direct Policy Evaluation

- "Health Effects of Pollution" $\neq$ "Health Effects of Policies"
  - Different questions, different challenges, different methods
- Increased focus on *effectiveness* of specific actions
  - Complement evidence derived from C-R relationships
- Best available tools from a variety of scientific disciplines
  - Statistics $+$ Epidemiology $+$ Econometrics $+$ Atmospheric Science $+ \ldots$
  - Increasingly rich data sources
- Best possible evidence of the consequences of air quality policies

Thank You!

Acknowledgments:

- NIH R01ES026217
- Health Effects Institute 4953
- USEPA RD-83479801

This work's contents contents are solely the responsibility of the grantee and do not necessarily represent the official views of the USEPA. Further, USEPA does not endorse the purchase of any commercial products or services mentioned in the publication.