Impacts of transitioning to clean household energy

Evidence from policy reform in peri-urban Beijing

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Background

Prior work

- Measuring and monitoring health inequalities
- Analysis and decomposition of life expectancy gaps
- Evaluating the impact of policy interventions

Measurment and analysis of health inequalities

- Methodological development, software, applied analysis

Social inequalities in life expectancy

- Social group differences, time trends, decomposition

Impact of interventions and policies

THE CHANGING FACE OF EPIDEMIOLOGY

Editors' note*: This series addresses topics of interest to epidemiologists across a range of specialties. Commentaries start as invited talks at symposia organized by the Editors. This paper was presented at the Third North American Congress of Epidemiology held in Montreal in June 2011.*

Social Epidemiology

Questionable Answers and Answerable Questions

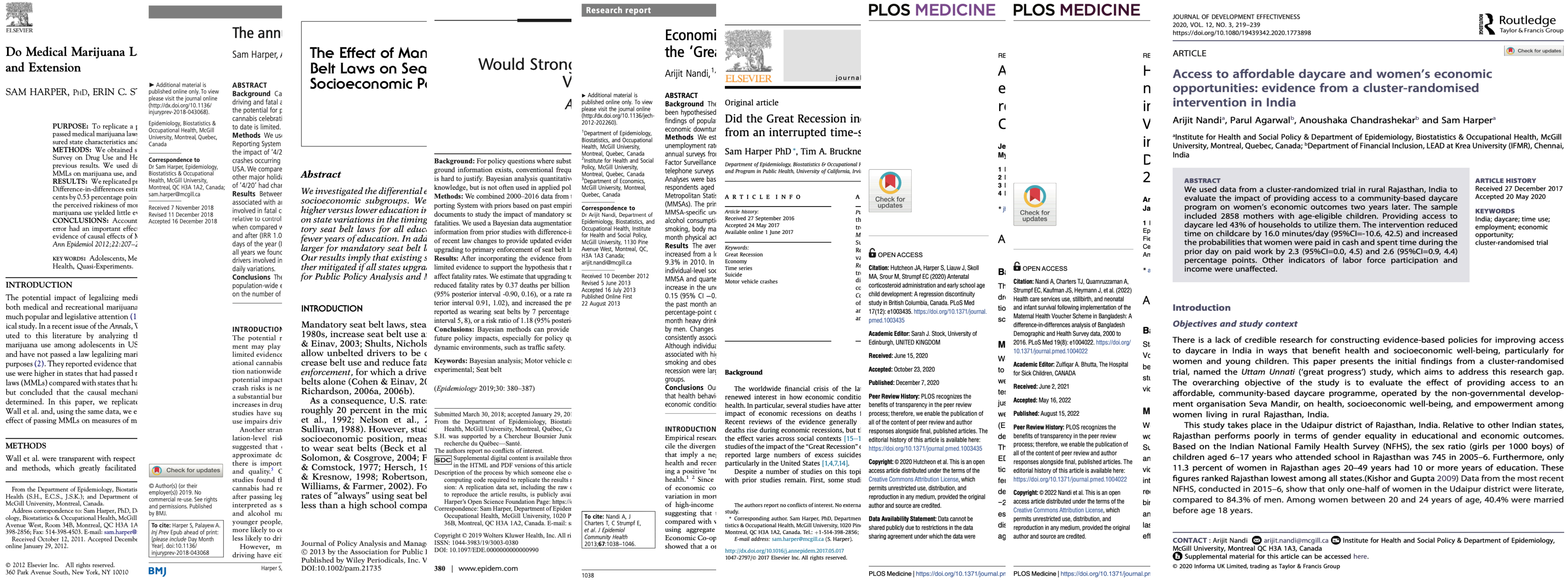
Sam Harper[a] *and Erin C. Strumpf*[a,b]

Social epidemiology encompasses the study of relationships between health and a broad range of social factors such as race, social class, gender, social policies, and so on. One could broadly partition the work of social epidemiology into surveillance (ie, descriptive relationships between social factors and health, tracking of health inequalities over time) and etiology (ie, causal effects of social exposures on health).[1] Many social epidemiologists believe these twin pursuits should ultimately serve to structure interventions aimed at reducing health-damaging social exposures or increasing exposure to social factors that enhance health.

Harper and Strumpf (2012)

Impact of interventions and policies

- Substance use, maternal / child health, social and economic policies



More at our 3PO website

Current projects

Early Childhood Education Policies and (

Photo: http://policynote.ca

(with Arijit Nandi, Emis Akbari, Jody Heymann, and Linda White)

This project aims to investigate how Early Childhood Education and
over time in the United States and how these policies affect childrer
health, and well-being.

The project's main objectives are to:

1. Create a free and publicly-available longitudinal database of sta
programmatic features, including those regulating access to ar
from 1995 to present;
2. Estimate the impact of specific state ECEC reforms on the deve
non-cognitive skills, health, and well-being, as well as heteroger
race/ethnicity, and socioeconomic position; and
3. Estimate the effect of children's participation in ECEC on the de
cognitive skills, health, and well-being, as well as heterogeneou
and socioeconomic position.

Examining the role of discrimination in re labor force participation in India

Photo: India Express

(with Arijit Nandi, Anoushaka Chandrashekar, Rosa Abraham, Nick K

The objective of this project in the longer term is to estimate the im
hiring behavior in India. Using an experimental "correspondence stu
applications from fictitious candidates for positions advertised in Ir
the magnitude of gender discrimination, measured by the gender di
varies based on the characteristics of the applicant (e.g., age, occup
time vs. full-time work, industry, number of employees). Additionally
gender discrimination in callbacks is greater for women of child-bea
school-aged child, depending on whether the prospective employer
stipulated by the 2017 Amendment to the Indian Maternity Benefit A

Beijing Houshold Energy Transitions [BHET]

Photo: The Straits Times

(with Jill Baumgartner)

Air pollution is a leading public health problem. Over 400 million Chinese homes burn coal to meet their indoor space heating needs, leading to high levels of air pollution and health impacts in adults and children. Coal burning in China also contributes to poor air quality and mercury contamination in Canada. This project will assess how transitioning away from coal and introducing new clean heating technology in China will impact the health and environment of people who live in homes impacted by policy changes.

Funding: Canadian Institutes for Health Research

Impacts of a Clean Energy Transition Policy

Interdisciplinary Team

McGill University

- Sam Harper (Epidemiology)
- Jill Baumgartner (Epidemiology)
- Brian Robinson (Geography)
- Chris Barrington-Leigh (Economics)
- Koren Mann (Toxicology)
- Arijit Nandi (Epidemiology)
- Robert Platt (Biostatistics)

Colorado State University

- Ellison Carter (Engineering)
- Xiaoying Li (Engineering)

Chinese Academy of Sciences

- Yuanxun Zhang (Air Chemistry)
- Zhongjie Fan (Cardiology)

Peking University

- Shu Tao (Environmental Science)
- Yaojie Li (project coordinator)

China National Center for Cardiovascular Disease

- Liancheng Zhao (CVD epidemiology)

Knowledge Users

- Barry Jessiman (Health Canada)
- Alison Dickson (Environ & Climate Change Canada)
- Iris Jin, Asia Pacific Foundation of Canada
- Richard Fuller, Pure Earth Foundation

Funders

- Canadian Institutes of Health Research
- Health Effects Institute

Why Did We Start?

The role of coal in China

~ 30% of global emissions

Still dominated by coal

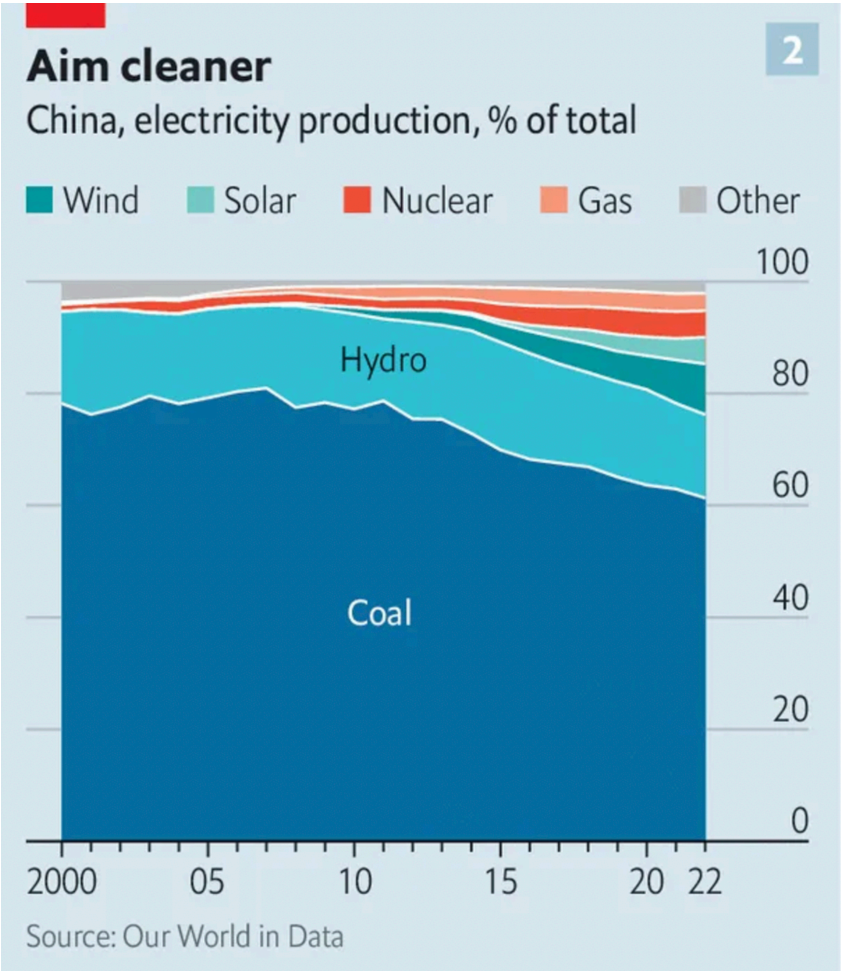
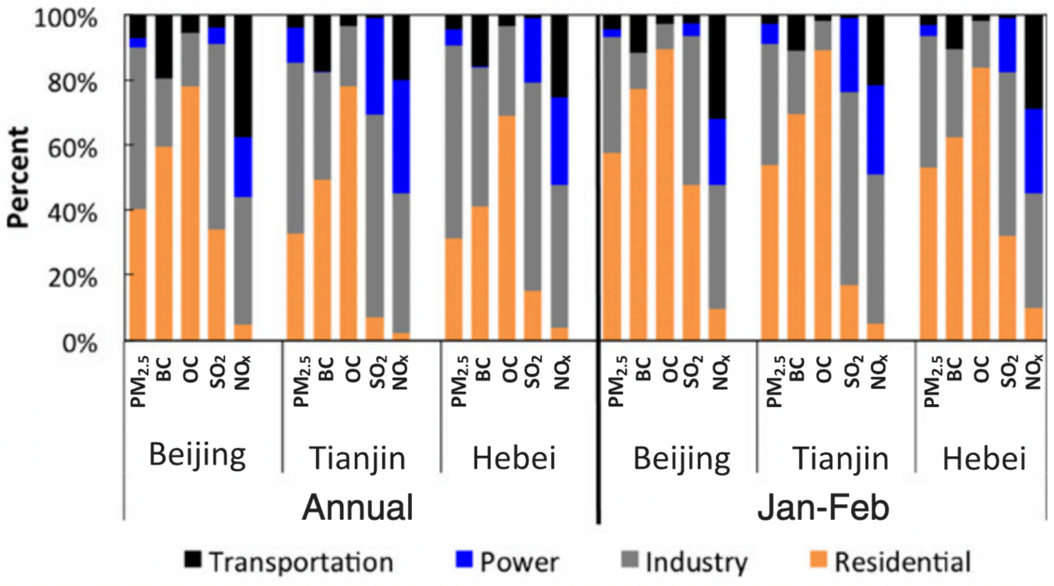


Image credits: The Economist

Residential coal burning in China



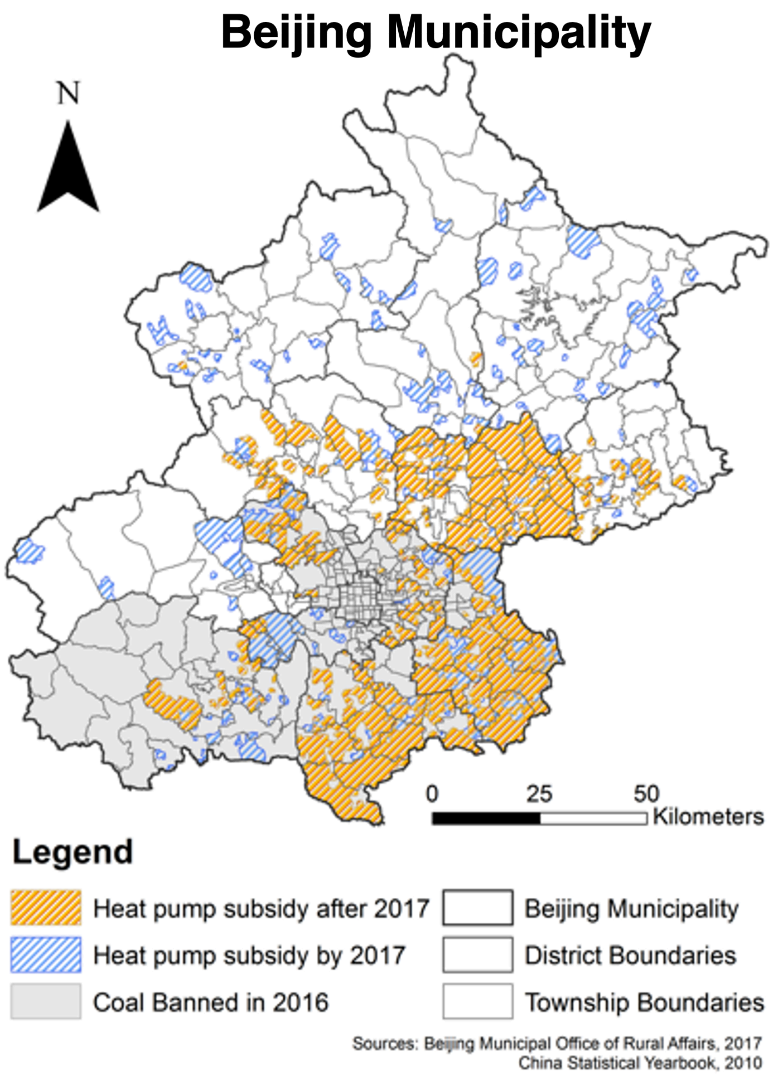
- Coal contains fluorine, arsenic, lead, selenium and mercury, which are not destroyed by combustion;
- Technical constraints make it difficult to burn coal cleanly in households;

- Residential coal burning makes a substantial contribution to emissions
- Particularly in winter months

Liu et al. (2016)

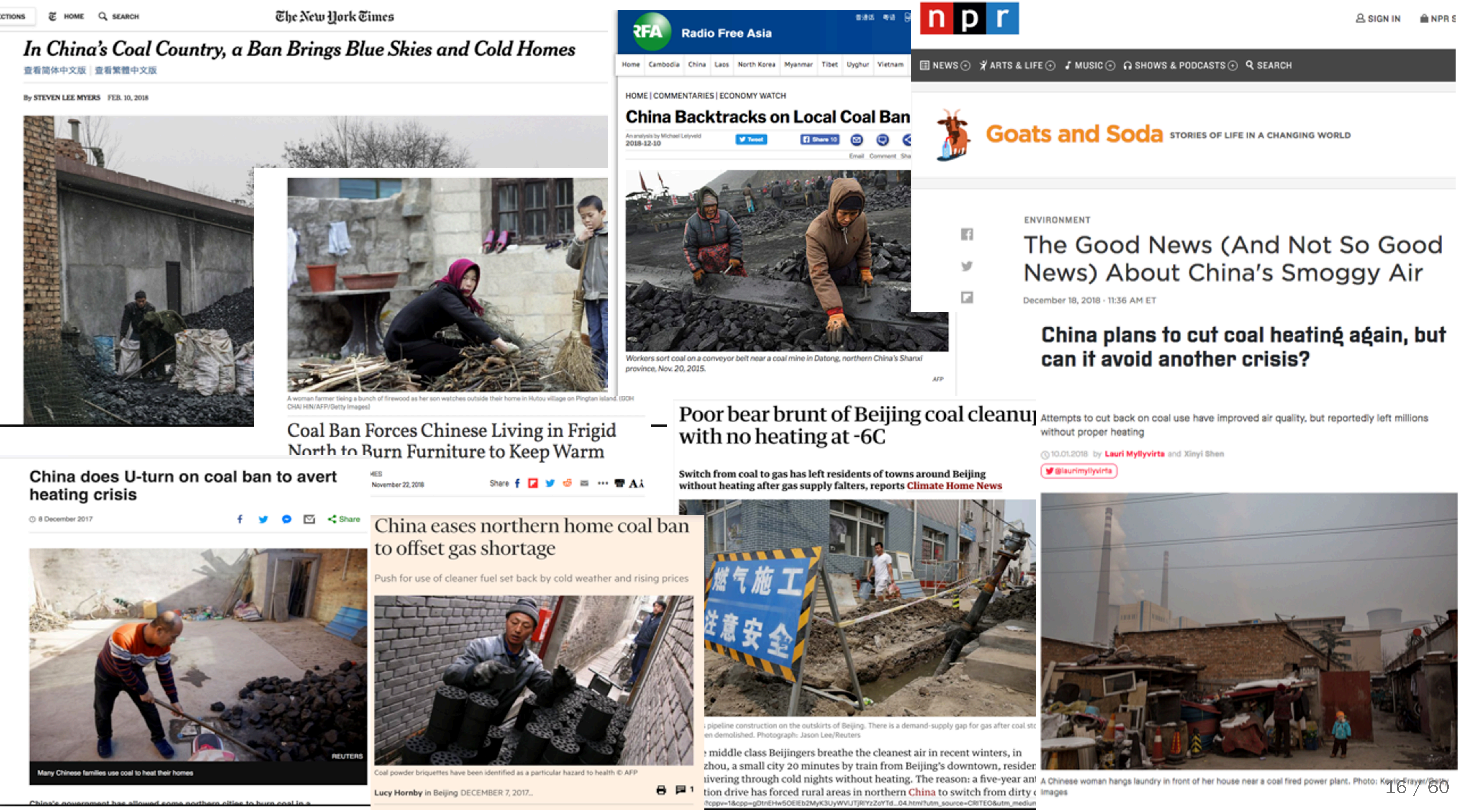
Policy Context

- Beijing designated “coal restricted areas”
- Government subsidized electric or gas-powered heat pumps (80% of $4,500 cost)
- 2017: required 1.5 million people to halt coal use (scaled to >2 million by ambitious local officials)
- Stepped implementation from 2017-2021 in Beijing and northern China (63 million homes)

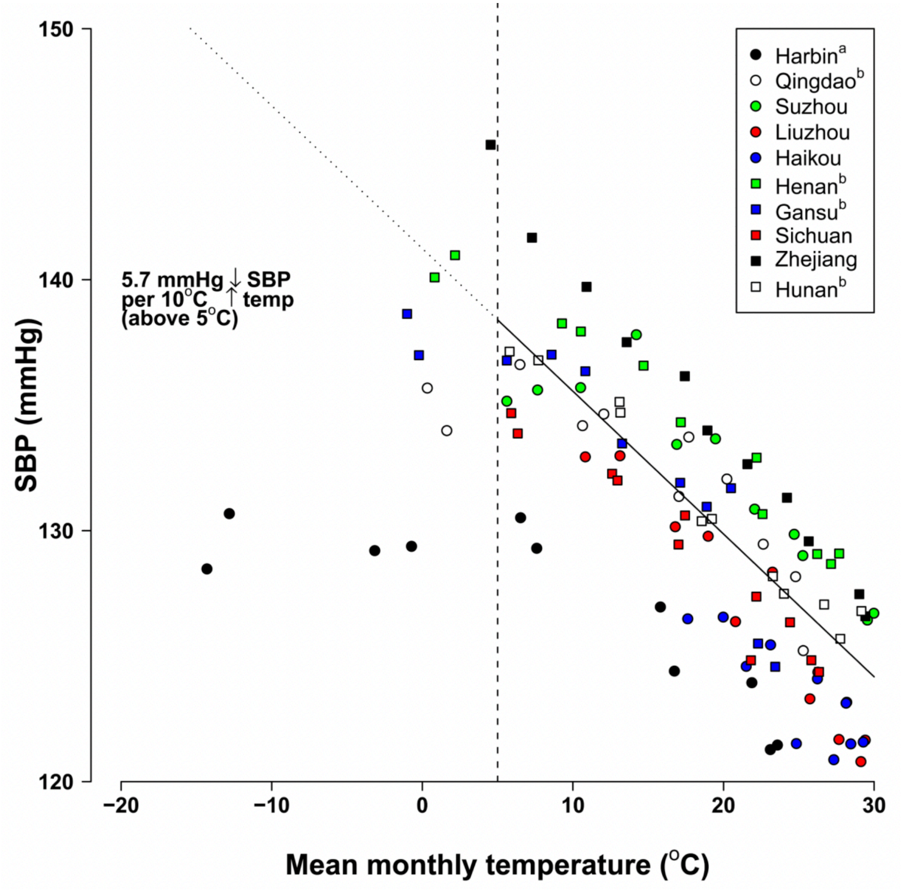


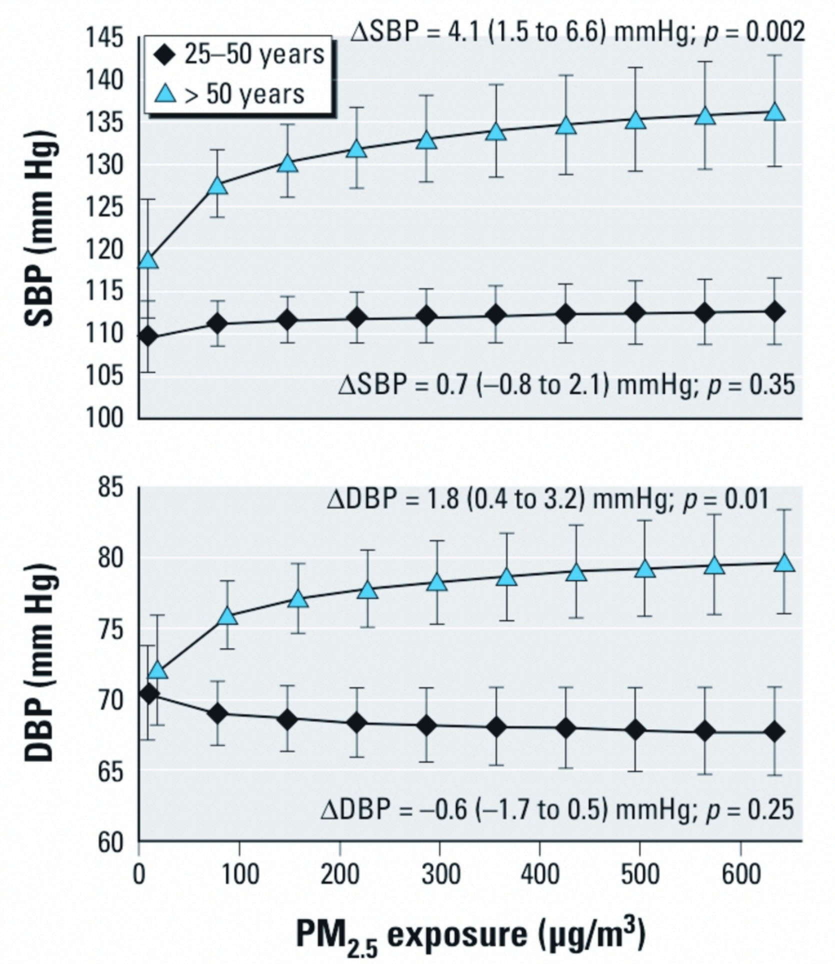
“Coal to Clean Energy Program”

- Village-level intervention.
- Subsidized purchase of heat pump; electricity subsidized regionally.
- Remove coal stoves.
- Retrofit existing homes or build new homes in the village.


The New York Times
In China's Coal Country, a Ban Brings Blue Skies and Cold Homes
查看简体中文版 | 查看繁體中文版
By STEVEN LEE MYERS FEB. 10, 2018
A woman farmer tieing a bunch of firewood as her son watches outside their home in Hutou village on Pingtan island. (GOH CHAI HIN/AFP/Getty Images)
Coal Ban Forces Chinese Living in Frigid North to Burn Furniture to Keep Warm
Radio Free Asia
Home Cambodia China Laos North Korea Myanmar Tibet Uyghur Vietnam
HOME | COMMENTARIES | ECONOMY WATCH
China Backtracks on Local Coal Ban
An analysis by Michael Lelyveld
2018-12-10
Workers sort coal on a conveyor belt near a coal mine in Datong, northern China's Shanxi province, Nov. 20, 2015.
AFP
npr
NEWS ARTS & LIFE MUSIC SHOWS & PODCASTS SEARCH
SIGN IN
Goats and Soda STORIES OF LIFE IN A CHANGING WORLD
ENVIRONMENT
The Good News (And Not So Good News) About China's Smoggy Air
December 18, 2018 · 11:36 AM ET
China plans to cut coal heating again, but can it avoid another crisis?
Attempts to cut back on coal use have improved air quality, but reportedly left millions without proper heating
10.01.2018 by Lauri Myllyvirta and Xinyi Shen
@laurimyllyvirta
A Chinese woman hangs laundry in front of her house near a coal fired power plant. Photo: Kevin Frayer/Getty Images
China does U-turn on coal ban to avert heating crisis
8 December 2017
Share
REUTERS
Many Chinese families use coal to heat their homes
November 22, 2018
Share
China eases northern home coal ban to offset gas shortage
Push for use of cleaner fuel set back by cold weather and rising prices
Coal powder briquettes have been identified as a particular hazard to health © AFP
Lucy Hornby in Beijing DECEMBER 7, 2017
Poor bear brunt of Beijing coal cleanup with no heating at -6C
Switch from coal to gas has left residents of towns around Beijing without heating after gas supply falters, reports Climate Home News
燃气施工
注意安全
pipeline construction on the outskirts of Beijing. There is a demand-supply gap for gas after coal st
en demolished. Photograph: Jason Lee/Reuters
middle class Beijingers breathe the cleanest air in recent winters, in
zhou, a small city 20 minutes by train from Beijing's downtown, residen
ivering through cold nights without heating. The reason: a five-year an
tion drive has forced rural areas in northern China to switch from dirty

Low indoor temps and higher $PM_{2.5}$ increase BP





Images: Lewington et al. (2012), Baumgartner et al. (2011). Also see Sternbach et al. (2022)

Research Gaps

- Most prior work only on cookstoves
- Several RCTs
- Mixed evidence on air pollution
- Challenges with uptake
- Multiple sources (e.g., stove-stacking)
- Unclear whether possible to scale-up
- Weaker and mixed evidence on health impacts, even when HAP reduced

AMERICAN THORACIC SOCIETY DOCUMENTS

Household Air Pollution Interventions to Improve Health in Low- and Middle-Income Countries

An Official American Thoracic Society Research Statement

Peggy S. Lai*, Nicholas L. Lam*, Bill Gallery, Alison G. Lee, Heather Adair-Rohani, Donee Alexander, Kalpana Balakrishnan, Iwona Bisaga, Zoe A. Chafe, Thomas Clasen, Anaité Díaz-Artiga, Andrew Grieshop, Kat Harrison, Stella M. Hartinger, Darby Jack, Seyram Kaali, Melissa Lydston, Kevin M. Mortimer, Laura Nicolaou, Esther Obonyo, Gabriel Okello, Christopher Olopade, Ajay Pillarisetti, Alisha Noella Pinto, Joshua P. Rosenthal‡, Neil Schluger, Xiaoming Shi, Claudia Thompson‡, Lisa M. Thompson, John Volckens, Kendra N. Williams, John Balmes§, William Checkley§, and Obianuju B. Ozoh§; on behalf of the American Thoracic Society Assembly on Environmental, Occupational, and Population Health

THIS OFFICIAL RESEARCH STATEMENT OF THE AMERICAN THORACIC SOCIETY WAS APPROVED FEBRUARY 2024

> Household energy solutions need to go beyond cooking interventions alone; there are multiple sources that contribute to HAP

Lai et al. (2024)

Overall Study Objectives

Aim 1. 👉

Estimate the total effect of the intervention.

Aim 2. ❌

Estimate the contribution of changes in the chemical composition of $PM_{2.5}$ to the overall effect on health outcomes.

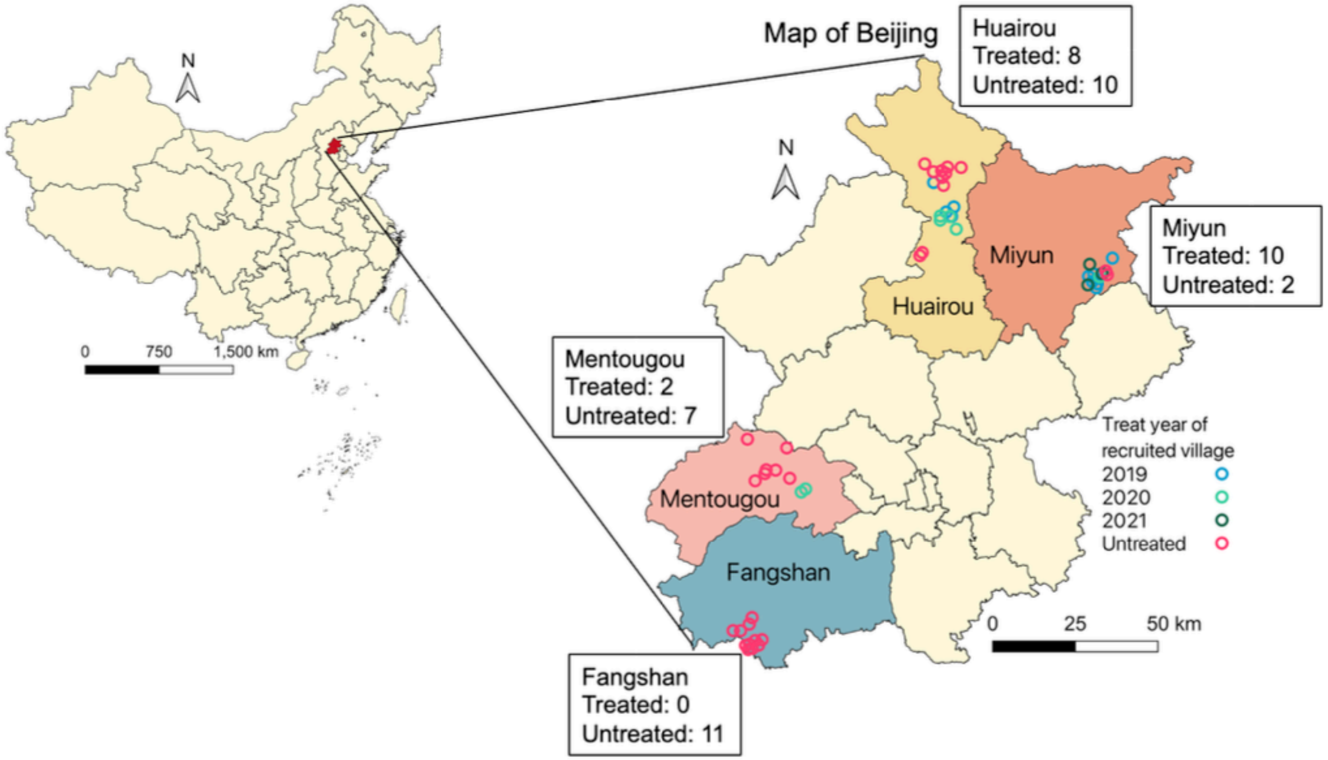
Aim 3. 👉

Examine alternative pathways and mechanisms that may contribute to the intervention's impact.

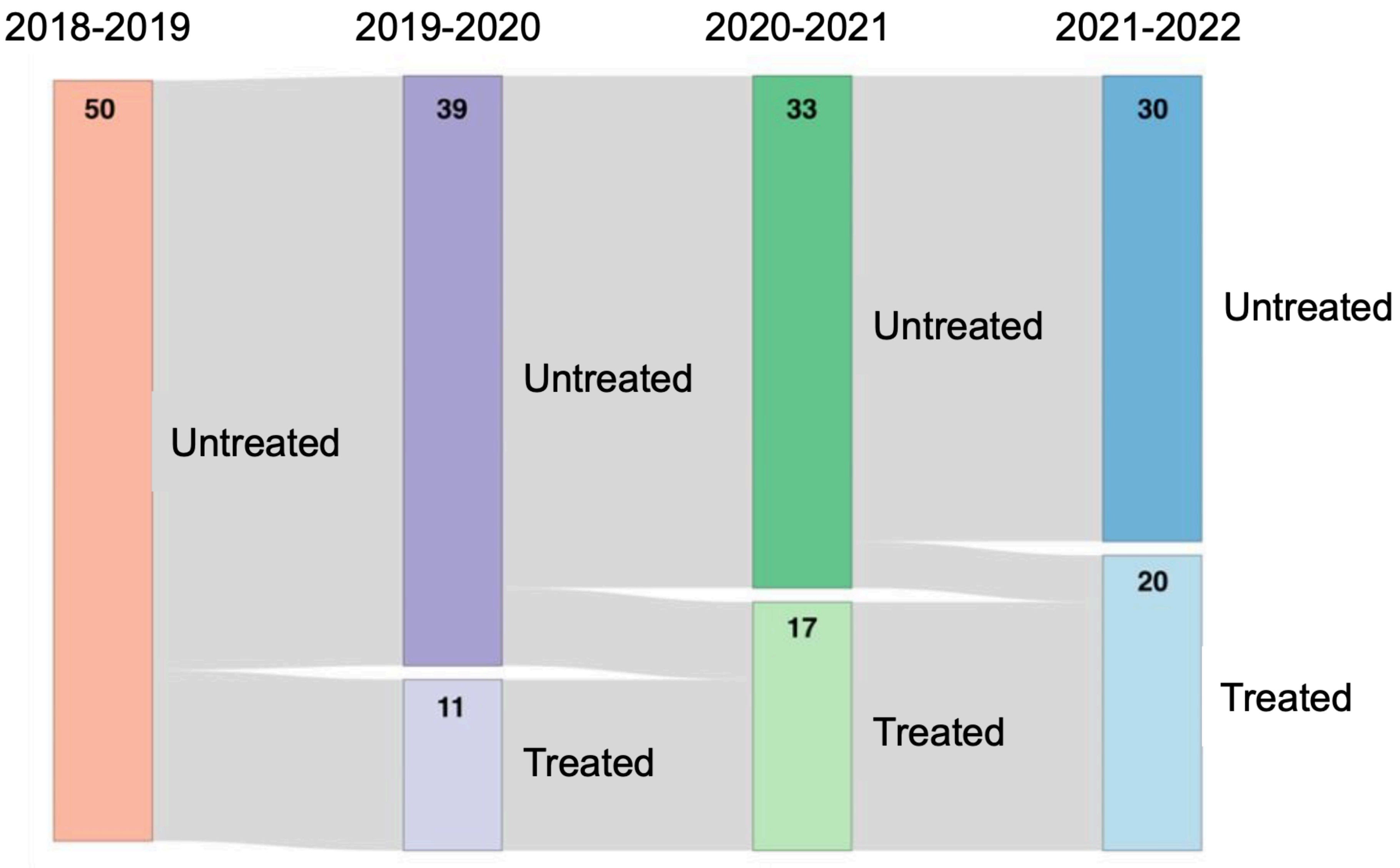
What Did We Do?

Village sampling

- Identified 50 villages not yet exposed to policy
- Randomly selected ~20 homes in each village
- Enrolled 1 individual per home



Timing of study village treatment by the policy



Data Collection Overview

Year 1 (2018-19)
- Household questionnaire
- Health measurements
- Indoor temperature
- Indoor air pollution

Year 2 (2019-20)
- Household questionnaire
- Health measurements
- Indoor temperature
- Indoor air pollution
- Heating device use

Year 3 (2020-21)
- Indoor temperature
- Indoor air pollution
- Heating device use

Year 4 (2021-22)
- Household questionnaire
- Health measurements
- Indoor temperature
- Indoor air pollution
- Heating device use

	Year 1	Year 2	Year 3	Year 4
Participants:	1,003	1,110	---	1,028
Households:	977	1,055	530	1,012
Villages:	50	50	41	50

Staff training

Household visits

Clinic visits

Measurements

Village

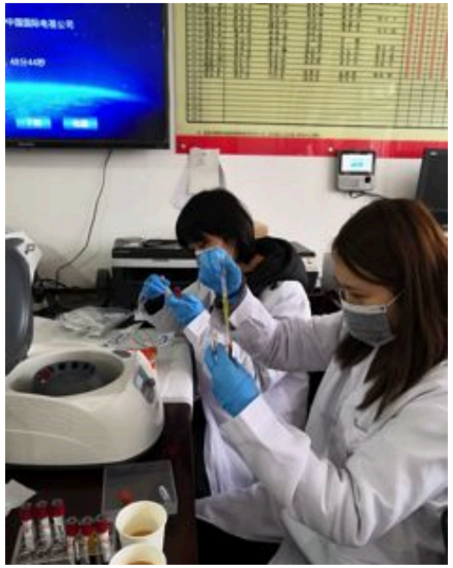
- Outdoor air pollution (1-2 months per season)
- Information on village policies/programs

Household

- Questionnaire to assess energy patterns and related expenditures
- Indoor air temperature (~75% of homes for 2+ winter months)
- Electricity use based on meters

Individual

- Questionnaires on health status, behaviors, conditions, and medication use
- Exposures to $PM_{2.5}$ and black carbon (50% of participants)
- Health measurements (BP, self-reported respiratory symptoms, blood inflammatory and oxidative stress markers (~75%), grip strength (~75%), airway inflammation via exhaled NO (~25%)



Blood pressure measurement

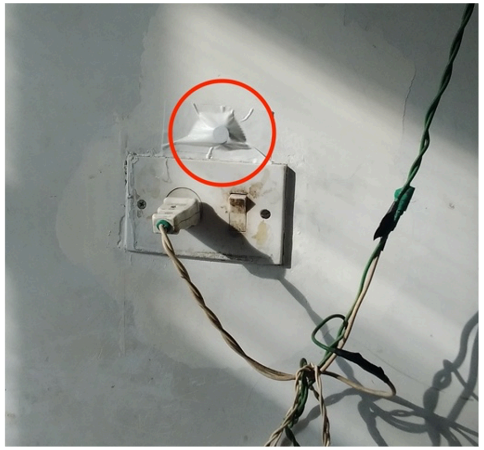
- Automated oscillometric device.
- Calibrated by manufacturer before Years 1 and 4.

- Home BP measurement by trained staff.
- Measured blood pressure 3 to 5 times on participants supported right arm, after 5 mins of quiet, seated rest.
- Mean of final 2 measurements used in analysis.

Indoor temperature

- Measured indoor temperature in the 5-min before BP.
- Long-term measurement in a subsample of households with sensor taped to household wall.
- Thermochron iButton or LabJack Digit-THL sensors.
- Interior wall of most commonly used room.
- 1.5m height (~ participant height).
- Measured 5-12 months
- 125-min sampling interval.






Indoor air pollution ($PM_{2.5}$)

1. Long-term measurement with real-time sensors.
   - 6 households per village.
   - Run with standard measurements (BAM/TOEM) pre- and post-data collection, each year.
   - Measured 5-mo., 1-min sampling interval
2. 24h measurement with filter-based instrument.
   - 3 households per village.
   - Accepted (gold-standard) measurement.
   - Used to calibrate real-time measurements.

Basic idea for mediation study

To understand the pathways, mechanisms, and intermediates through which a treatment affects an outcome.

How much of the policy effect is through:

- Reduced exposure to $PM_{2.5}$
- Other pathways (indoor temperature, behavioral changes)
- Consider multiple mediators

First part of mediation: total effect

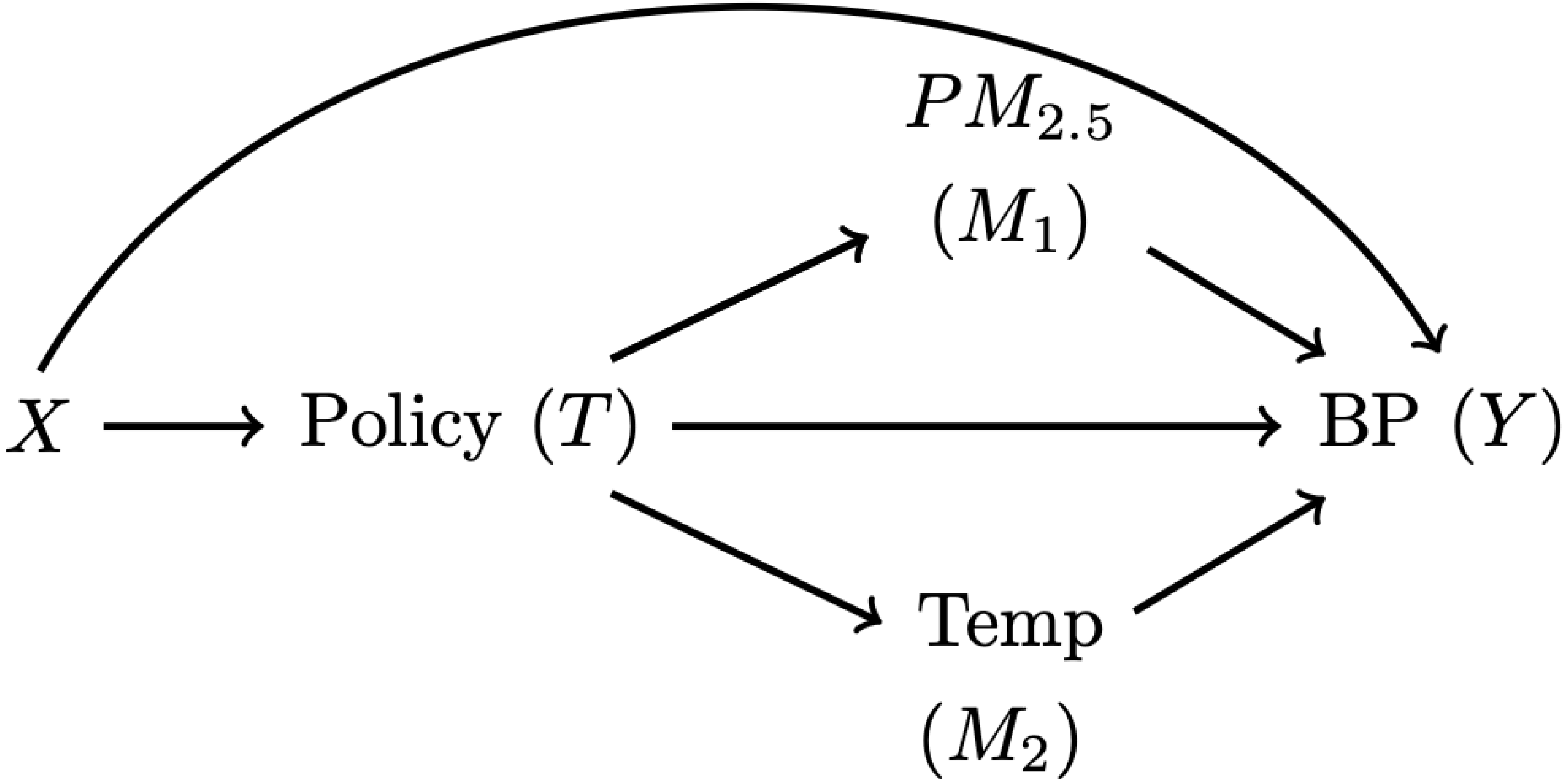
Step 1: Estimate the total effect of T.

$$\begin{tikzcd} X \arrow[r] \arrow[rr, bend left] & \text{Policy } (T) \arrow[r] & \text{BP } (Y) \end{tikzcd}$$

Second part of mediation: decomposition

Basic idea: understand pathways of effects

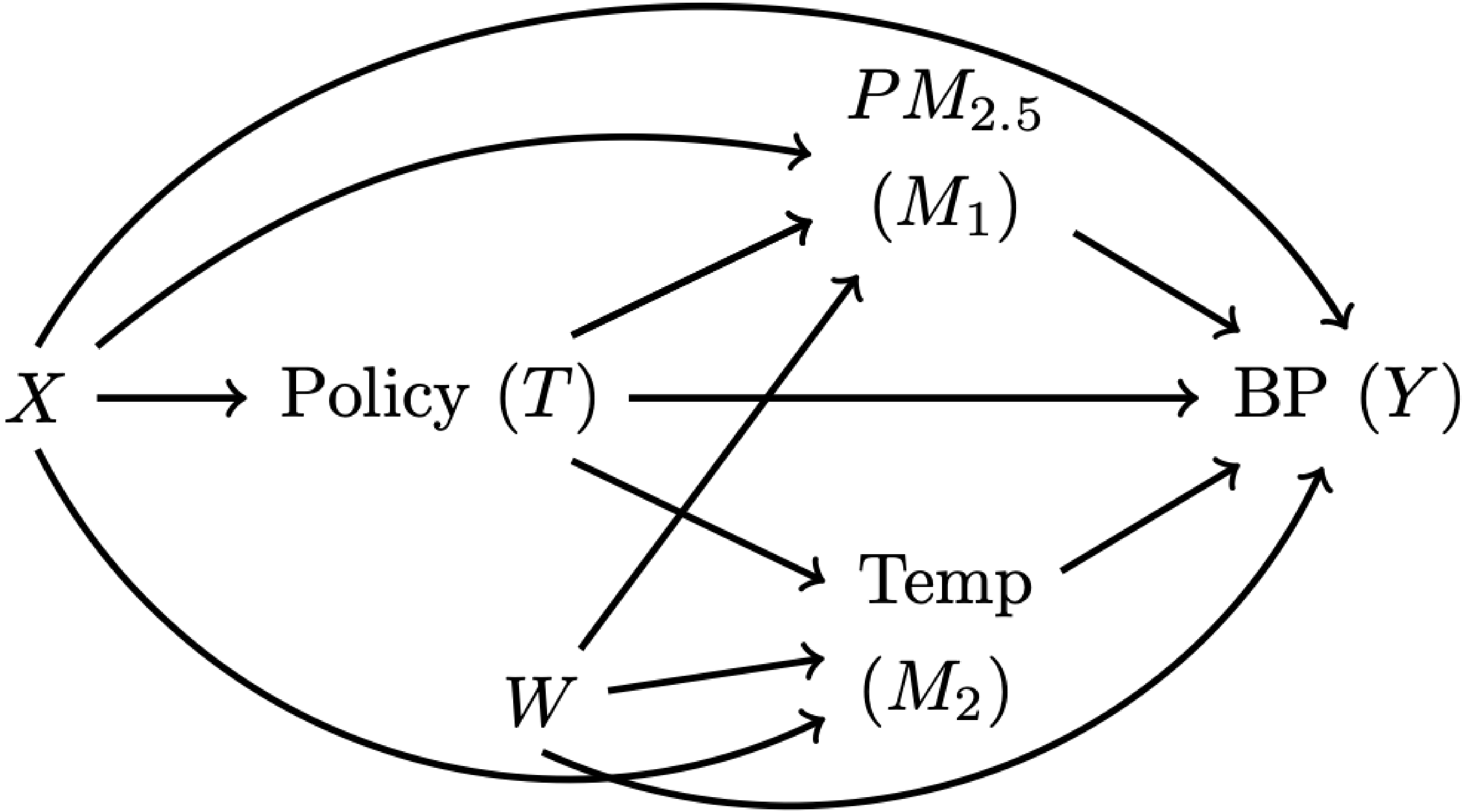
Step 2: Estimate how much of the total effect is due to $PM_{2.5}$ vs. other pathways?



Second part of mediation: decomposition

Basic idea: understand pathways of effects

Step 2: Estimate how much of the total effect is due to $PM_{2.5}$ vs. other pathways?



Quantities of interest

$$\begin{tikzcd} X \arrow[r] \arrow[rr, bend left] & \text{Policy } (T) \arrow[r, blue] & \text{BP } (Y) \end{tikzcd}$$

Total effect:

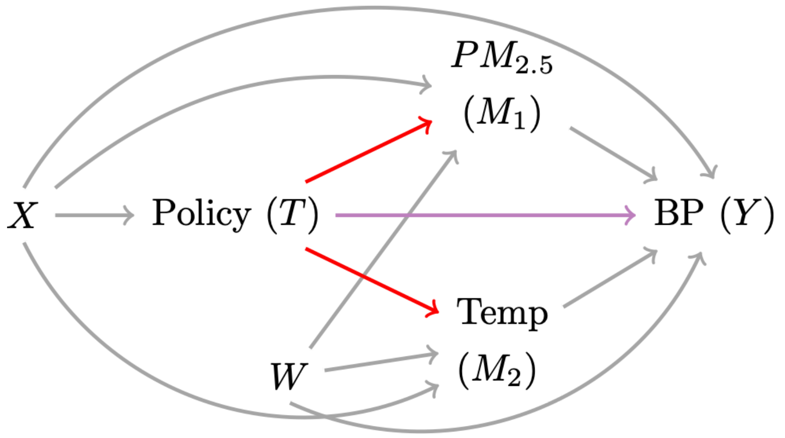
$$E[Y|T, X] = \beta_0 + \beta_1 T + \beta_2 X$$

This equation estimates the total effect of the ban:

$$TE = \beta_1(T^* - T)$$

where T^* is exposure to ban and T is no exposure.

Mediation model



Estimate two regressions:

1. Treatment on mediator:

$$E[M|T,X] = \beta_0 + \beta_1 T + \beta_2 X$$

2. Treatment and mediator on outcome:

$$E[Y|T,X,M] = \theta_0 + \theta_1 T + \theta_2 M + \theta_3 TM + \theta_4 X + \theta_5 W$$

Second equation estimates the “Controlled Direct Effect”:

$$CDE = \theta_1 + \theta_3 TM$$

See VanderWeele (2015). Other quantities include the “Natural Direct Effect” ($\theta_1 + \theta_3(\beta_0 + \beta_1 + \beta_2)$) and the “Natural Indirect Effect” ($\theta_2\beta_1 + \theta_3\beta_1$)]

What the hell is the CDE?

Interpretation

This effect is the contrast between the counterfactual outcome if the individual were exposed at $T = t$ *and the counterfactual outcome if the same individual were exposed at* $T = t*$*, with the mediator set to a fixed level* $M = m$.

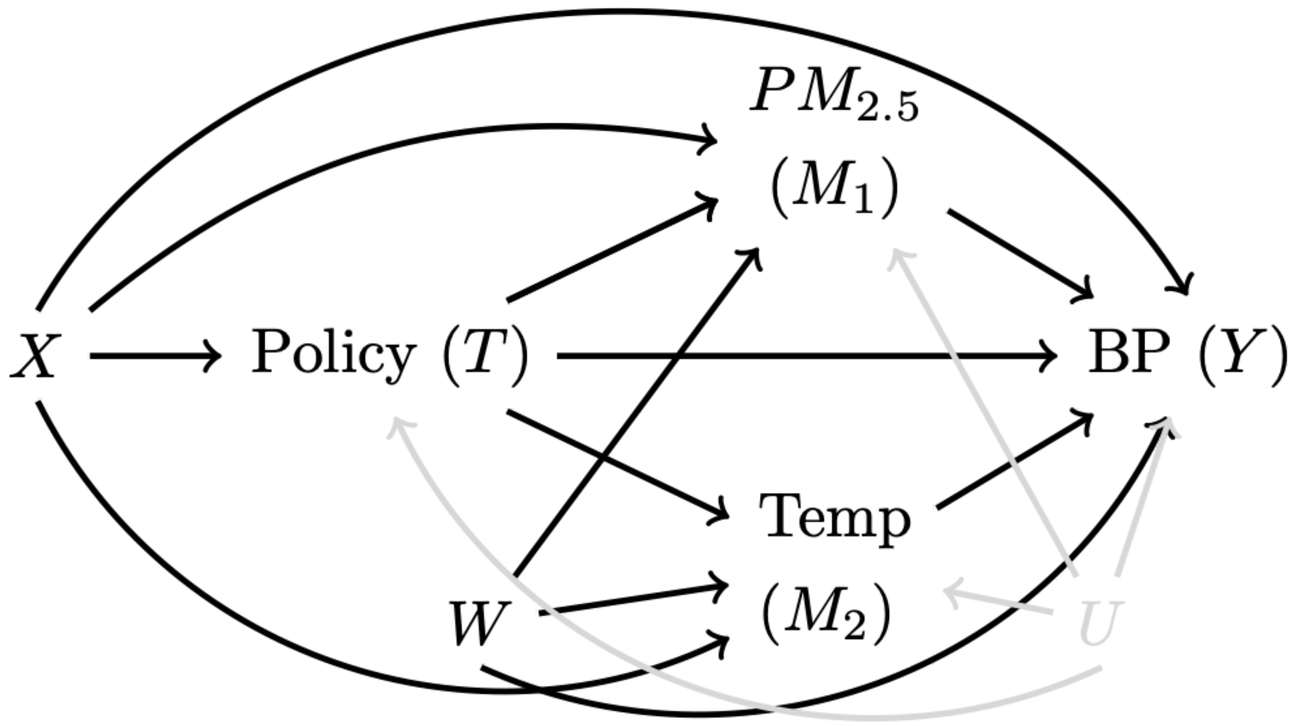
English:

"How much would blood pressure change if the policy were implemented and we held $PM_{2.5}$ *fixed at* m *?"*

Key assumptions

Assumptions for valid CDE:

- No confounding of the total effect.
- No confounding of the mediator-outcome effect.

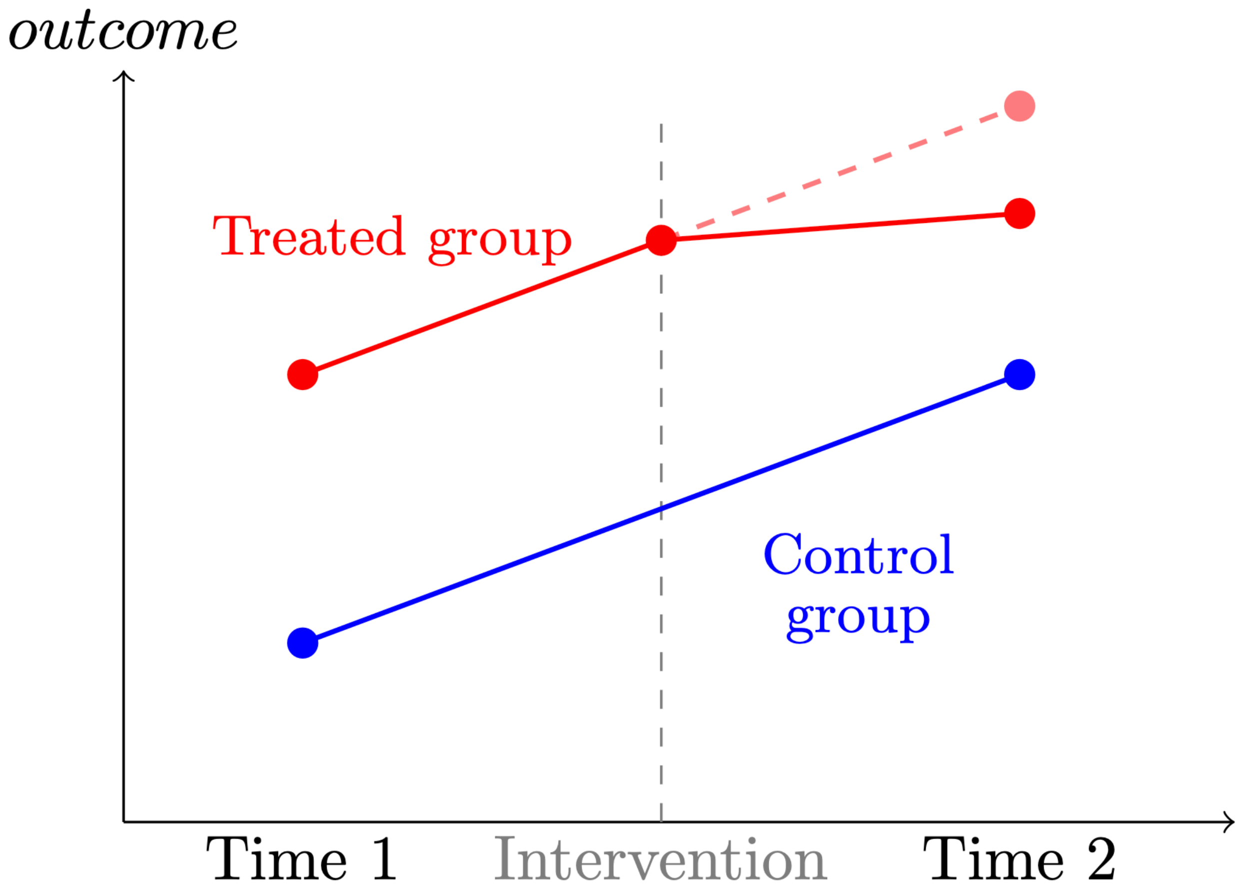


Basic Design: Difference-in-Differences

Need a *counterfactual* for treated group.

Challenges:

- Group differences
- Time trends
- Time-varying confounders
- Staggered implementation



Challenges with staggered adoption

- Using earlier treated groups as controls only 'works' under homogeneity.
- Early treatment effects get subtracted from the DD estimate.
- Generates poor summary estimate if there is heterogeneity.

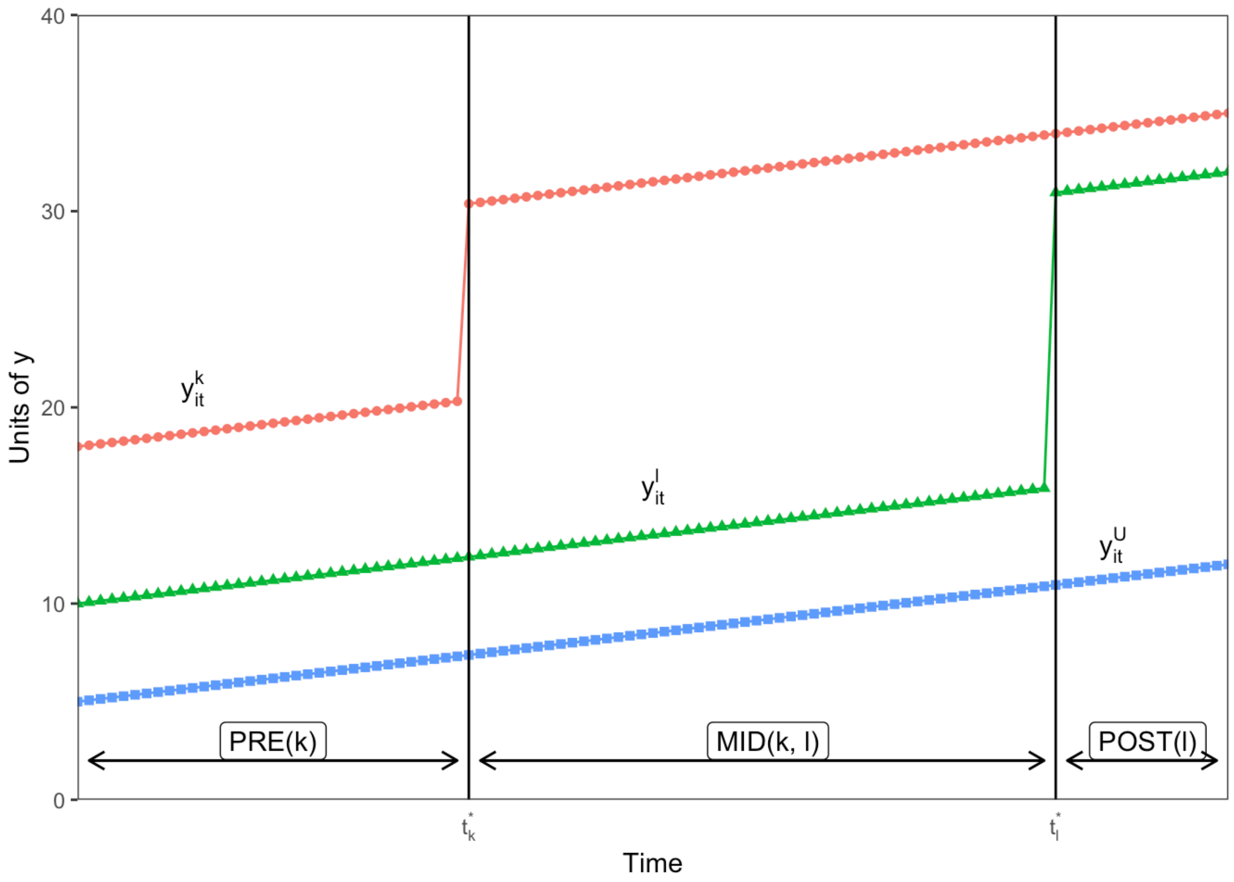
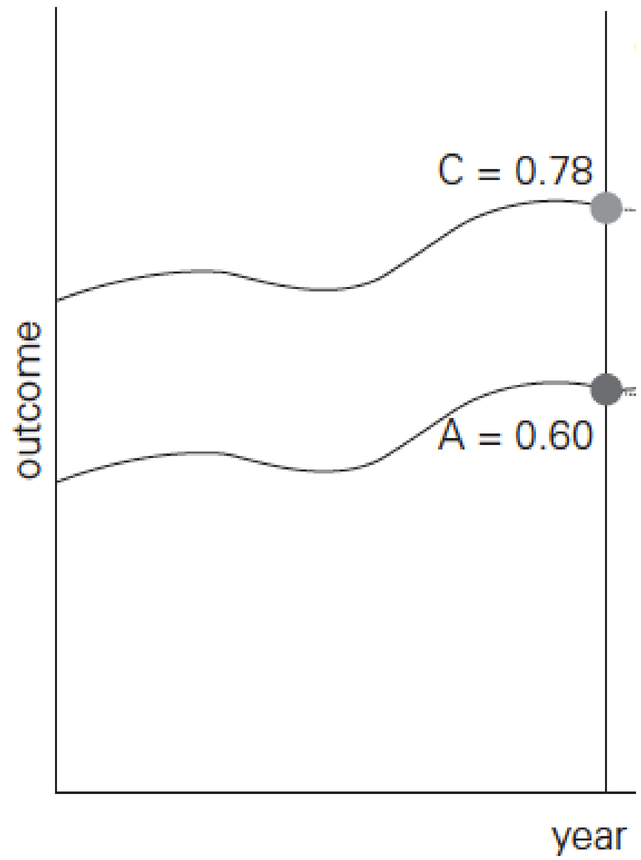


Image: Andrew Baker. See also Goodman-Bacon (2021), Callaway and Sant'Anna (2021), Sun and Abraham (2021)

Key Assumption: Parallel Trends



- Basic DD controls for any time invariant characteristics of both treated and control groups.
- Does not control for any time-varying characteristics.
- If another policy/intervention occurs in the treated (or control) group at the same time as the intervention, we cannot cleanly identify the effect of the program.
- DD main assumption: in the absence of the intervention treated and control groups would have displayed similar trends.
- This is called the *parallel trends* assumption.

Impossible to verify, see Gertler et al. (2016).

Statistical model

$$\begin{tikzcd} X \arrow[r] \arrow[rr, bend left] & \text{Policy } (T) \arrow[r, blue] & \text{BP } (Y) \end{tikzcd}$$

Total effect via "extended" two-way fixed effects:

$$Y_{ijt} = \alpha + \sum_{r=q}^{T} \beta_r d_r + \sum_{s=r}^{T} \gamma_s fs_t + \sum_{r=q}^{T} \sum_{s=r}^{T} \tau_{rs}(d_r \times fs_t) + \mathbf{Z}_{ijt} + \varepsilon_{ijt}$$

X includes:

- d_r = treatment cohort fixed effects
- fs_t = time fixed effects
- $\mathbf{Z}_{ijt}$ = time-varying covariates

TE is average of marginal *ATTs* τ_{rs}, averaged over cohort and time.

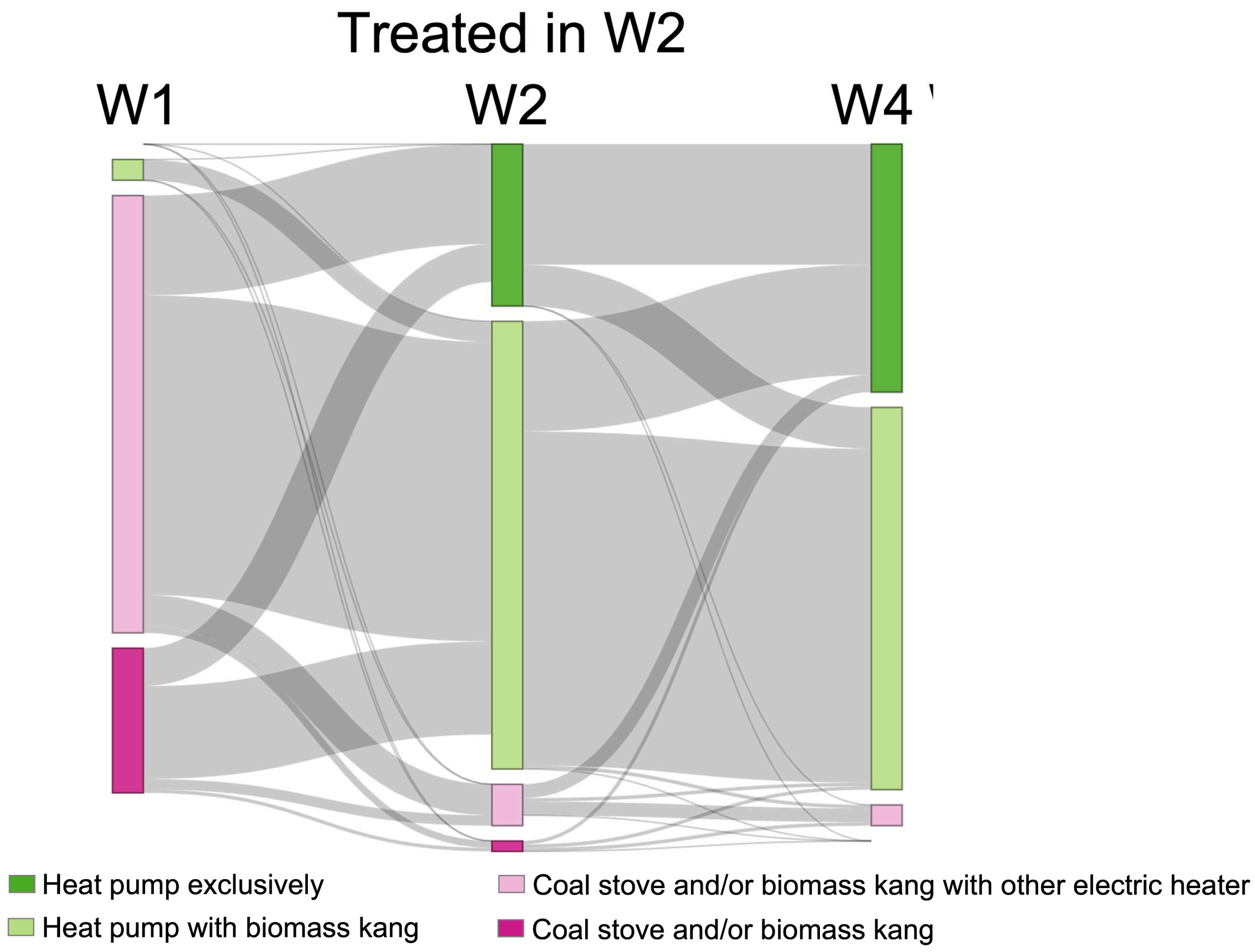
See Wooldridge (2021), Goin and Riddell (2023)

What Did We Find?

Treatment groups were generally balanced

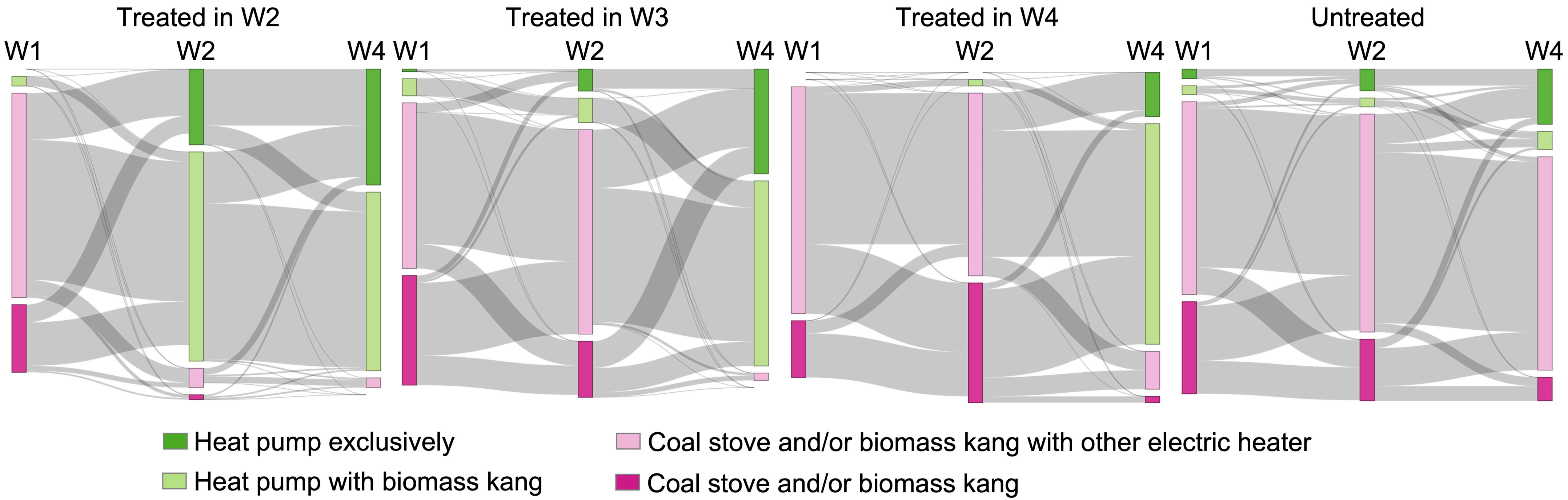
	Never treated (N=603)		Ever treated (N=400)			
	Mean	SD	Mean	SD	Diff	SE
Age (years)	59.9	9.4	60.4	9.2	0.5	0.6
Female (%)	59.5	49.1	60.0	49.1	0.5	3.2
Secondary+ education (%)	12.6	33.2	9.8	29.7	-2.9	2.0
Wealth index (bottom 25%)	26.9	44.4	22.3	41.7	-4.6	2.8
Current smoker (%)	26.2	44.0	25.4	43.6	-0.8	2.8
Daily drinker (%)	17.8	38.3	21.9	41.4	4.1	2.6
Systolic (mmHg)	131.4	16.8	128.7	14.3	-2.7	1.0
Diastolic (mmHg)	82.7	11.6	82.1	11.3	-0.6	0.8
Body mass index (kg/m2)	26.3	3.7	25.8	3.6	-0.5	0.3
Any respiratory problem (%)	50.6	50.0	54.3	49.9	3.7	3.2
Temperature (°C)	13.8	3.6	13.5	3.3	-0.3	0.2
Personal PM2.5 (ug/m3)	127.1	145.3	102.3	105.5	-24.7	11.9

Treated households adopted cleaner energy

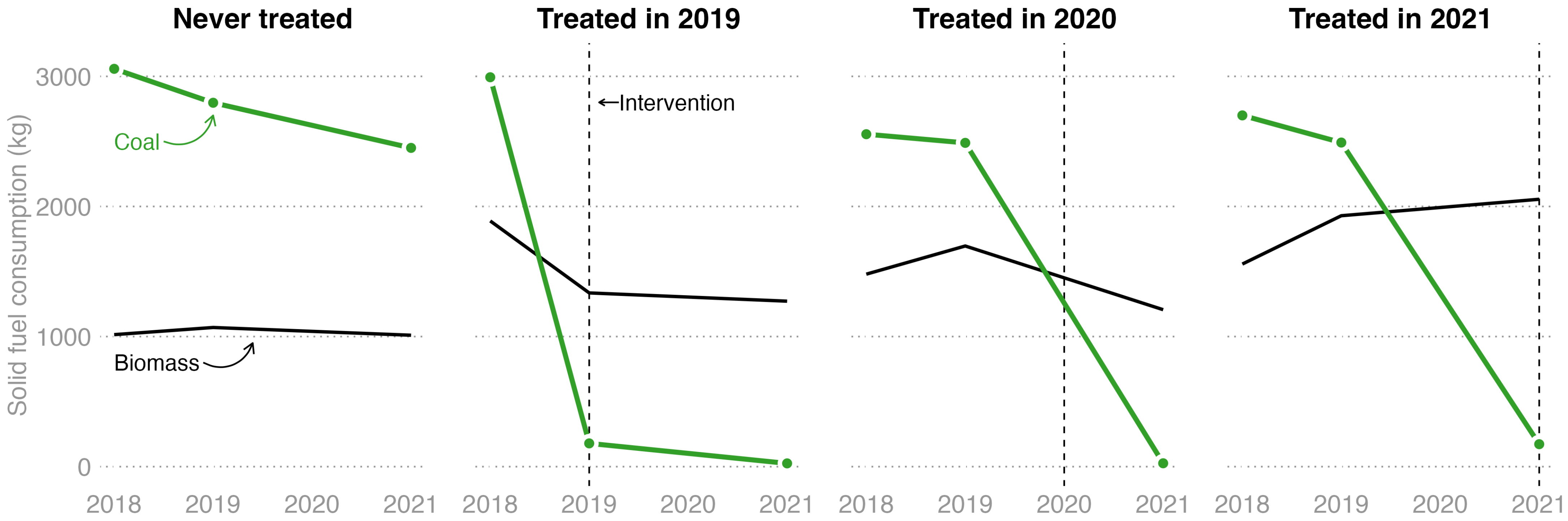


Treated households adopted cleaner energy

At the time of treatment



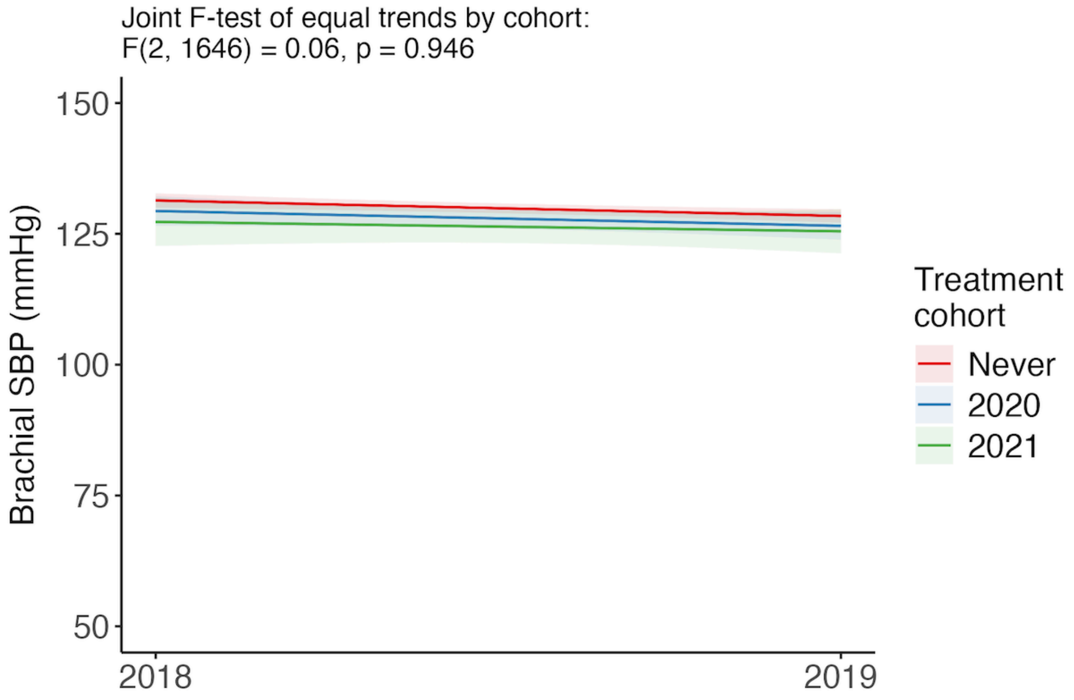
Treated households reported less coal use

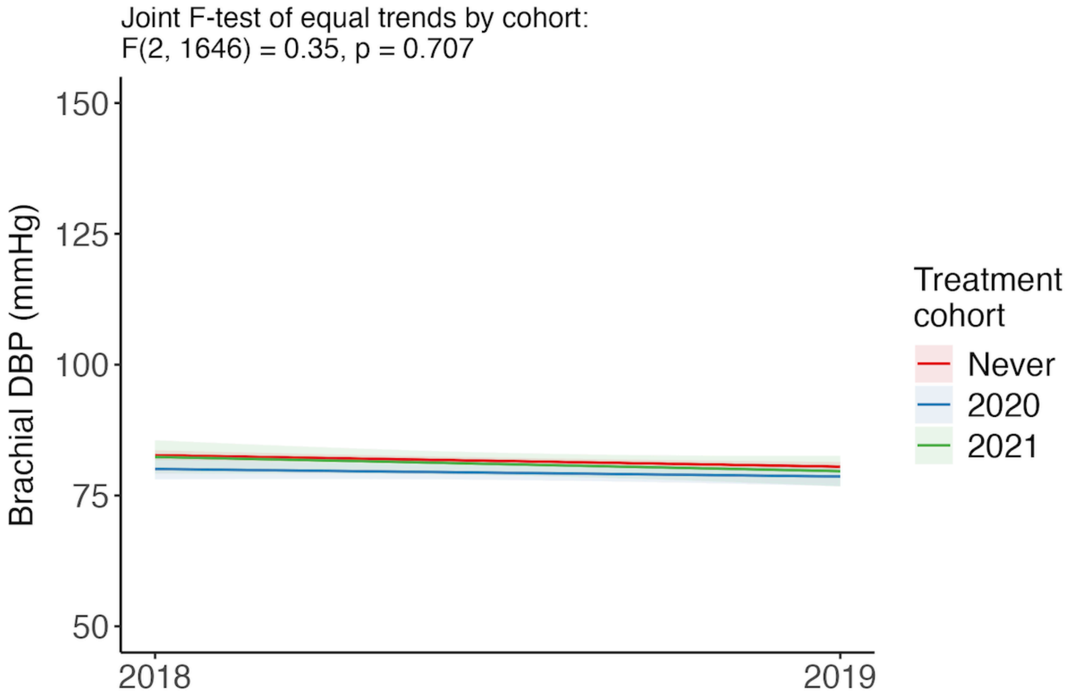


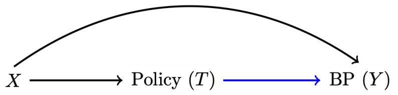
Did the policy affect outcomes?

$$
\begin{tikzcd}
X \arrow[r] \arrow[rr, bend left] & \text{Policy } (T) \arrow[r, blue] & \text{BP } (Y)
\end{tikzcd}
$$

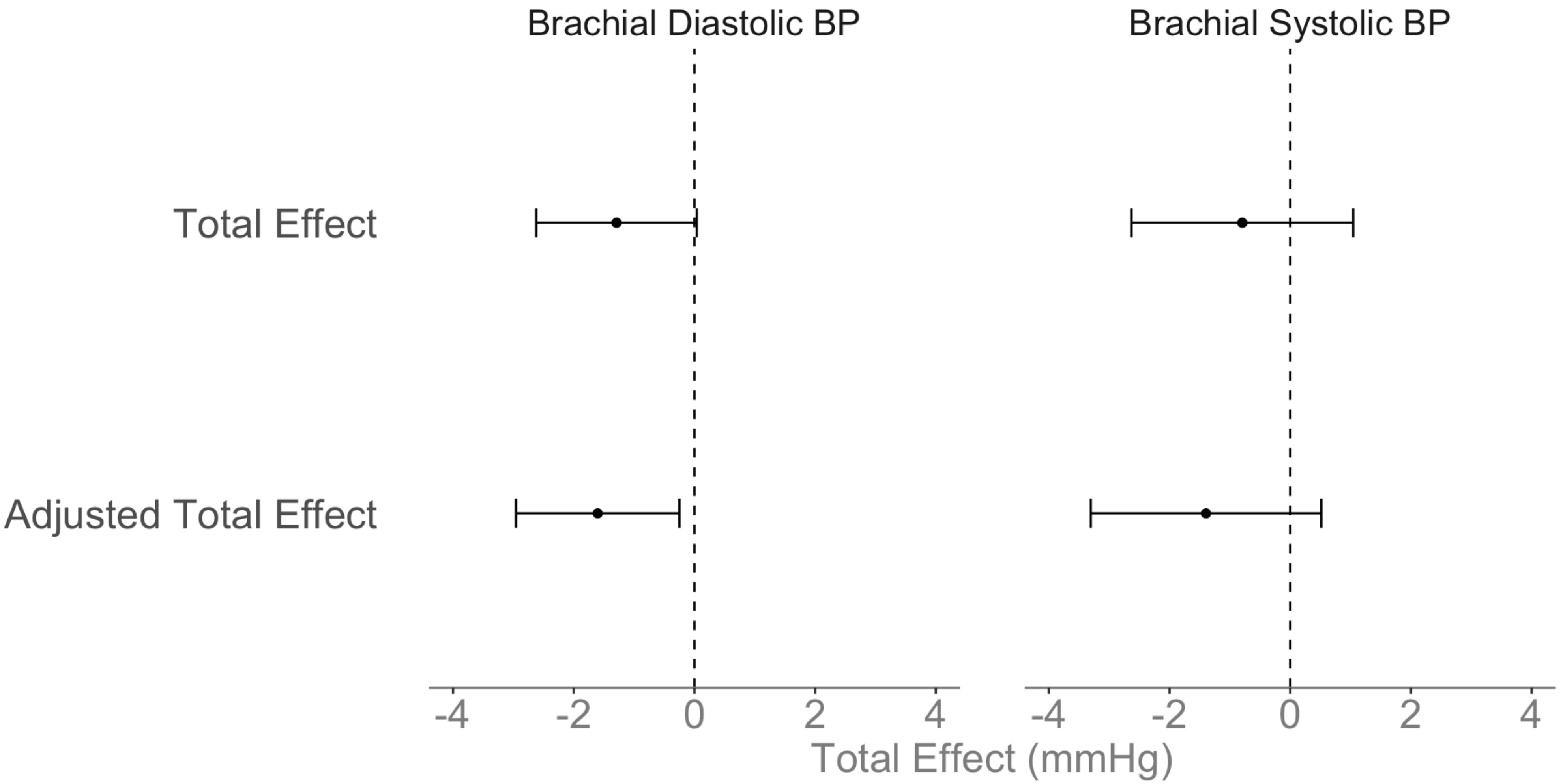
Evidence of parallel pre-trends for BP





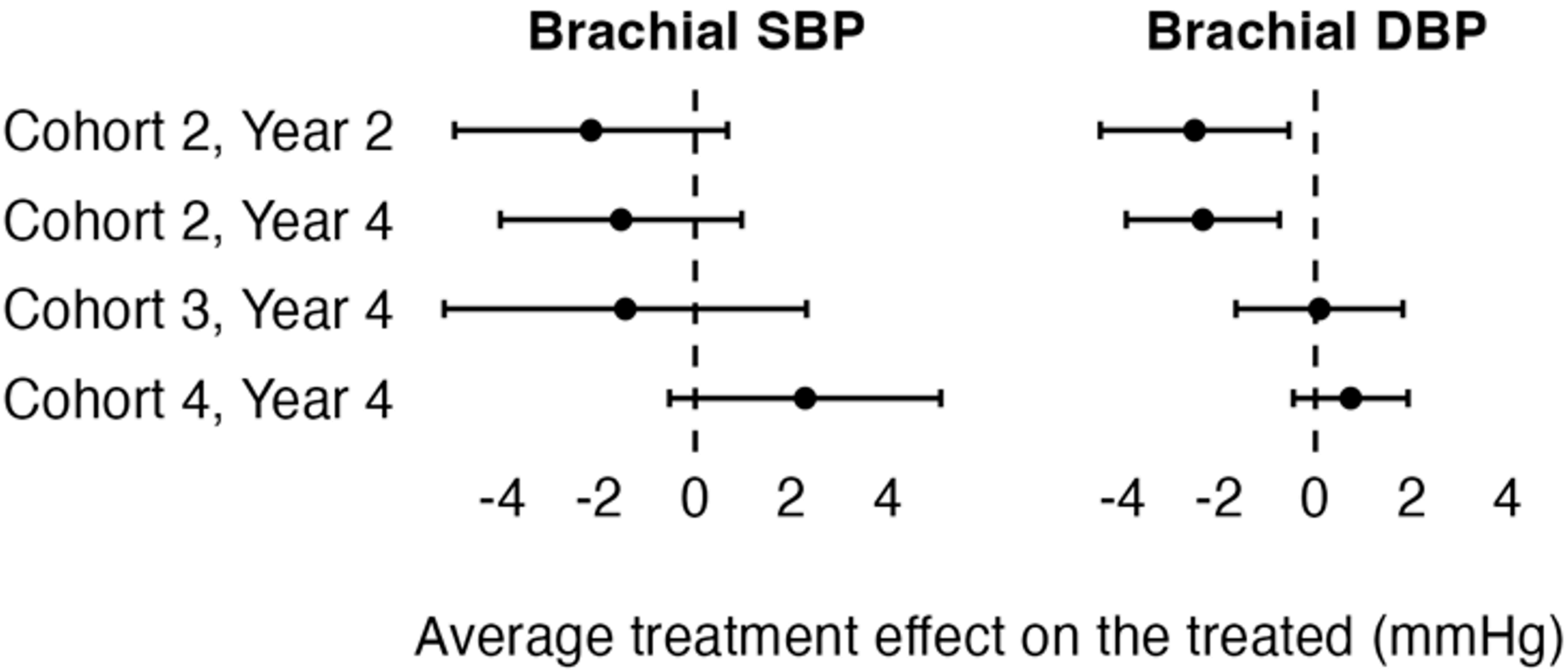


Impact on blood pressure



Time-varying covariates: age, sex, waist circumference, smoking, alcohol consumption, and use of blood pressure medication.

Some evidence of heterogeneity

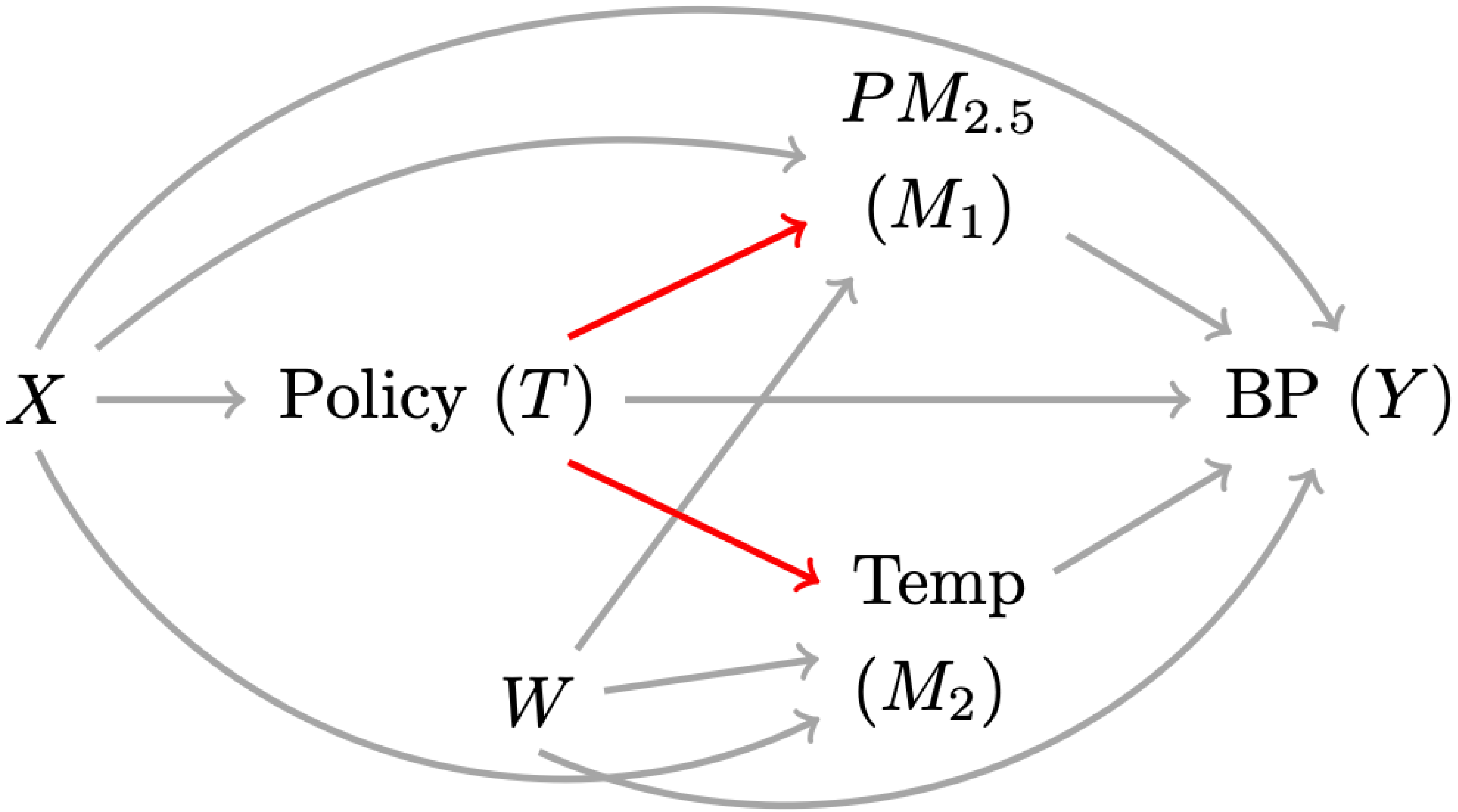


Reductions in some self-reported respiratory symptoms.

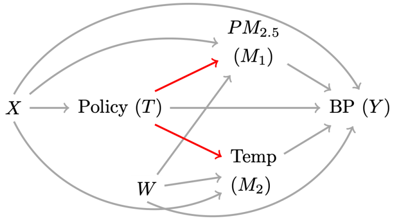
Little evidence of impact on inflammatory markers.

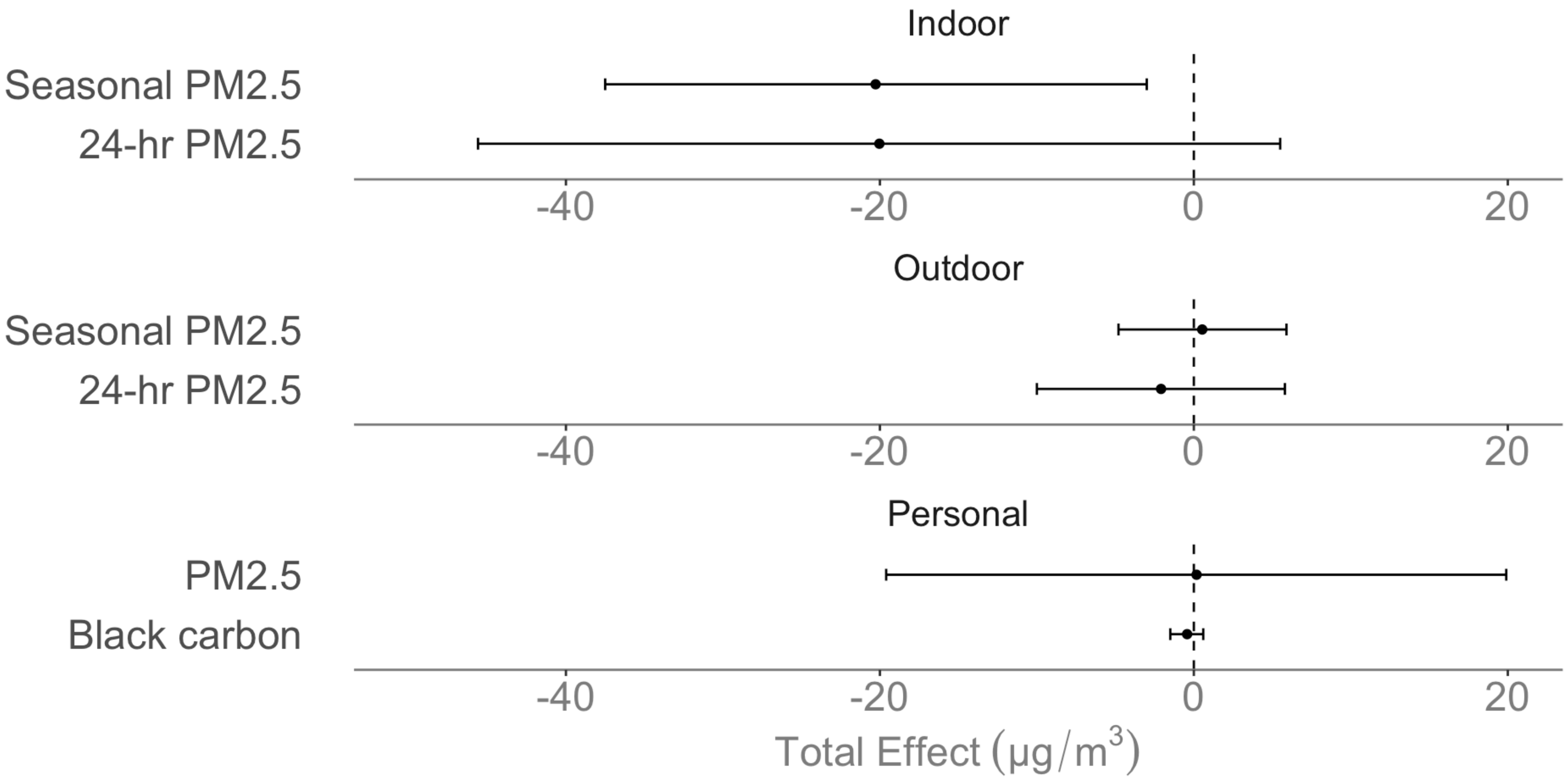
		Obs	ATT	(95% CI)
Respiratory outcomes				
Self-reported (pp)	Any symptom	3076	-7.5	(-12.7, -2.3)
	Coughing	3076	-2.7	(-7.1, 1.7)
	Phlegm	3076	-1.6	(-5.6, 2.4)
	Wheezing attacks	3076	1.0	(-1.9, 3.9)
	Trouble breathing	3076	-3.4	(-9.2, 2.4)
	Chest trouble	3076	-3.4	(-8.1, 1.3)
Measured	FeNO (ppb)	793	0.3	(-2.2, 2.8)
Inflammatory markers				
Measured	IL6 (pg/mL)	1603	0.8	(-0.3, 2.0)
	TNF-alpha (pg/mL)	1603	0.8	(-0.1, 1.7)
	CRP (mg/L)	1603	0.1	(-0.5, 0.6)
	MDA (μM)	1603	0.2	(-0.2, 0.6)

Did the policy affect the mediators?



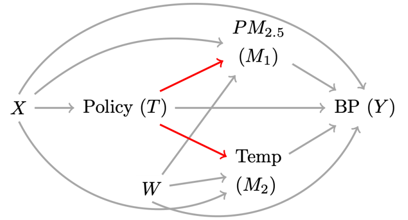
Policy reduced (only) indoor PM

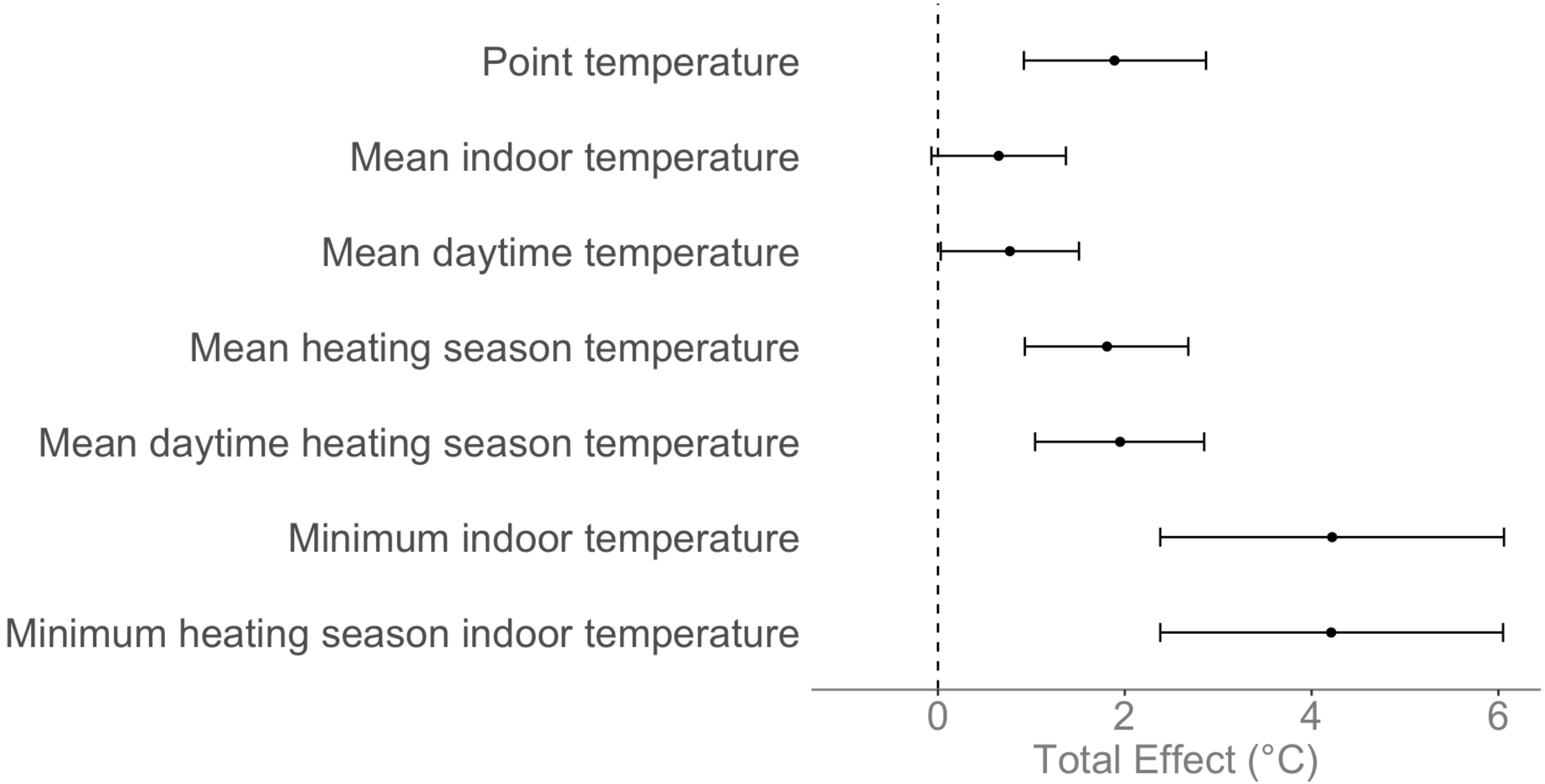




ETWFE models adjusted for household size, smoking, outdoor temperature, and outdoor dewpoint.

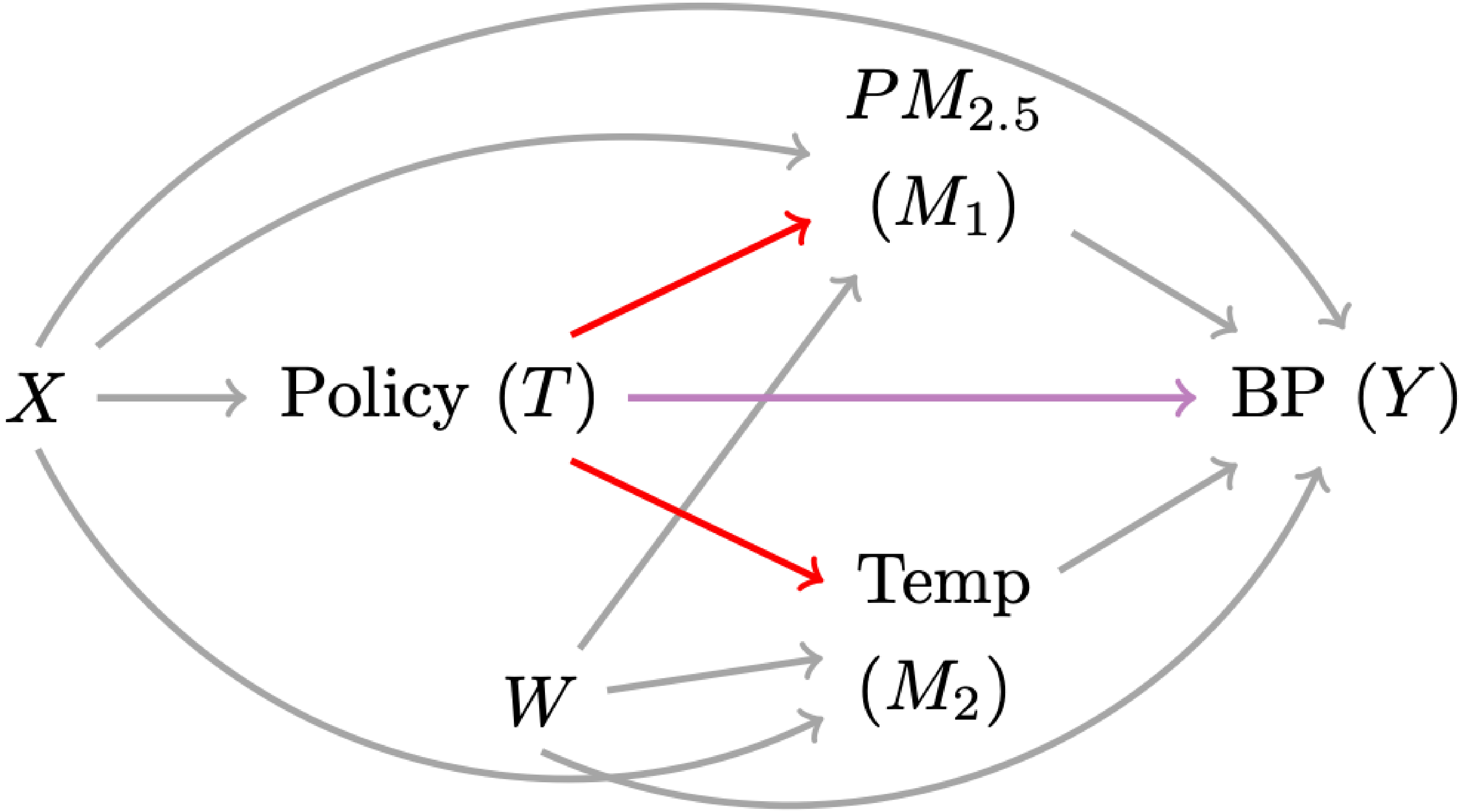
Policy increased indoor temperature



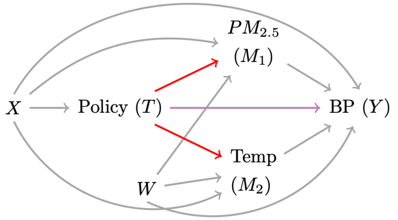


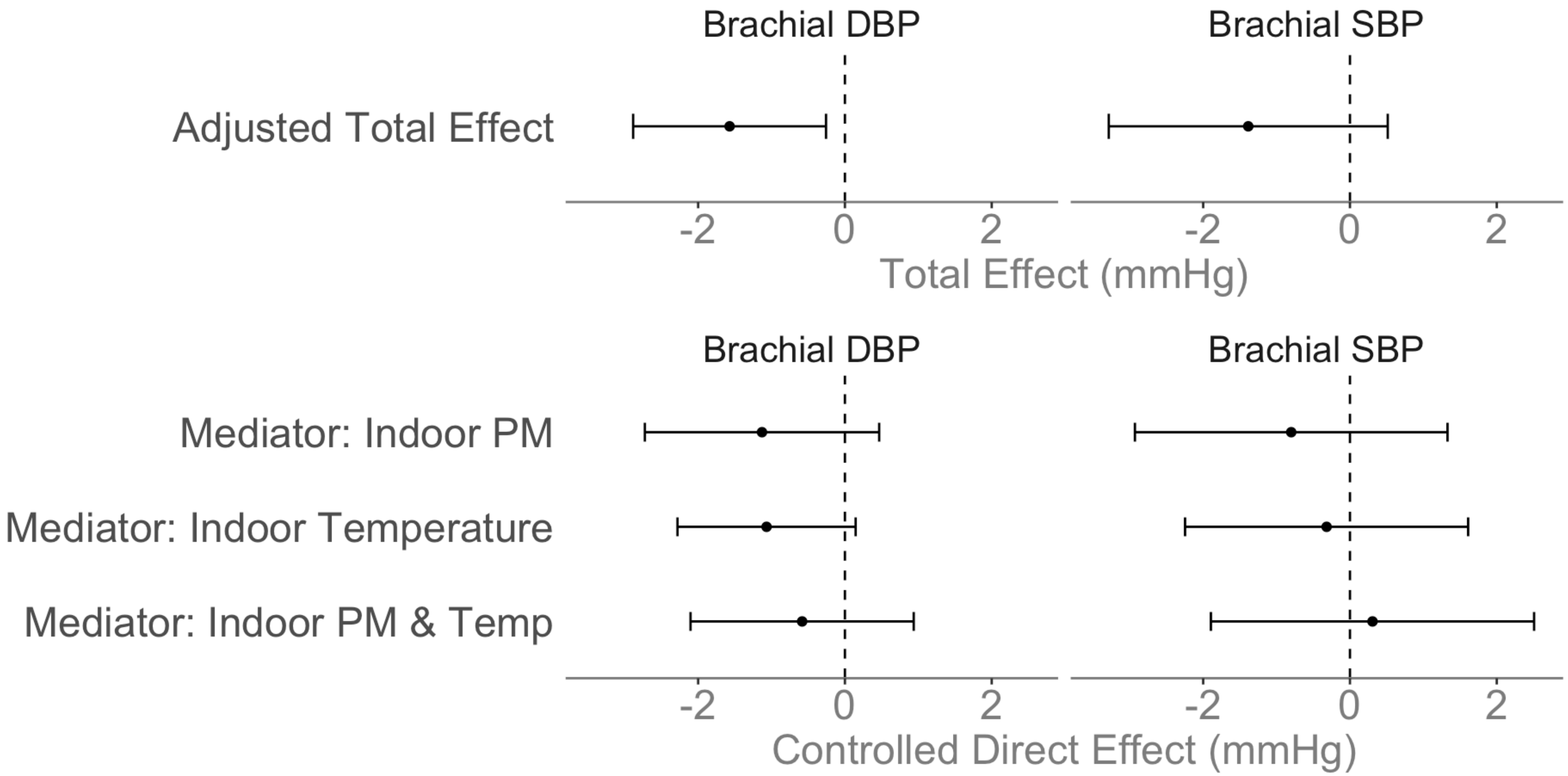
ETWFE models adjusted for the number of rooms and wintertime occupants in the household, age of the primary respondent, and wealth index.

Do $PM_{2.5}$ and temperature mediate the BP effect?



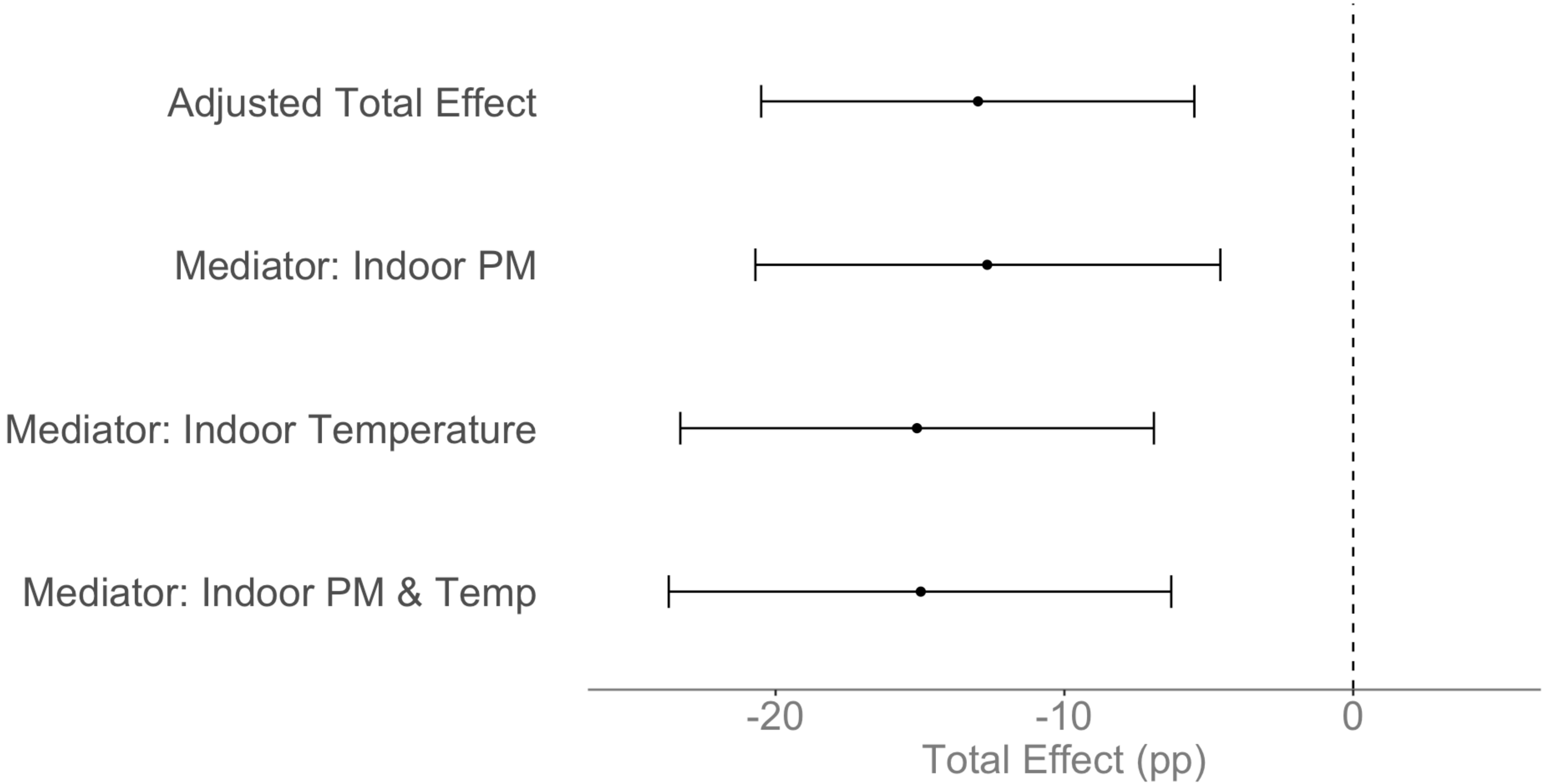
BP mostly mediated by $PM_{2.5}$ and temp





ETWFE model with exposure-mediator interaction, adjusted for time-varying covariates.

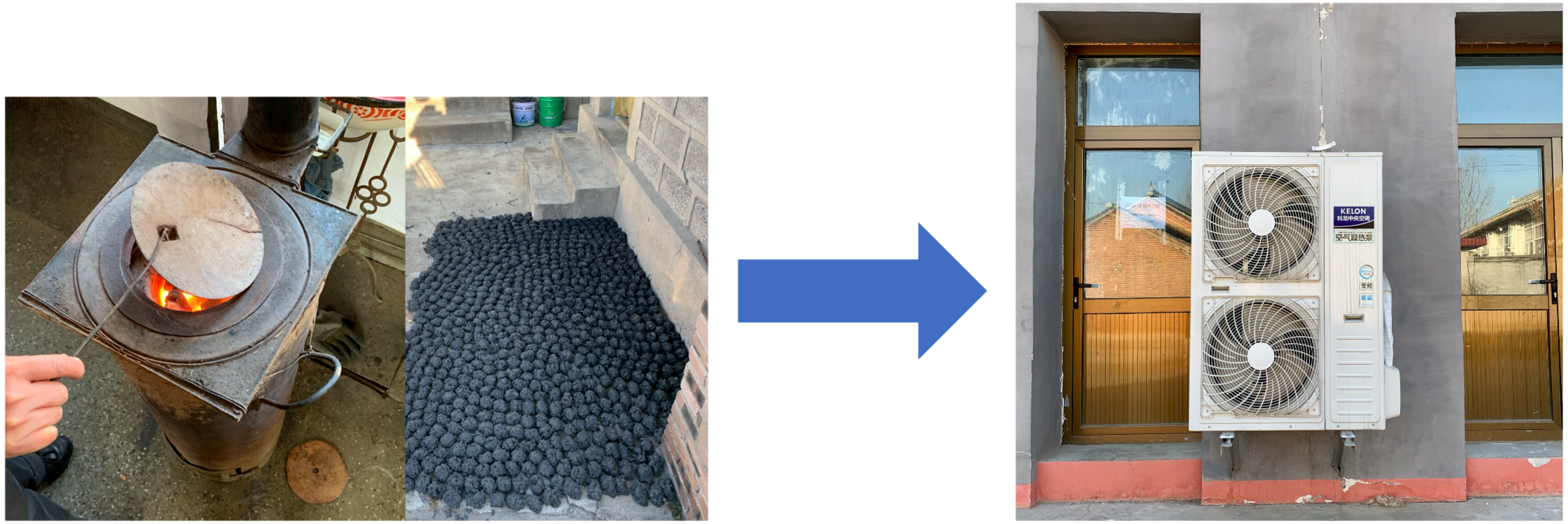
Little mediation for respiratory symptoms



What Does It Mean?

Uptake

- High uptake and consistent use of the new heat pump technology.
- Persistent effects for early treated villages.
- Large reductions in coal use in treated villages.



Impacts

Air pollution

- Impacts on indoor $PM_{2.5}$ but not personal exposures or outdoor $PM_{2.5}$
- Secular trends affected by large-scale policy changes
- Movement between indoor and outdoor

Health outcomes

- Overall lower BP, some evidence of heterogeneity
- Improvements in respiratory symptoms
- BP impacts largely mediated by $PM_{2.5}$ and temperature

Questions?

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