Impacts of transitioning to clean household energy

Evidence from policy reform in peri-urban Beijing

Sam Harper

2025-02-24

McGill | Department of Epidemiology, Biostatistics and Occupational Health

Beijing Household Transitions Project

Impact of transitioning to clean heating in rural China on:

1. Community and personal air pollution exposure;
2. Indoor temperatures in homes;
3. Blood pressure, respiratory symptoms, markers of inflammation and oxidative stress
4. Energy use patterns
5. Wellbeing and income

Interdisciplinary Team

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Knowledge Users

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

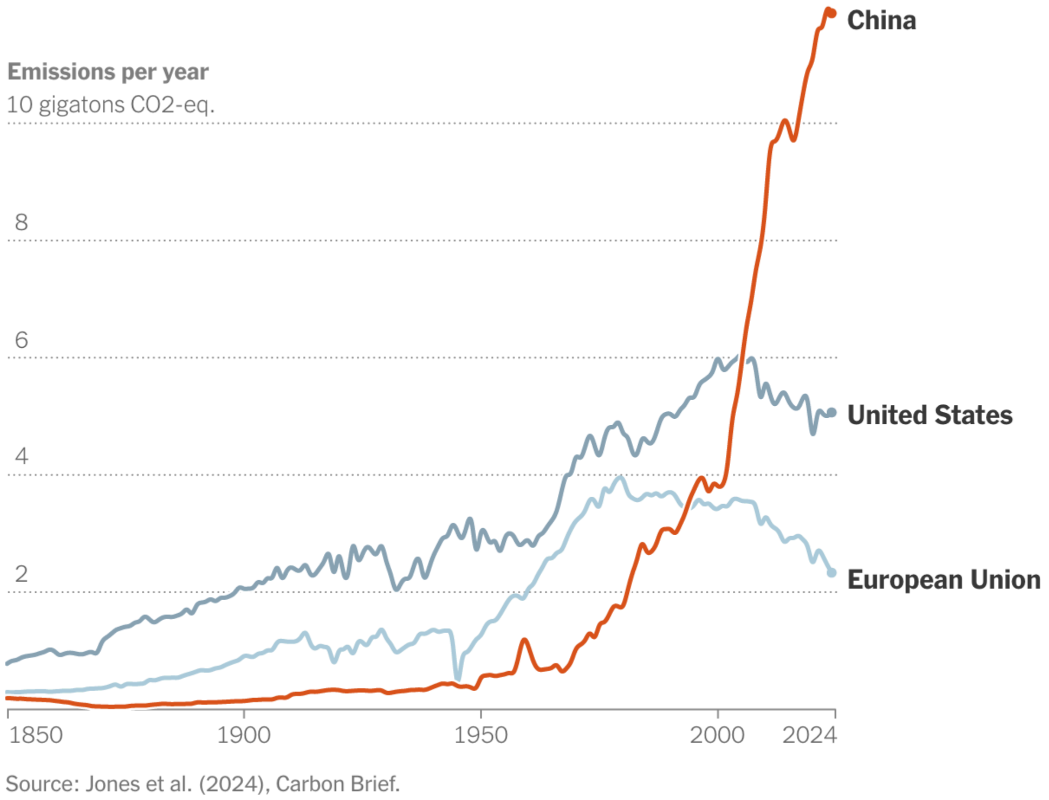
Funders

- Canadian Institutes of Health Research
- Health Effects Institute (USA)

Background

The role of coal in China

~ 30% of global emissions



Still dominated by coal

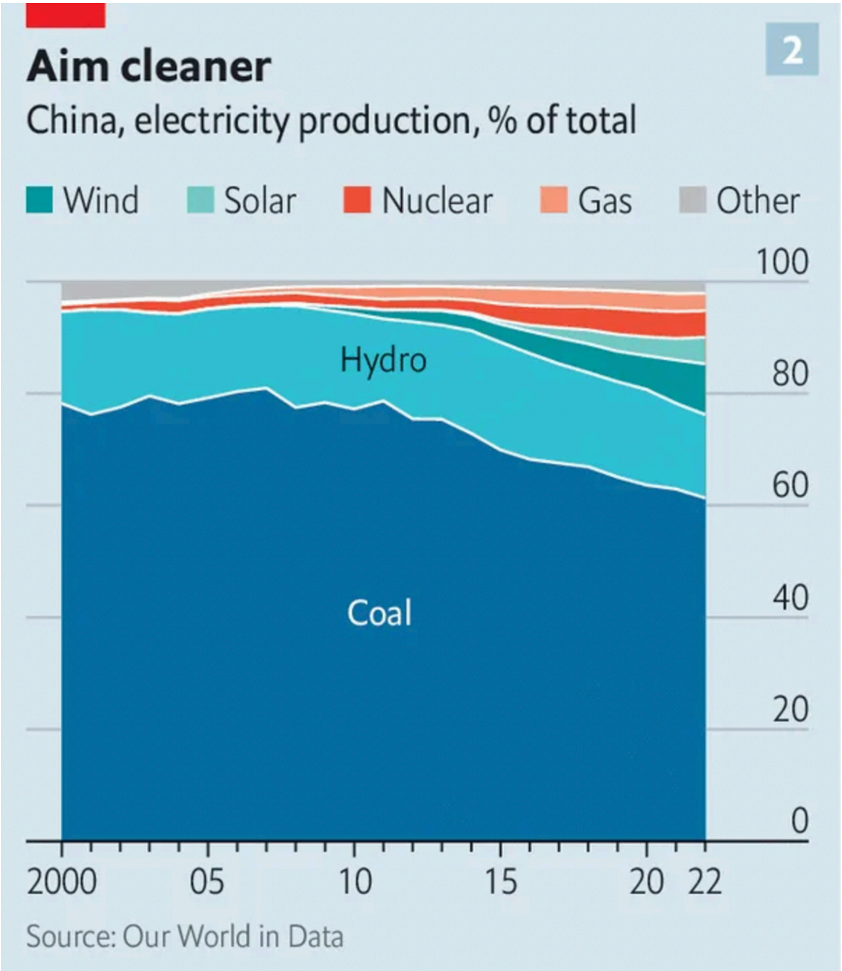
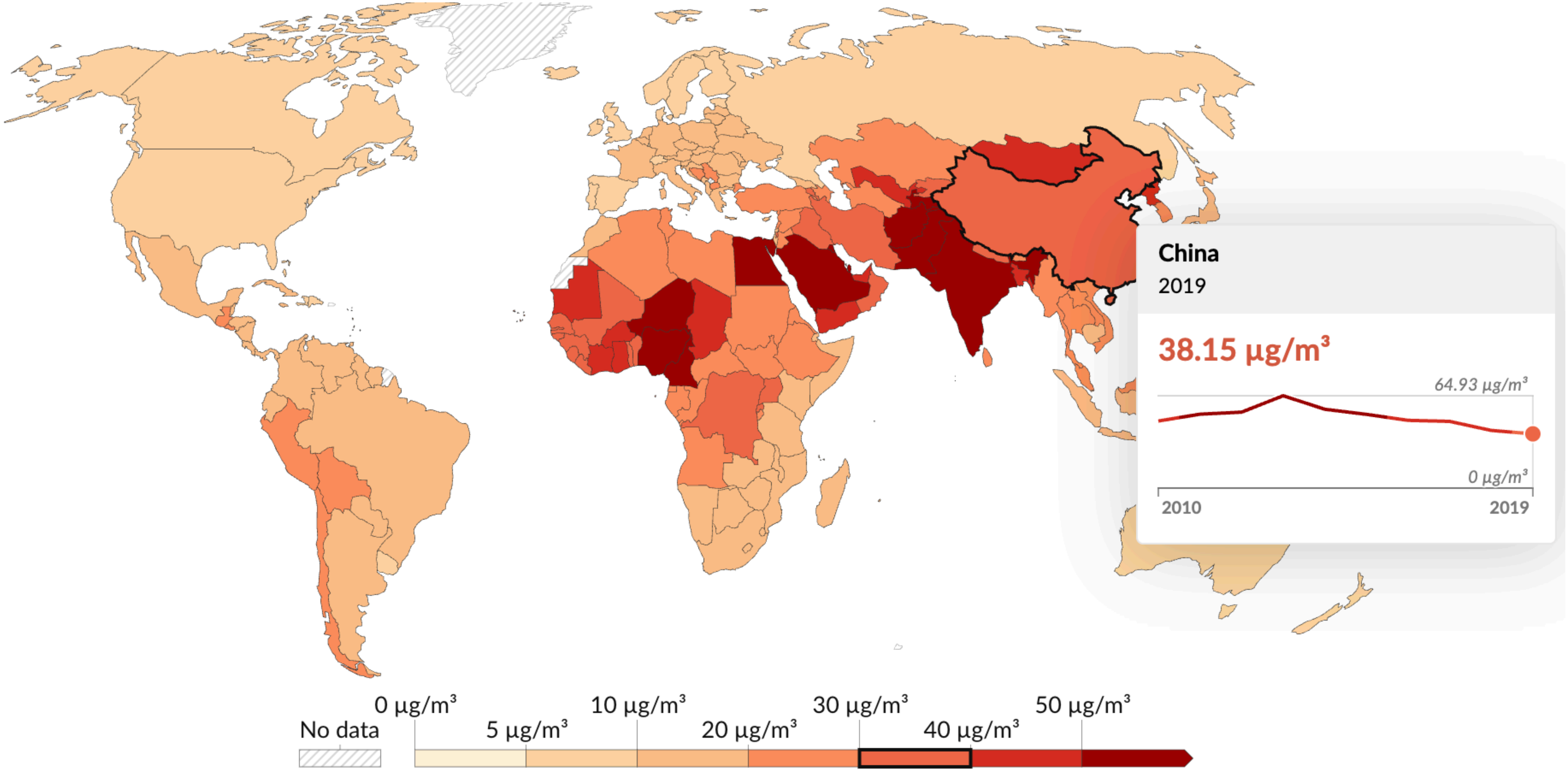


Image credits: New York Times, The Economist

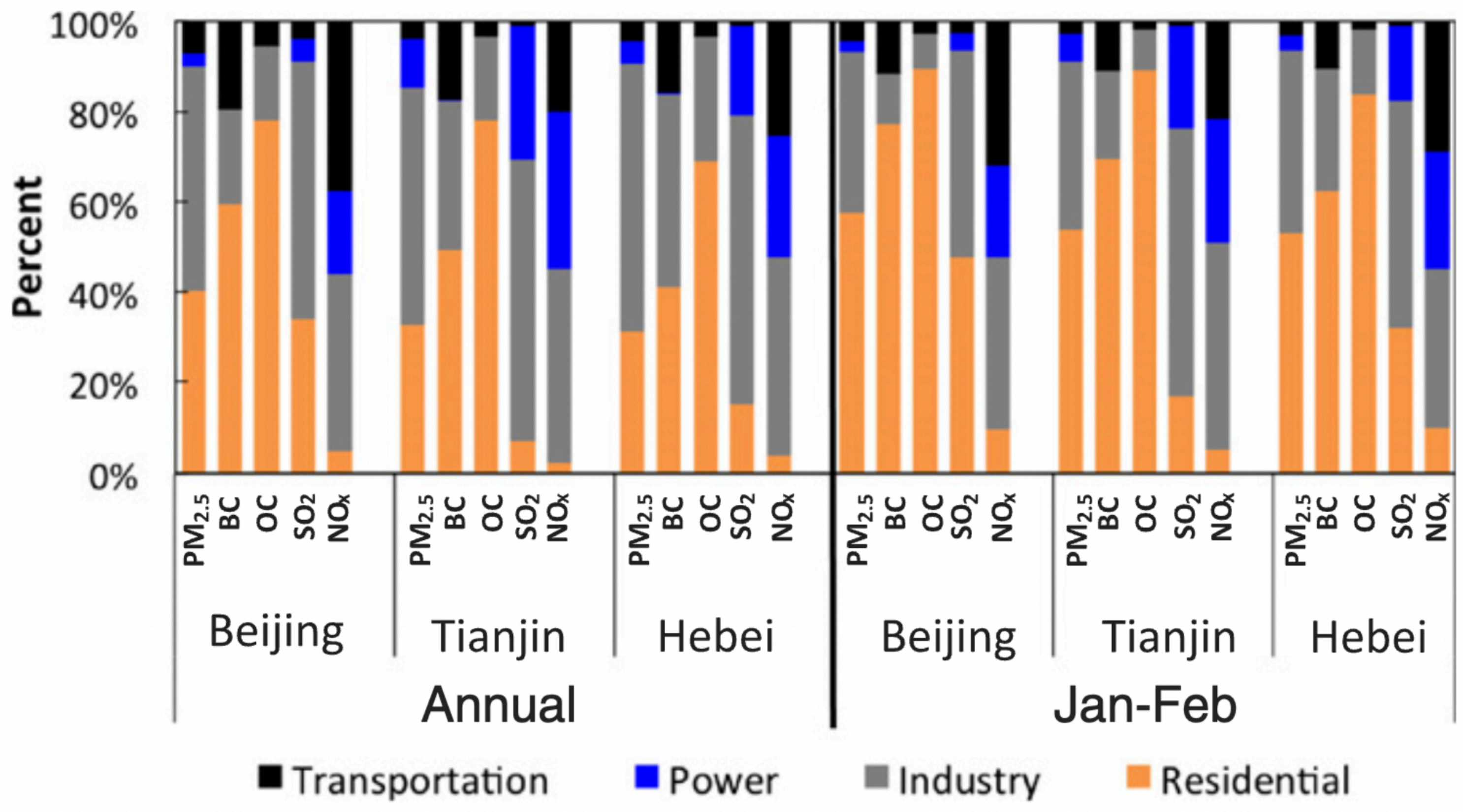
Global exposure to suspended particles <2.5 microns in diameter ($PM_{2.5}$)



Source: World Health Organization - Global Health Observatory (2024) – processed by Our World in Data

Residential coal burning in China

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



Liu et al. (2016)

Residential cooking vs. heating

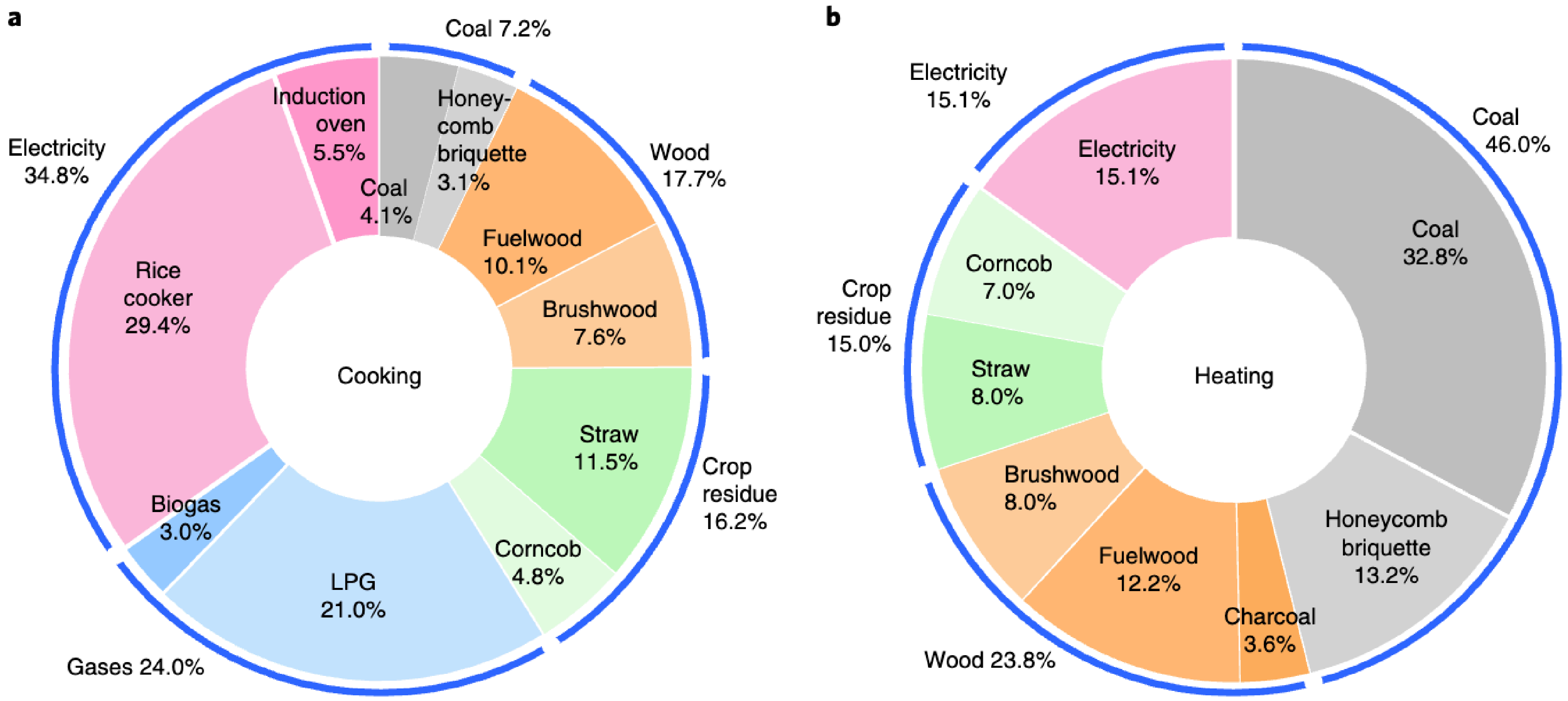


Fig. 1 | Percentage share of fuel type in residential energy use in rural China in 2012. a, Overall time-sharing data for cooking (staple food cooking, subsidiary food preparation and water boiling). **b**, Time-sharing data for heating.

Tao et al. (2018)

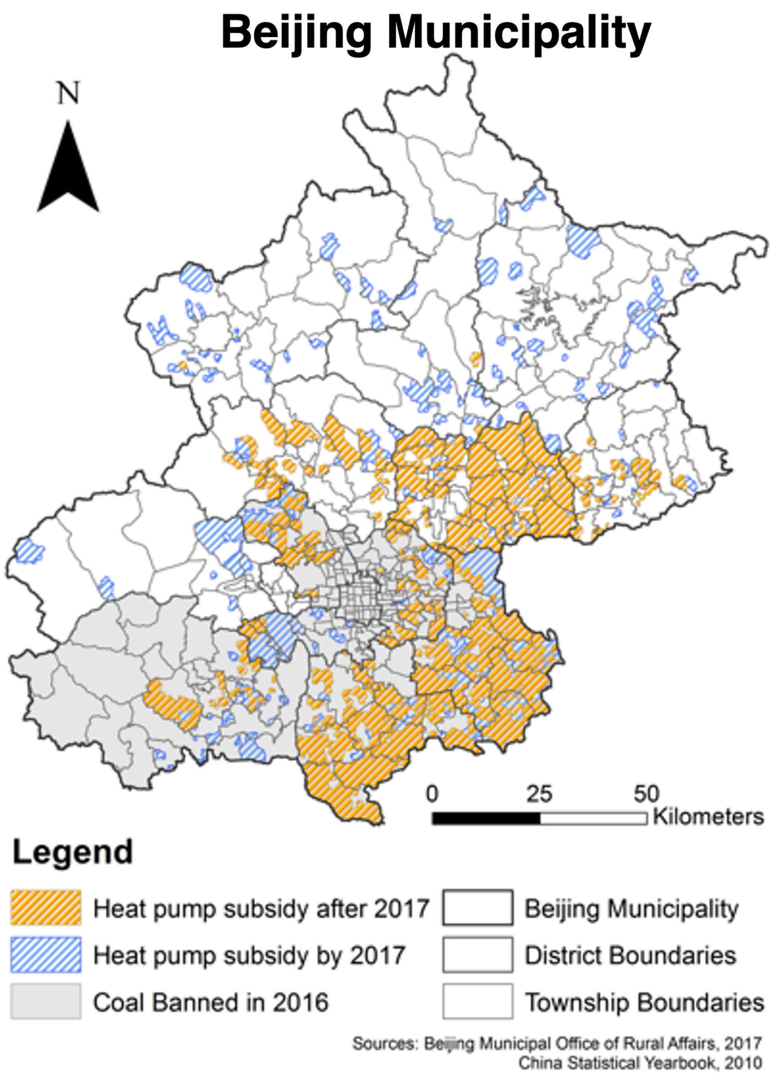
Residential coal burning in China

- 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;

Liu et al. (2016)

Policy Context

- Beijing designated "coal restricted areas" in 2016
- Government subsidized electric or gas-powered heat pumps (80% of $4,500 cost)
- 2017: required up to 2 million people to halt coal use
- 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; reduce supply.
- Retrofit existing homes or build new homes in the village.

Traditional coal stove

Heat pump

CTIONS HOME SEARCH 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

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Workers sort coal on a conveyor belt near a coal mine in Datong, northern China's Shanxi province, Nov. 20, 2015.

AFP

npr

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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

Many Chinese families use coal to heat their homes

China's government has allowed some northern cities to burn coal in a

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

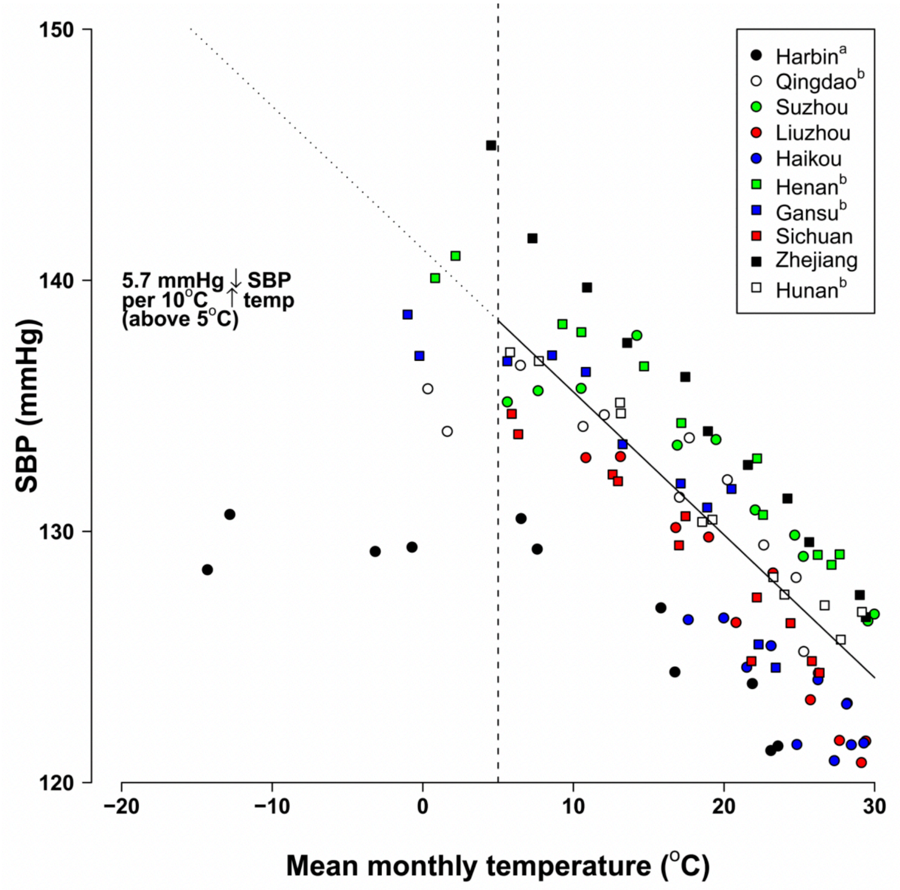
Poor bear brunt of Beijing coal cleanup with no heating at -6C

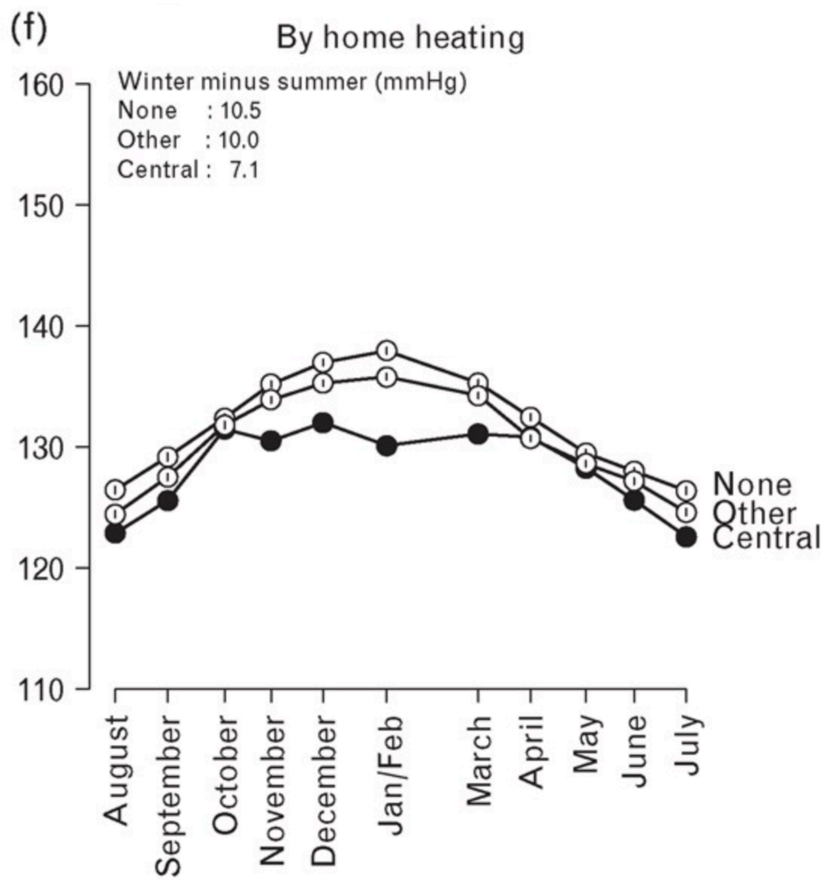
Switch from coal to gas has left residents of towns around Beijing without heating after gas supply falters, reports Climate Home News

pipeline construction on the outskirts of Beijing. There is a demand-supply gap for gas after coal sto... 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 ant... ...tion drive has forced rural areas in northern China to switch from dirty ...

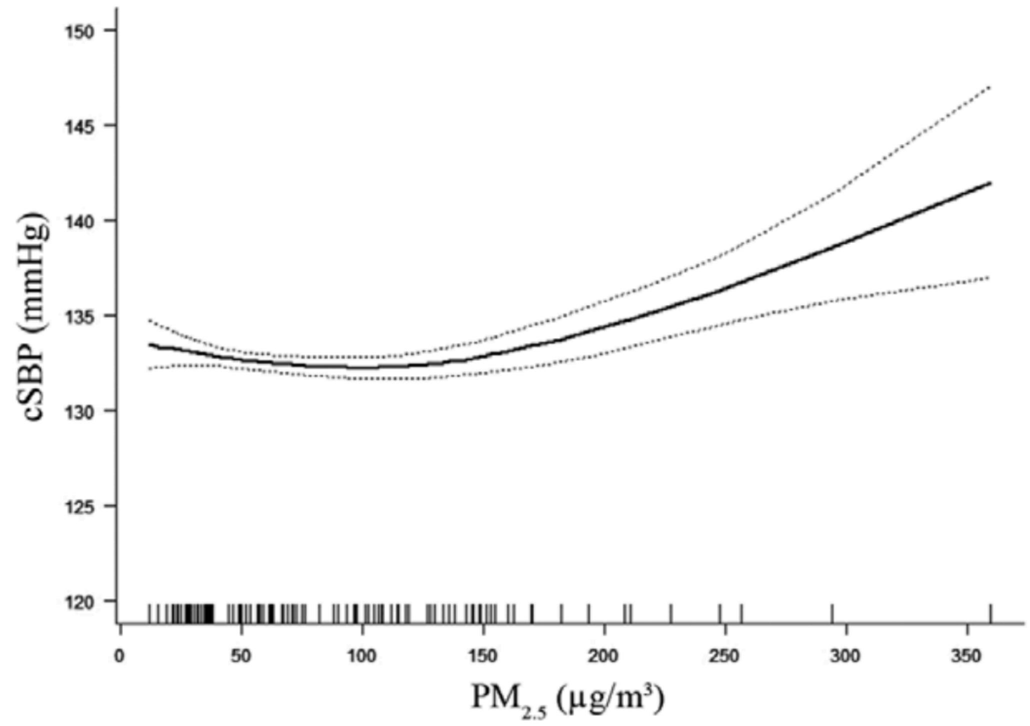
Lower temperatures, higher blood pressure

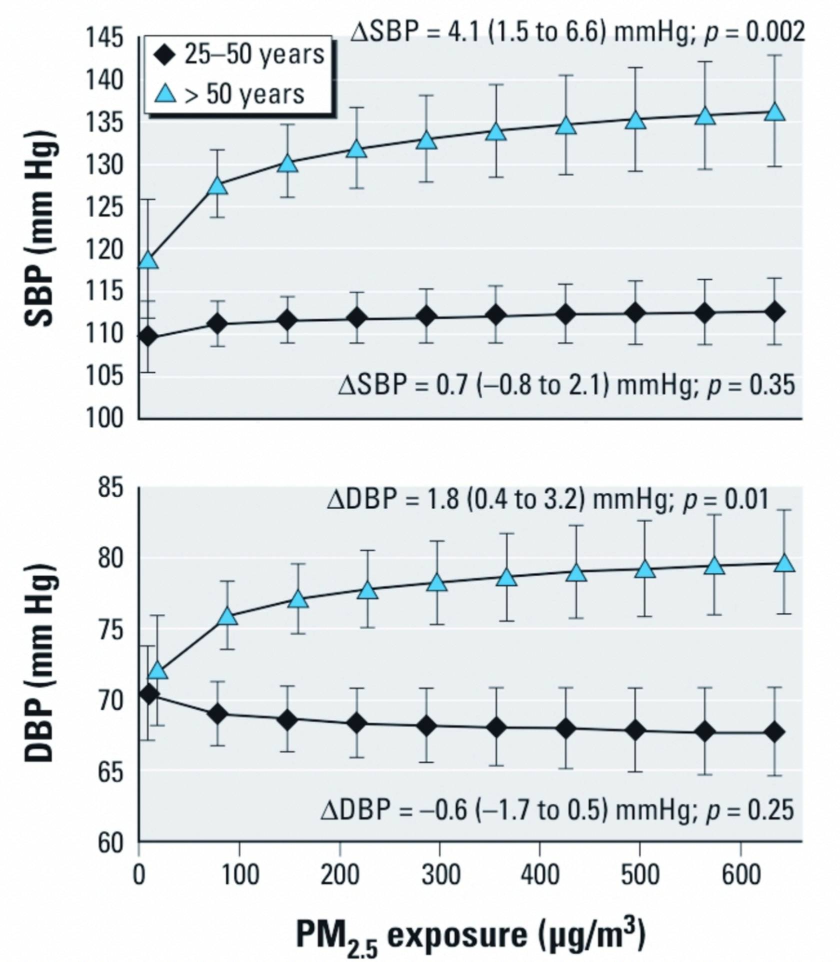




Images: Lewington et al. (2012). Also see Sternbach et al. (2022)

Higher $PM_{2.5}$, higher blood pressure





Images: Fan et al. (2019), Baumgartner et al. (2011).

Research Gaps (1)

- Focused on ambient $PM_{2.5}$ or economic growth
- No credible identification strategy
- Often model-based simulation of health impacts
- No direct measurements of health or personal exposure

Energy and air pollution benefits of household fuel policies in northern China

Wenjun Meng[a], Qirui Zhong[a], Yilin Chen[b], Huizhong Shen[b], Xiao Yun[a], Kirk R. Smith[c,d,1], Bengang Li[a], Junfeng Liu[a], Xilong Wang[a], Jianmin Ma[a], Hefa Cheng[a], Eddy Y. Zeng[e,f], Dabo Guan[g], Armistead G. Russell[b], and Shu Tao[a,h,1]

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Contributed by Kirk R. Smith, June 6, 2019 (sent for review March 11, 2019; reviewed by Yingwen Zhang)

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

China's Coal Ban policy: Clearing skies, challenging growth

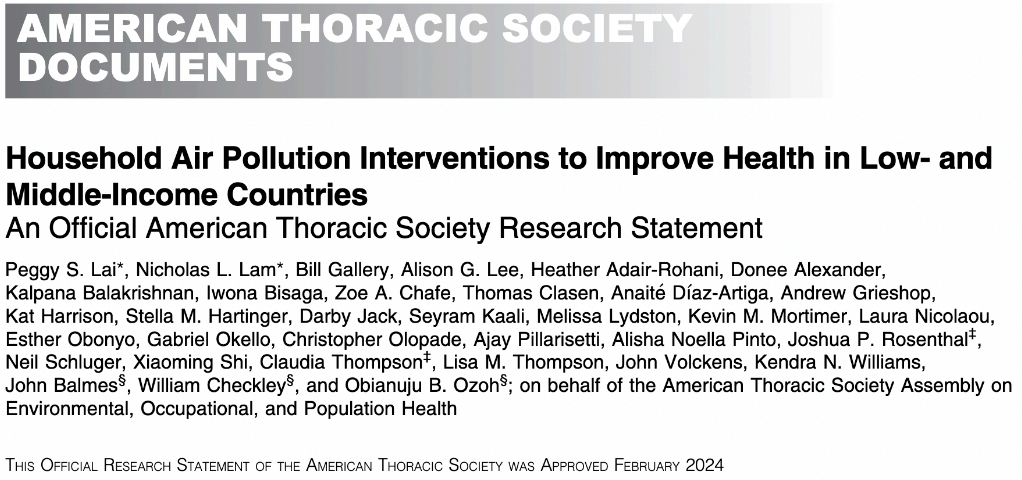
Jiamei Niu[a,b], Xiaodong Chen[a,b,*], Shuwei Sun[a,b]

[a] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, 100085, China
[b] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, 100049, China

Meng et al. (2019); Niu et al. (2024)

Research Gaps (2)

- Most prior work only on cookstoves
- Several RCTs
- Mixed evidence on air pollution
- Challenges with uptake
- Multiple sources (e.g., stove-stacking)
- Weak evidence on health impacts, even when household PM 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 household air pollution

Lai et al. (2024)

Research Gaps (3)

- Limited evidence on *how* heating interventions might affect health
- Through reduced air pollution?
- Raising indoor temperature?
- Transitioning may increase expenses, change behaviors

nature sustainability
ARTICLES
https://doi.org/10.1038/s41893-021-00837-w
Check for updates

Environmental benefits and household costs of clean heating options in northern China

Mi Zhou[1,2,7], Hongxun Liu[1,3,7], Liqun Peng[1], Yue Qin[4], Dan Chen[5], Lin Zhang[2] ✉ and Denise L. Mauzerall[1,6] ✉

> We find, even when all available 2018–2020 subsidies are applied, rural households in northern China…are still facing unaffordable clean heating costs.

Zhou et al. (2022)

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.

Methods: Data

Village 'enrollment'

- 'National' policy devolved to local governments
- Village leaders announce and explain the program at commission meetings

We:

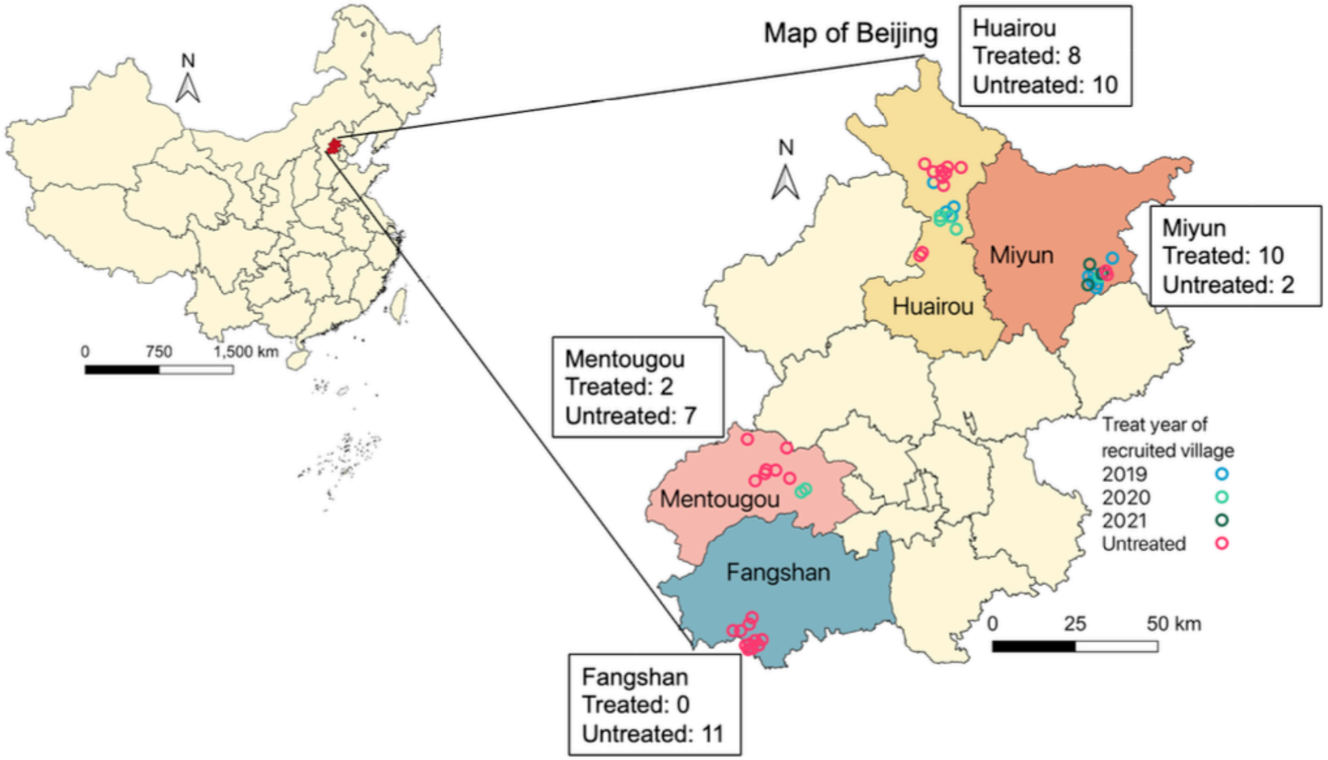
- Focus on eligible for the policy but not currently treated
- Semi-structured interviews with village committee reps
- Generally unaware of if or when they would be treated

> "(We are) get used to be asked when to change to electricity. There is a little pressure before when everyone was asking, but this is not the thing that a village can decide. There are district level, township level approval processes to complete."

Wang and Xie (2023)

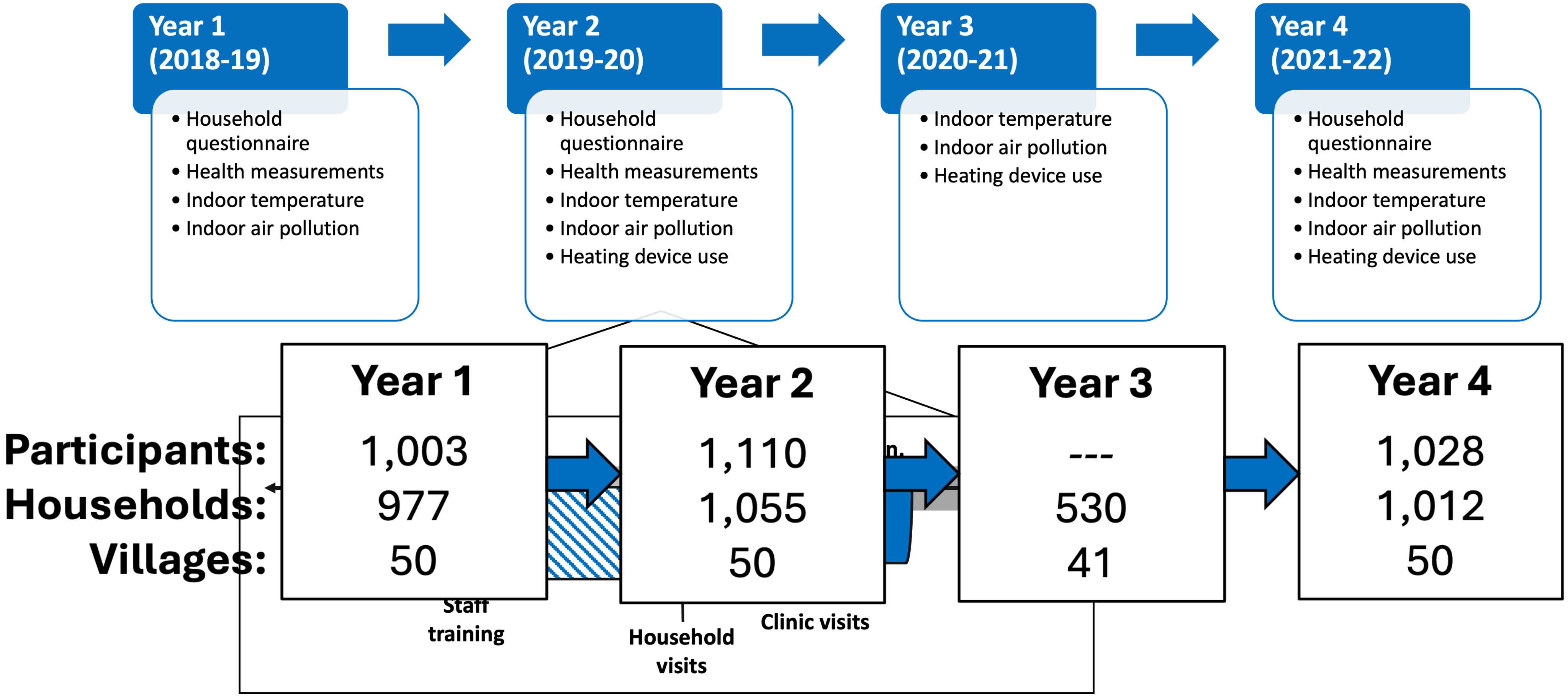
Village sampling

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



Cumulative villages treated: 11 (2019), 17 (2020), 20 (2021)

Data Collection Overview



Measurements

Village

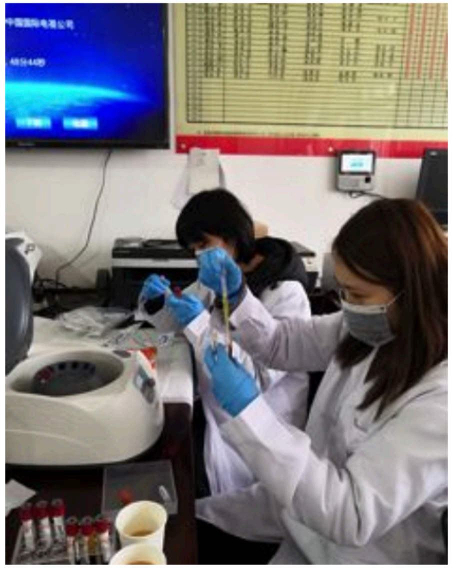
- Outdoor air pollution (1-2 months per season)
- Information on village policies/programs

Household

- Questionnaire on 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%)



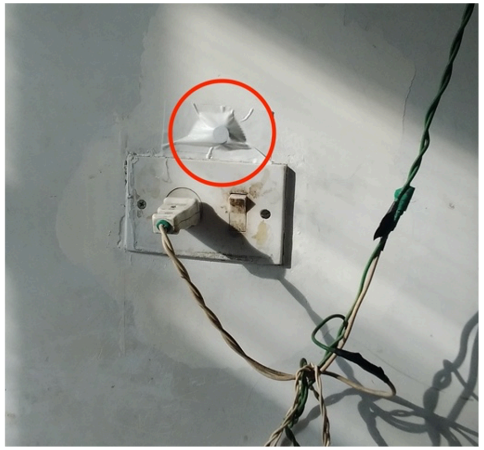
Blood pressure measurement

- 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.

Methods: Statistical Approach

Basic idea for mediation

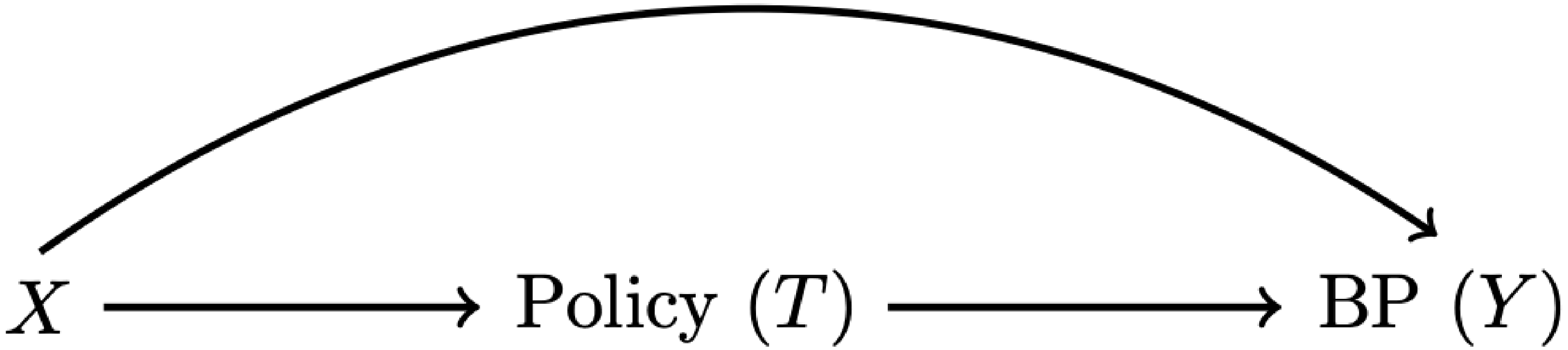
To understand the pathways, mechanisms, and intermediates through which a treatment affects an outcome.

How much of the policy effect is through:

- Policy impacts on $PM_{2.5}$, indoor temperature
- Other pathways (e.g., behavioral changes)
- Allow for multiple mediators

First part of mediation: total effect

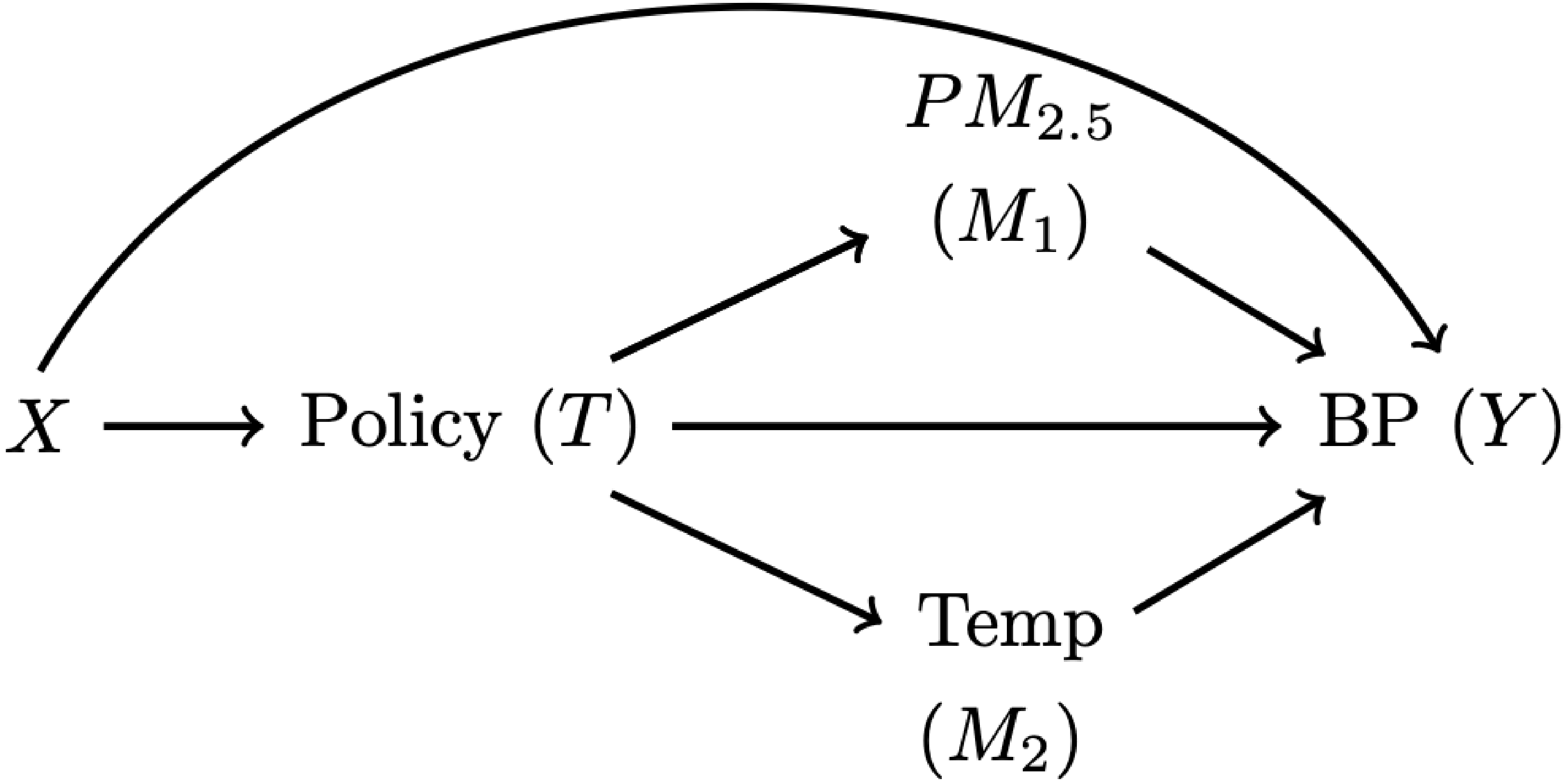
Step 1: Estimate the total effect of policy (T) on BP.



Second part of mediation: decomposition

Basic idea: understand pathways of effects

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



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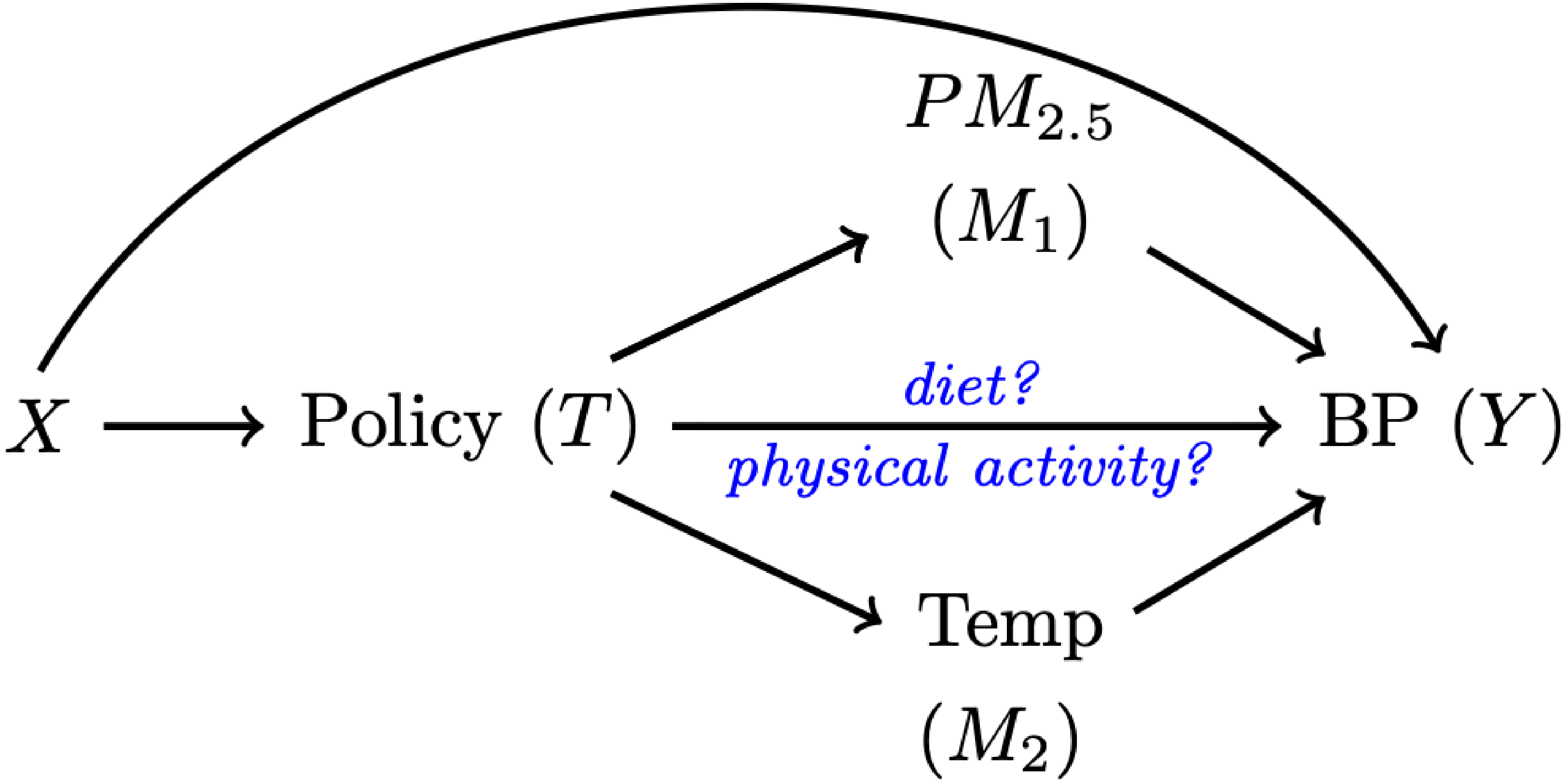

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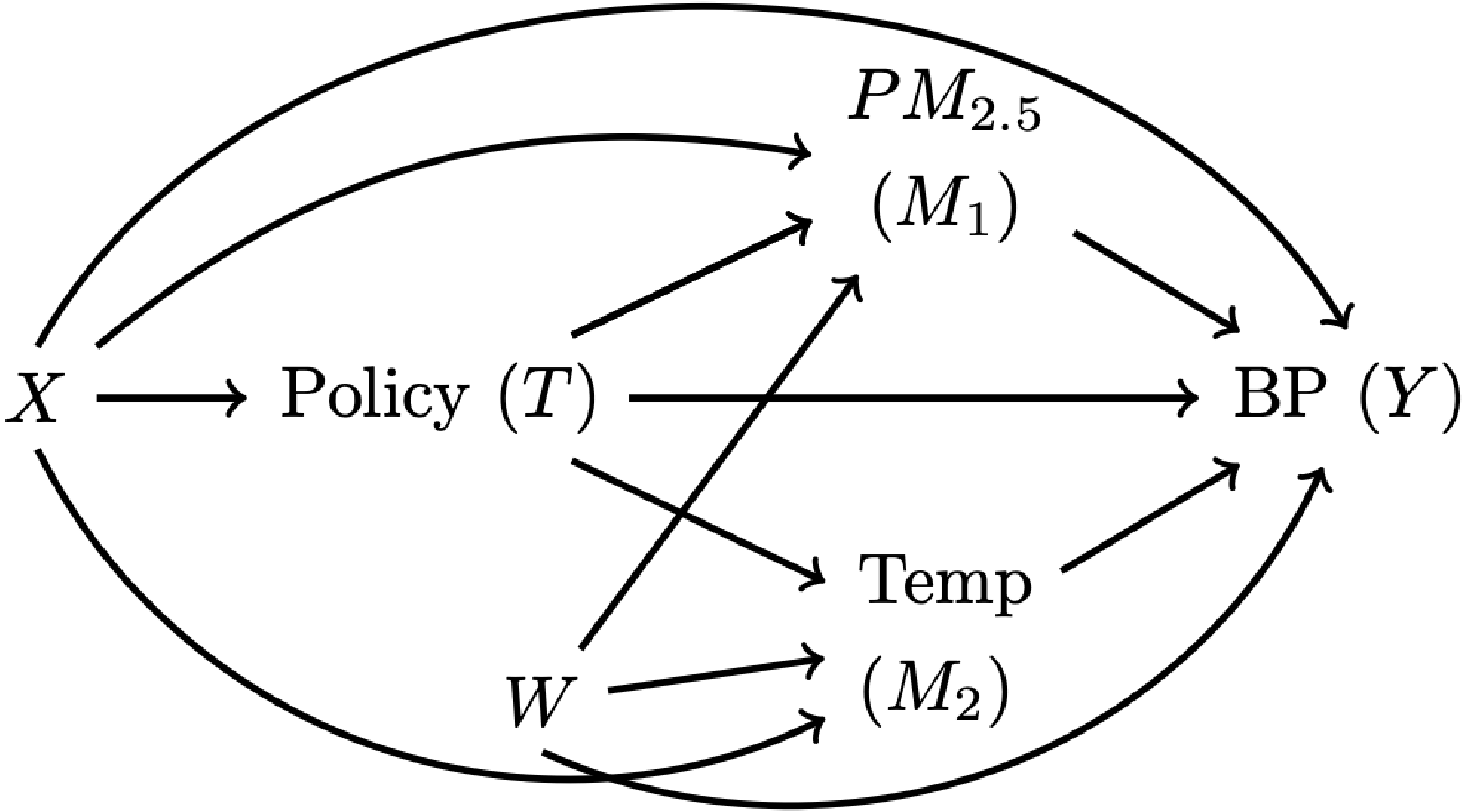
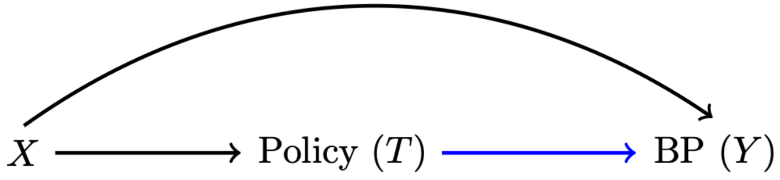


Quantities of interest



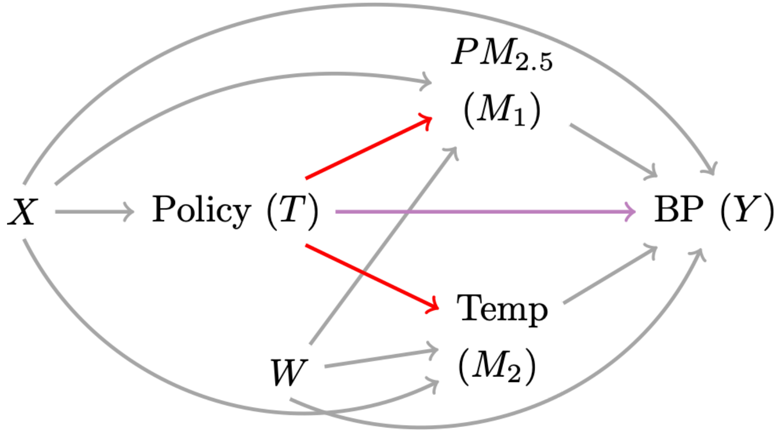
Total effect:

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

The estimated total effect,
where T^* is exposure to ban and T is no exposure:

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

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 $M = m$.

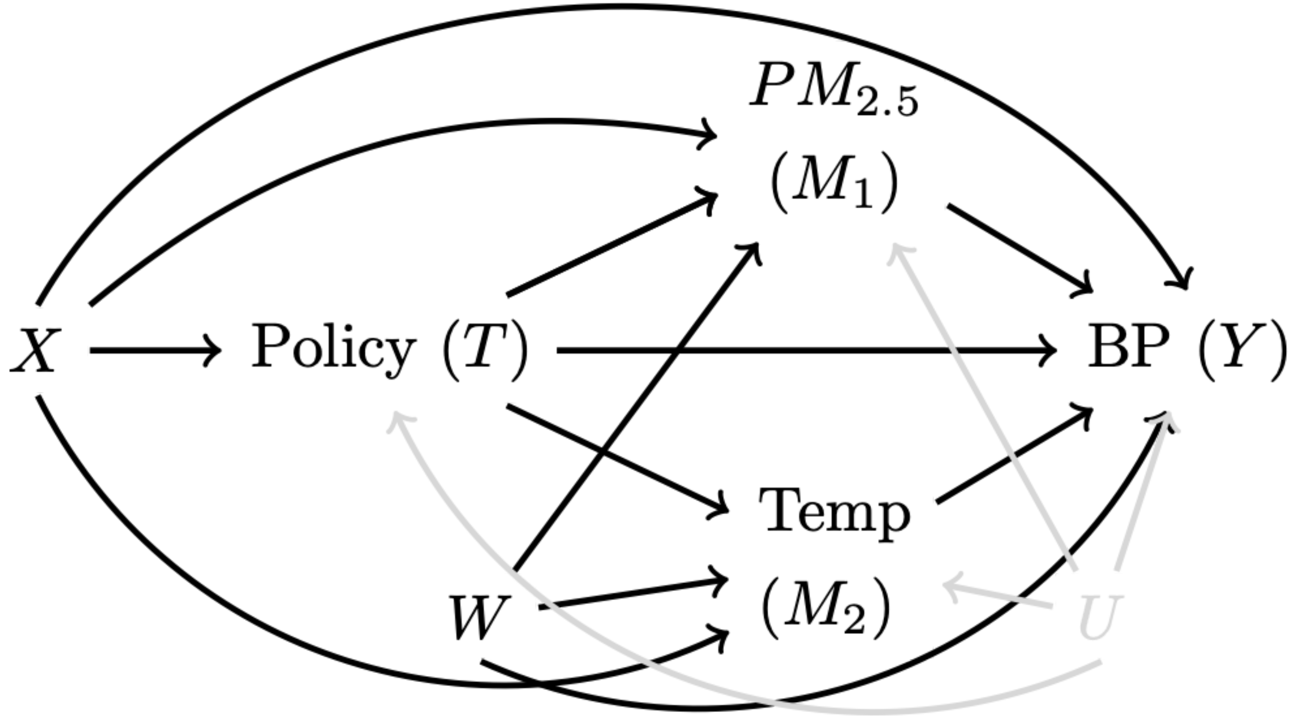
English:

"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.



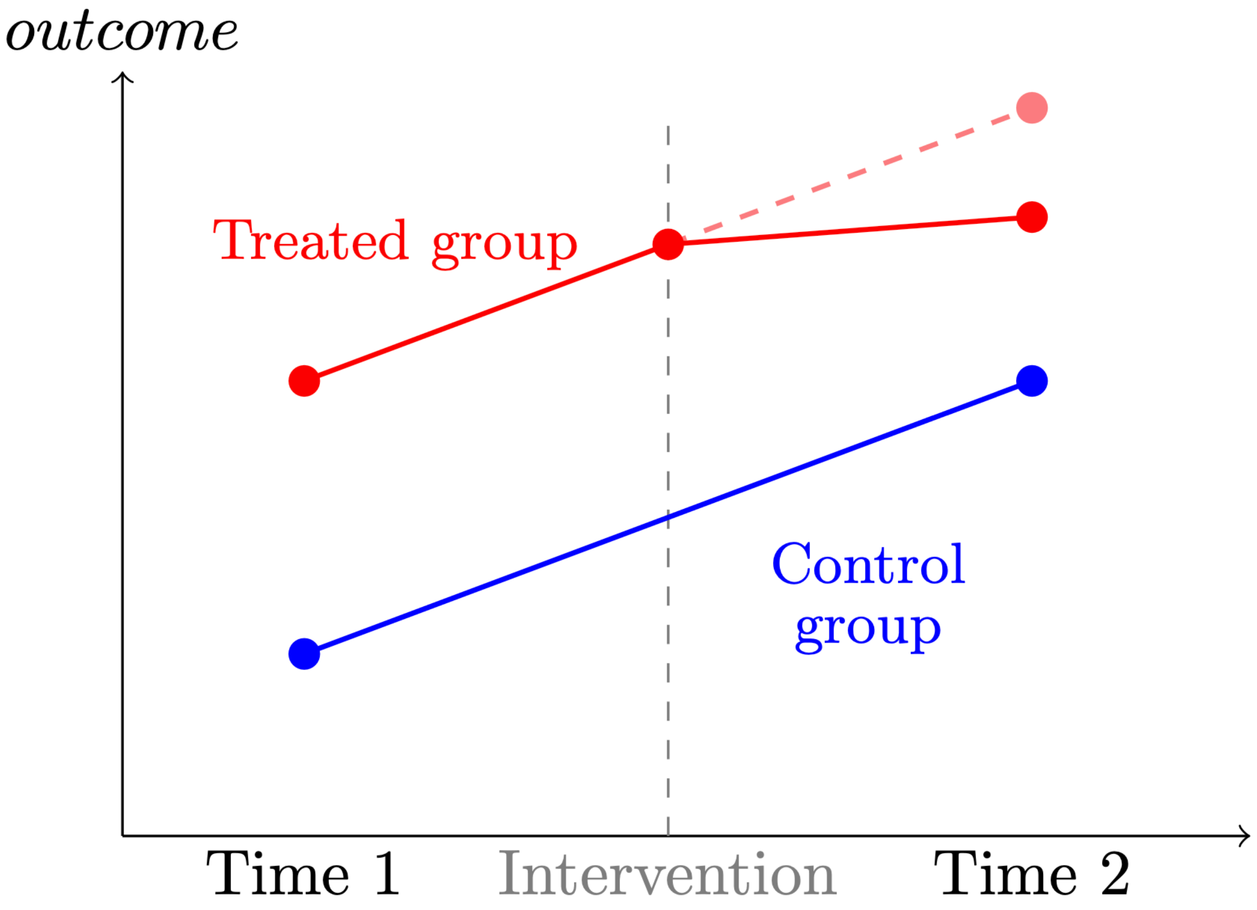
Basic Design: Difference-in-Differences

Challenges:

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

Key assumptions:

- No anticipation
- Parallel trends



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.

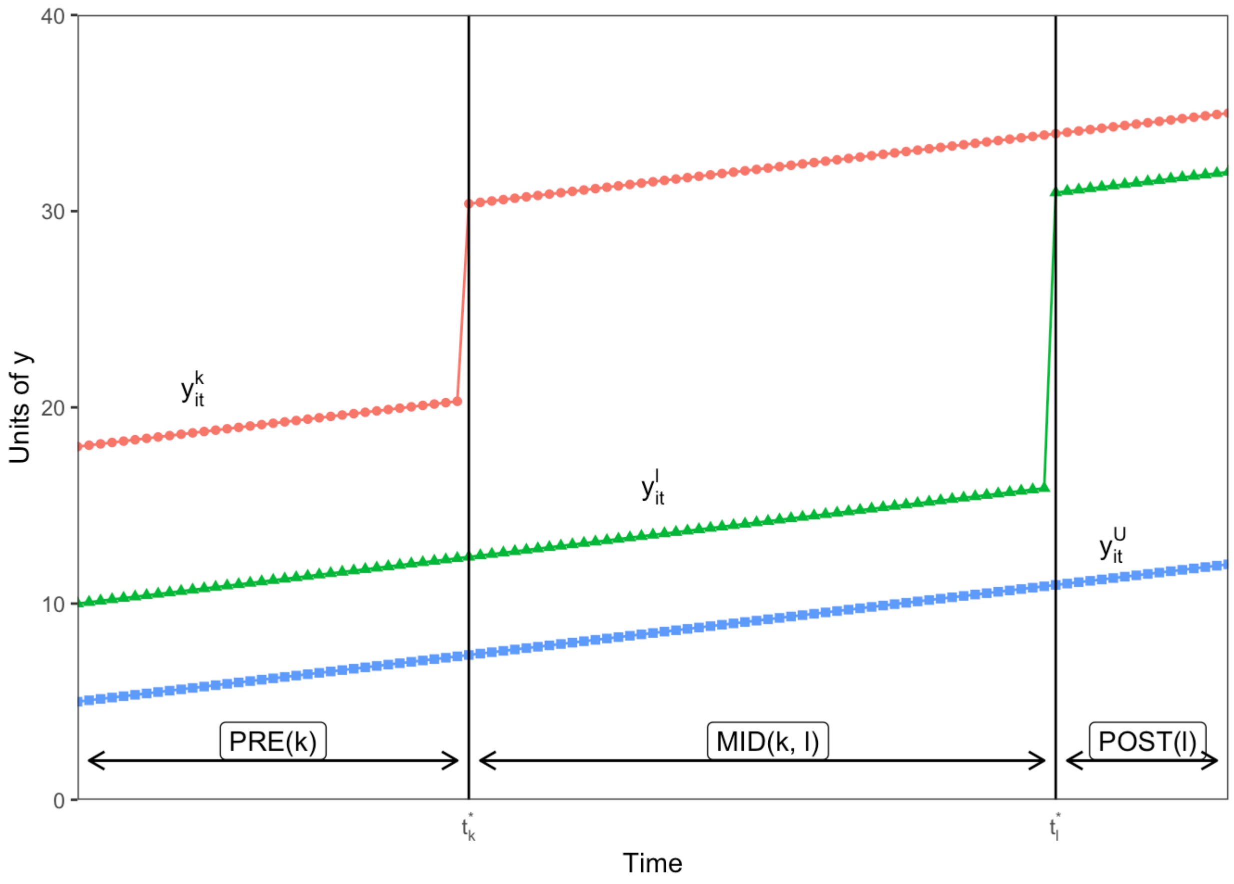
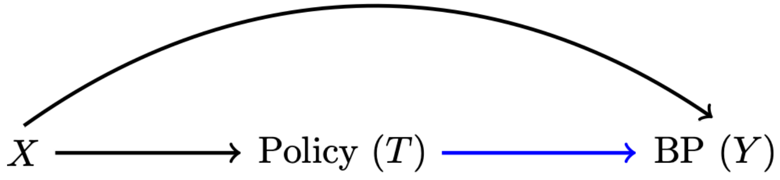


Image: Andrew Baker. See also Goodman-Bacon (2021), Callaway and Sant'Anna (2021), Sun and Abraham (2021)

Statistical model



Total effect via “extended” two-way fixed effects:

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

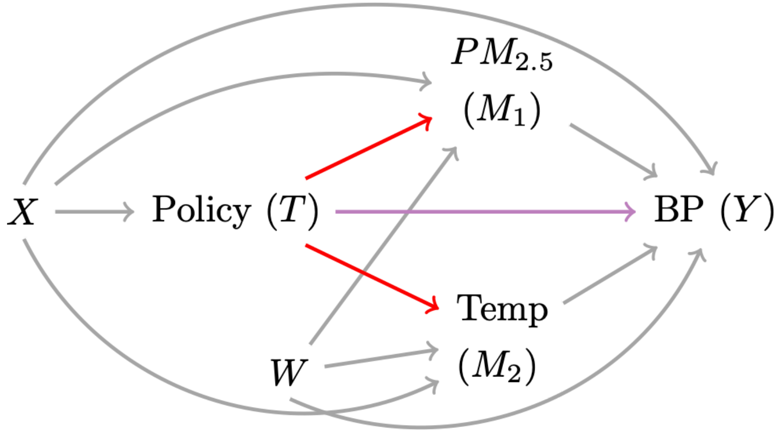
X includes:

- d_r = treatment cohort fixed effects
- fs_t = time fixed effects
- $\mathbf{Z}_{ijt}$ = time-varying covariates (age, sex, wealth index, waist circumference, smoking, alcohol consumption, BP medication)

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

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

Mediation model



CDE estimated by adding M_{it} mediators
plus time-varying covariates $\mathbf{W}_{ijt}$

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

$$+\delta M_{ijt} + \sum_{r=q}^{T} \sum_{s=r}^{T} \eta_{rs}(d_r \times fs_t \times M_{ijt}) + \zeta \mathbf{W}_{ijt} + \varepsilon_{ijt}$$

CDE is average of *ATTs* τ_{rs}, holding M constant.

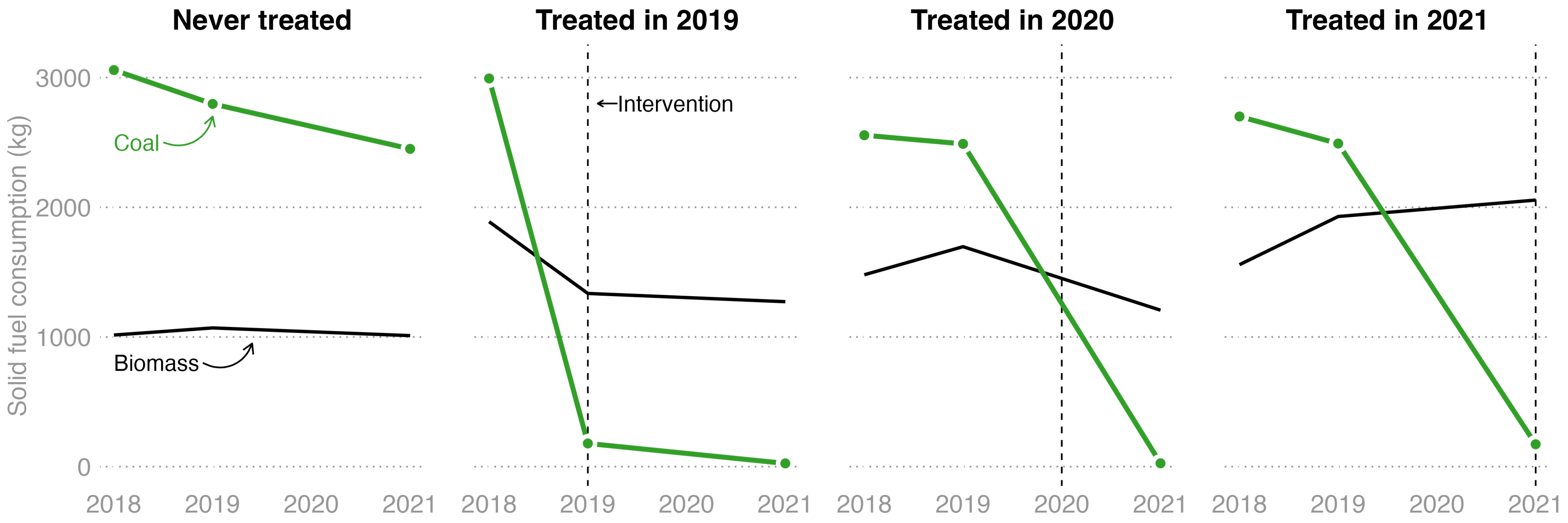
Results

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

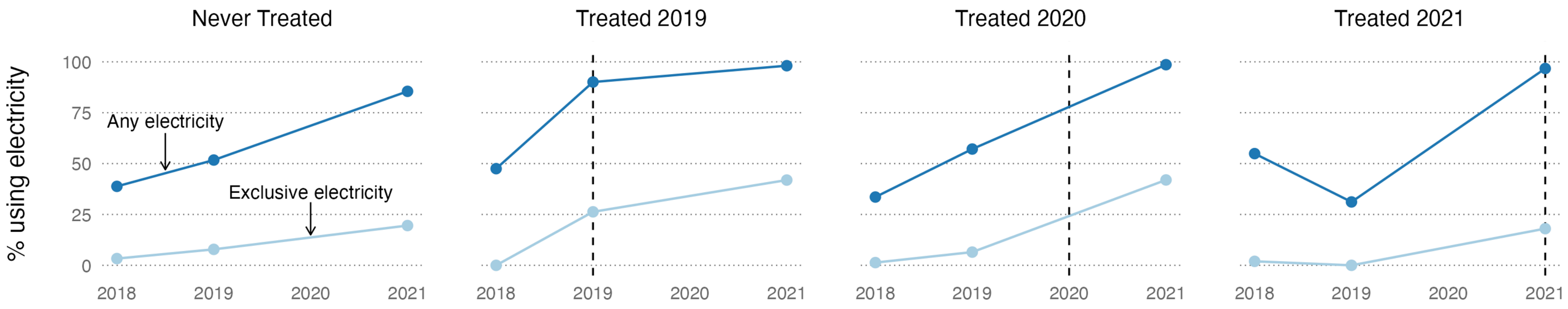
Uptake: Treated units reported using less coal

Also declining in never treated

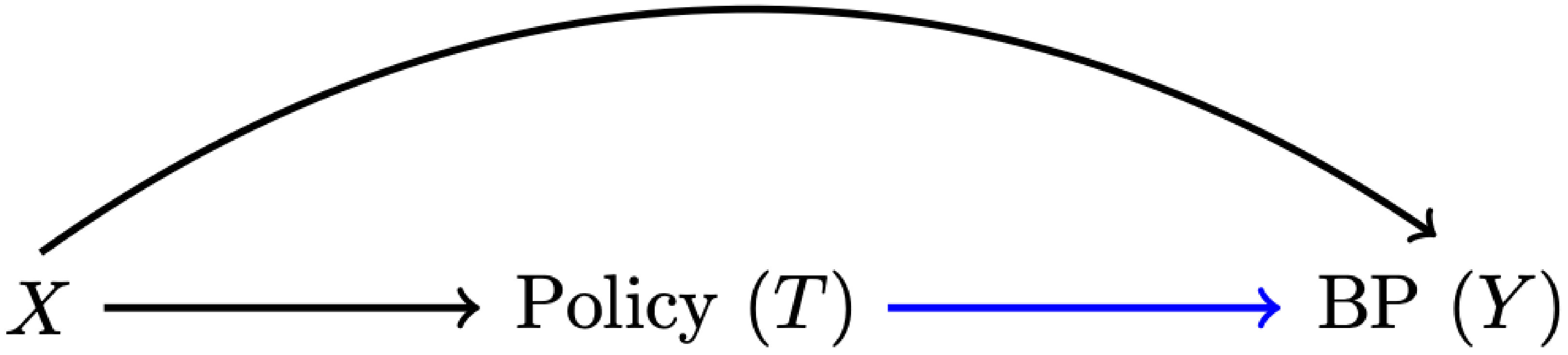


Larger increase in any/exclusive electricty use

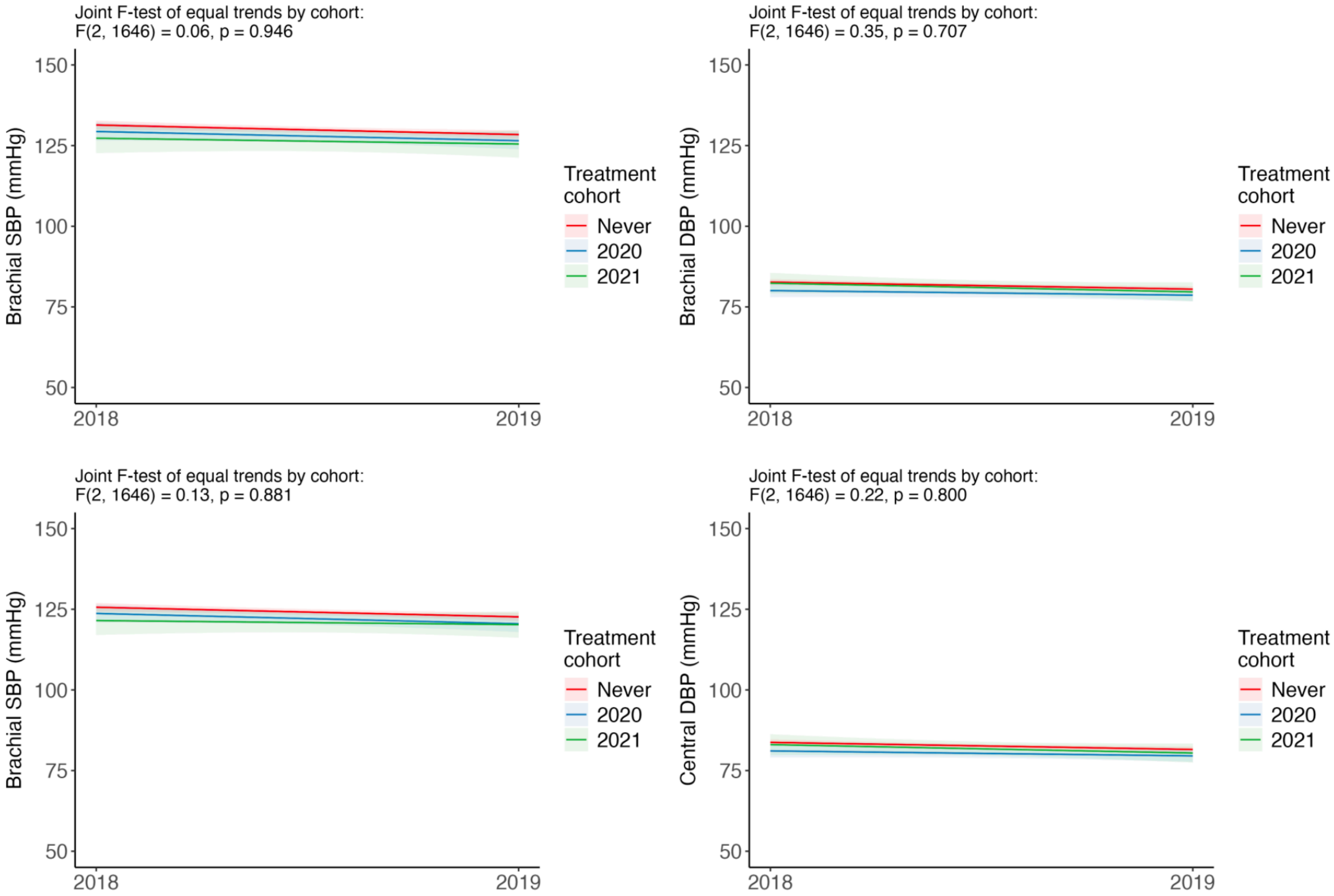
Again, also increasing in never treated



Did the policy affect outcomes?

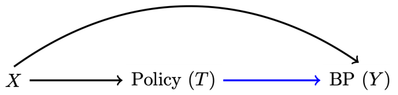


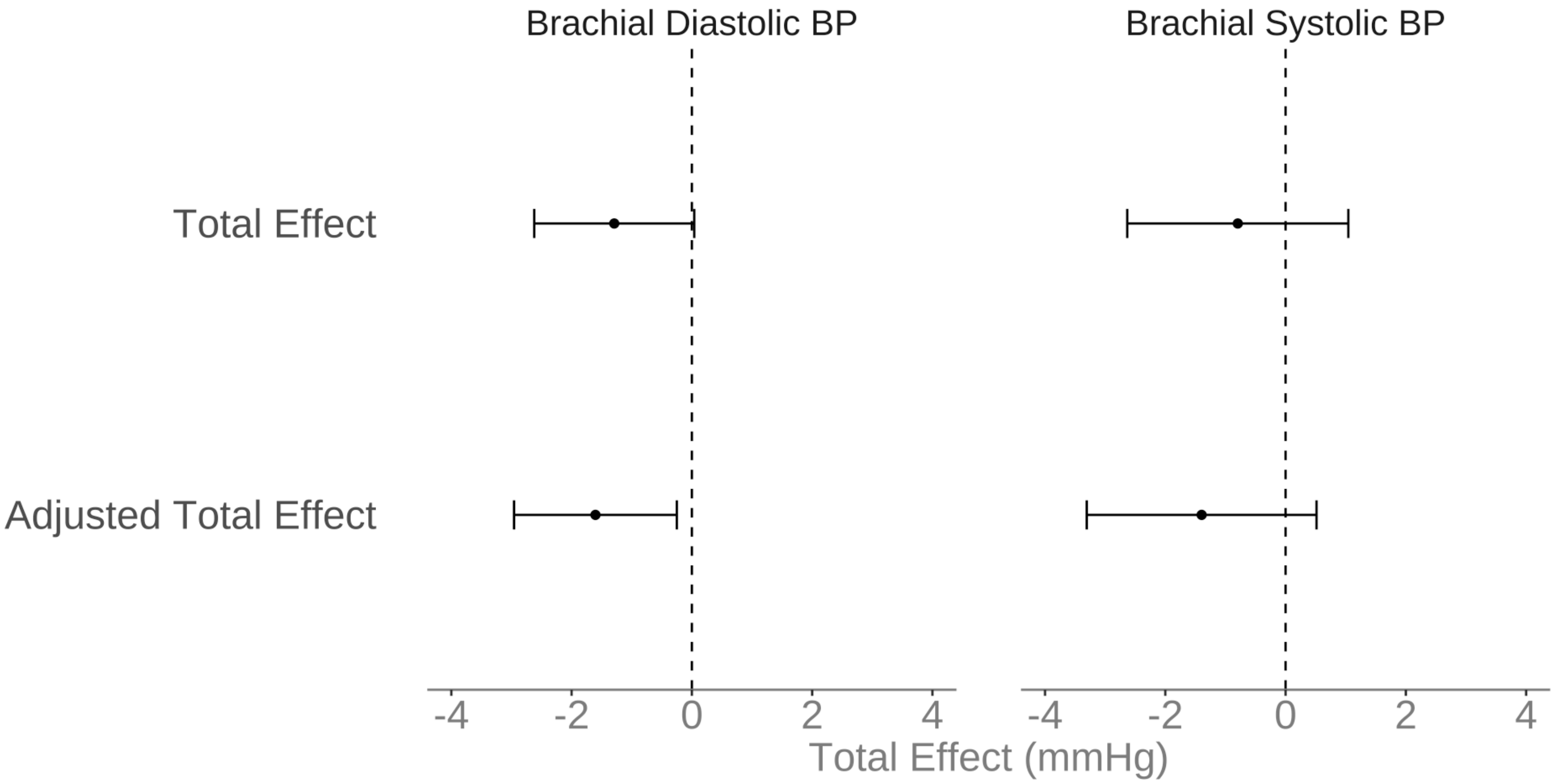
No evidence of non-parallel pretrends for later-treated cohorts



Note: Can't be tested for 2019 treated cohort

Impact on blood pressure





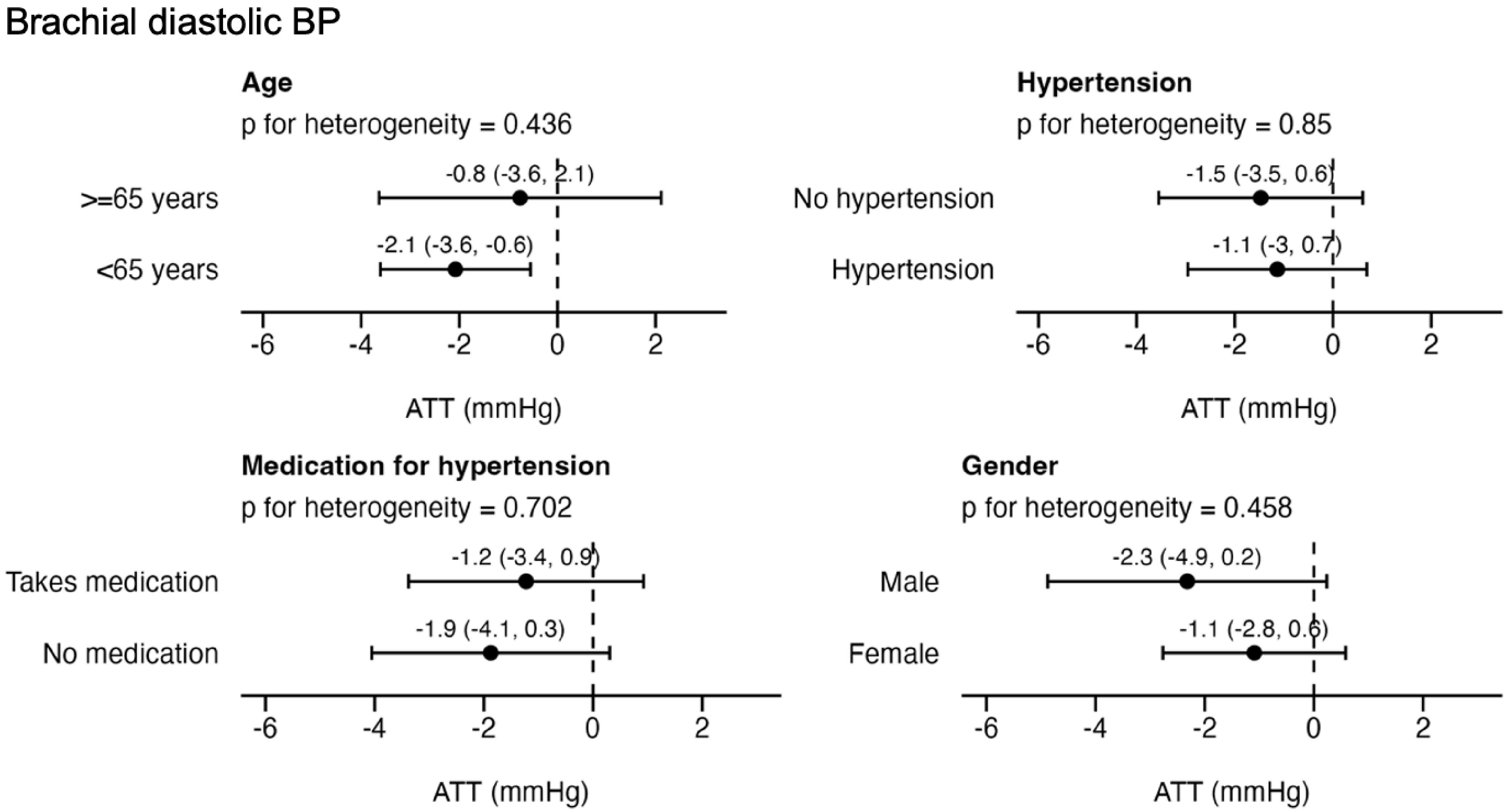
Time-varying covariates: age, sex, wealth index, waist circumference, smoking, alcohol consumption, and use of blood pressure medication.

Potential impact of compositional changes

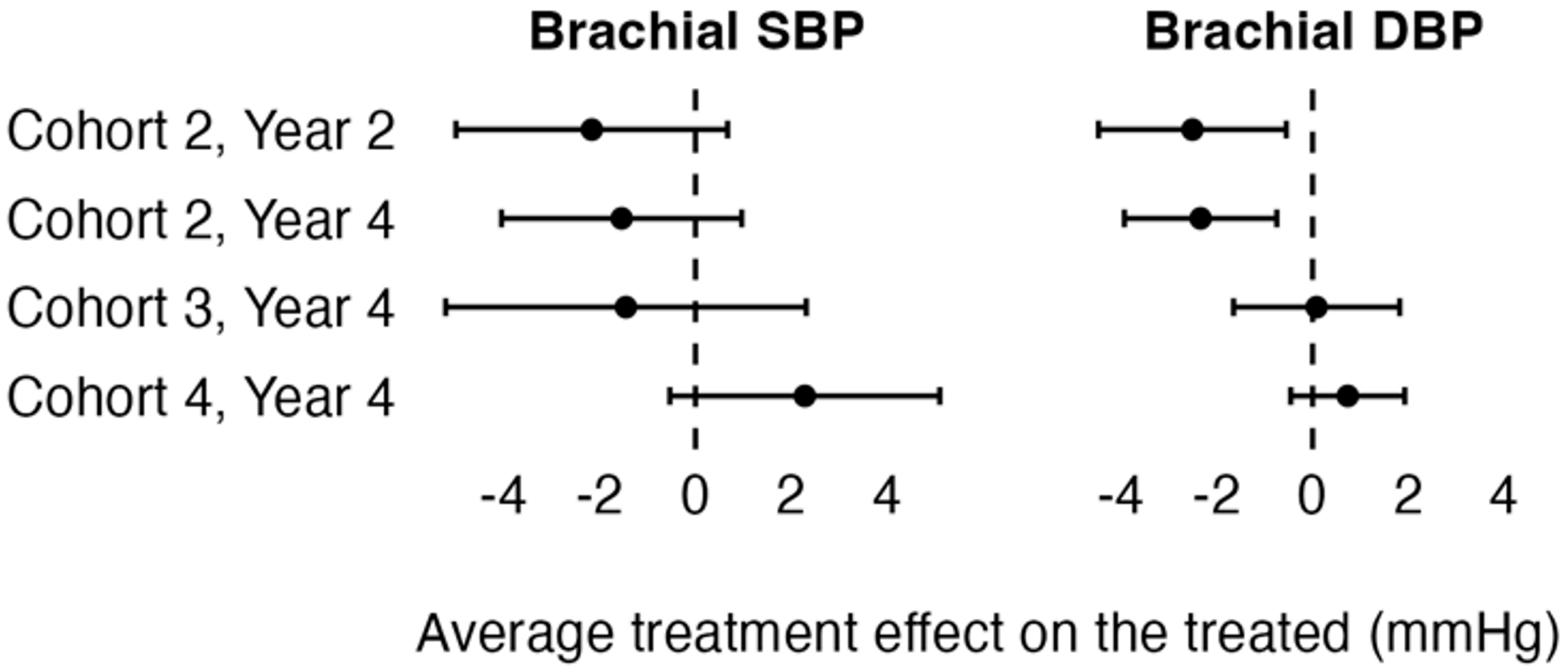
Restricted to *same* particpants across all 3 waves of data collection

	All Participants		Enrolled in W1	
BP Outcome	N	Adjusted ETWFE	N	Adjusted ETWFE
Brachial SBP	1423	-1.4 (-3.3, 0.5)	992	-1.6 (-3.3, -0.0)
Central SBP	1423	-1.4 (-3.3, 0.4)	992	-1.6 (-3.1, -0.1)
Brachial DBP	1423	-1.6 (-2.9, -0.3)	992	-1.7 (-2.9, -0.4)
Central DBP	1423	-1.6 (-2.9, -0.3)	992	-1.7 (-2.9, -0.5)

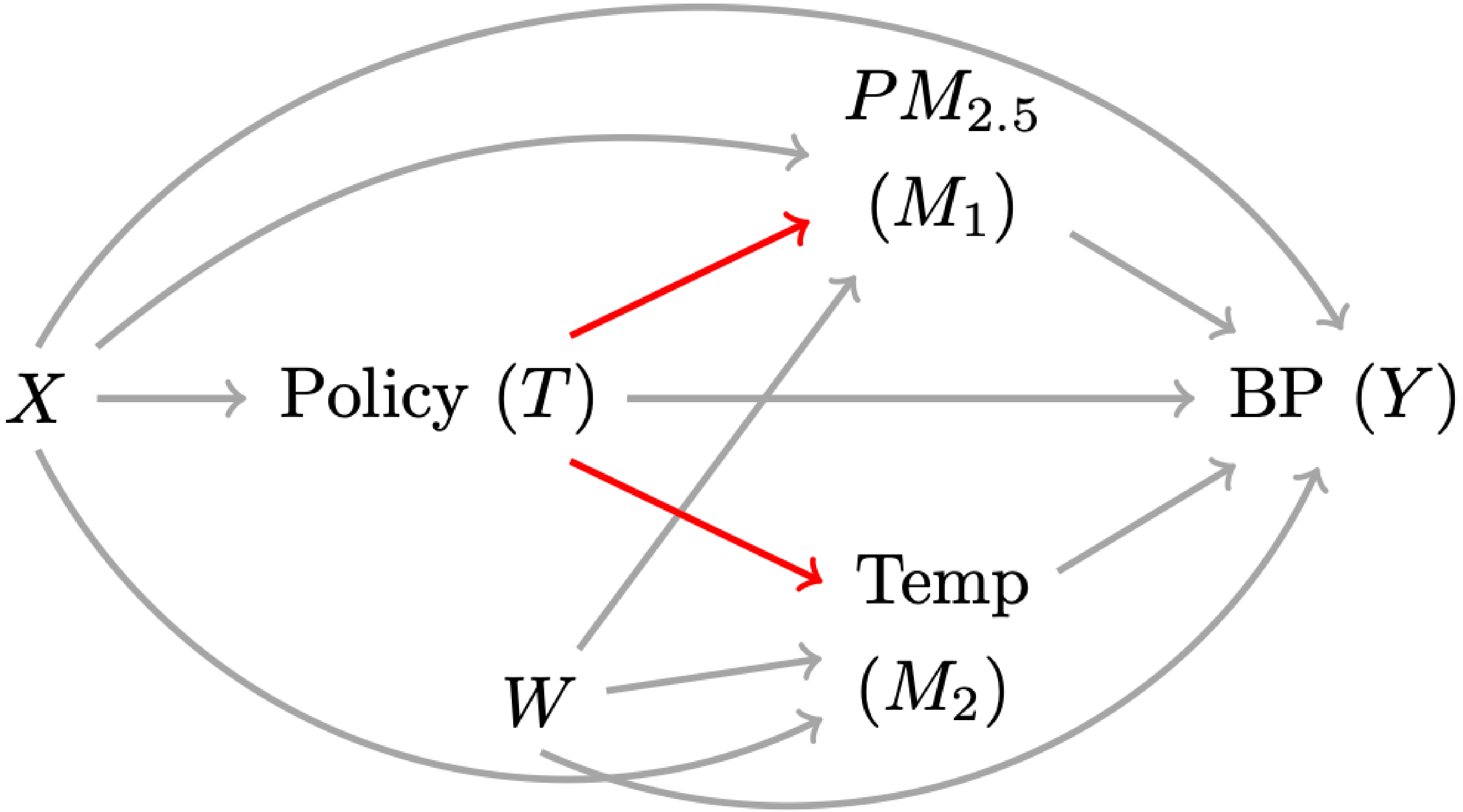
Limited evidence for subgroup differences



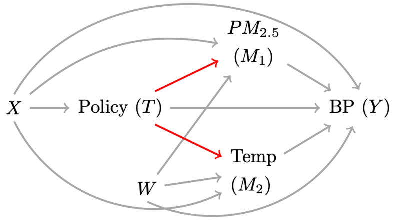
Some evidence of cohort heterogeneity

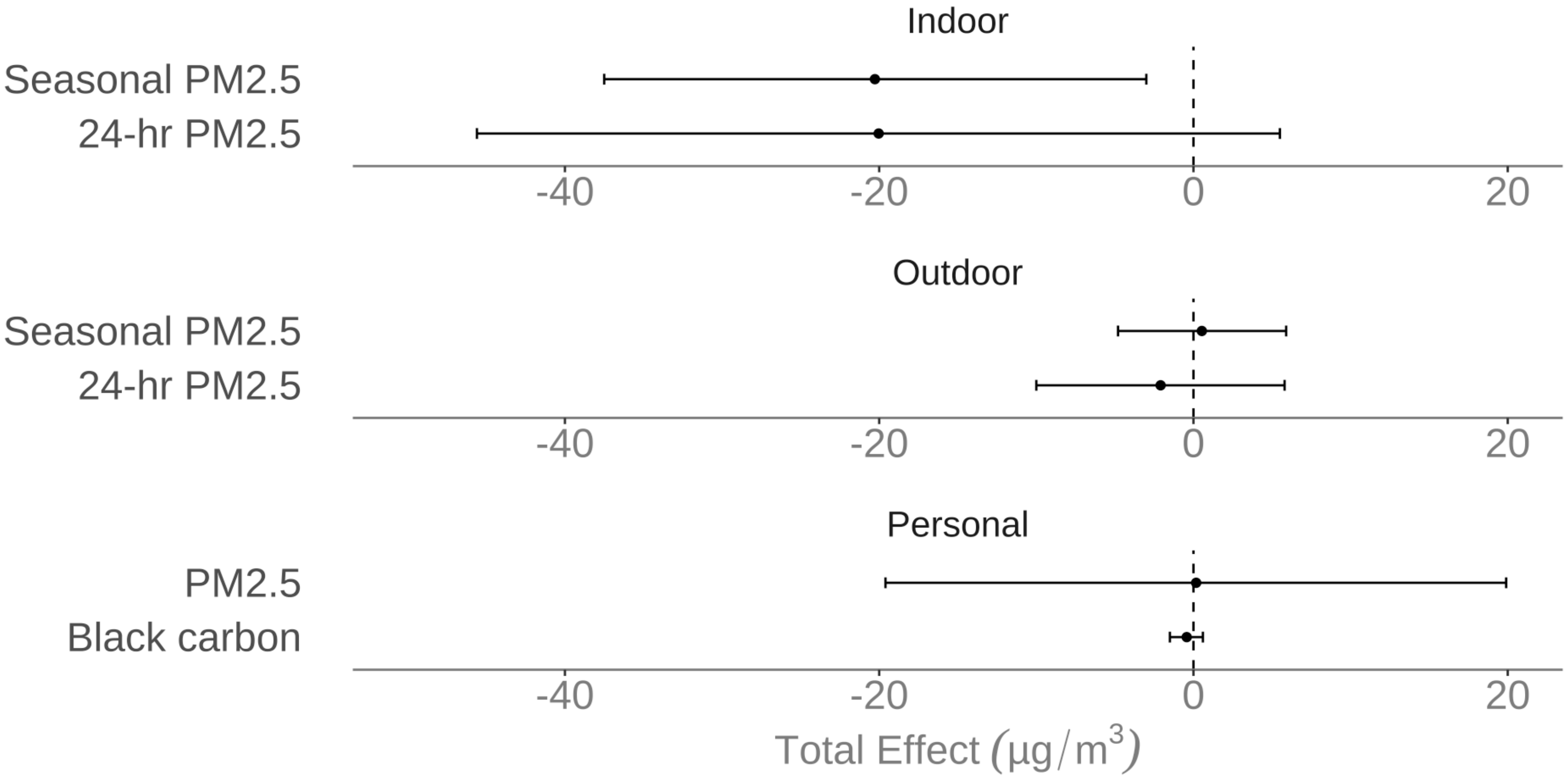


Did the policy affect the mediators?



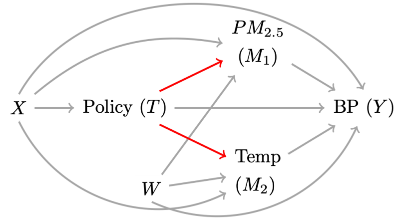
Policy reduced (only) indoor $PM_{2.5}$

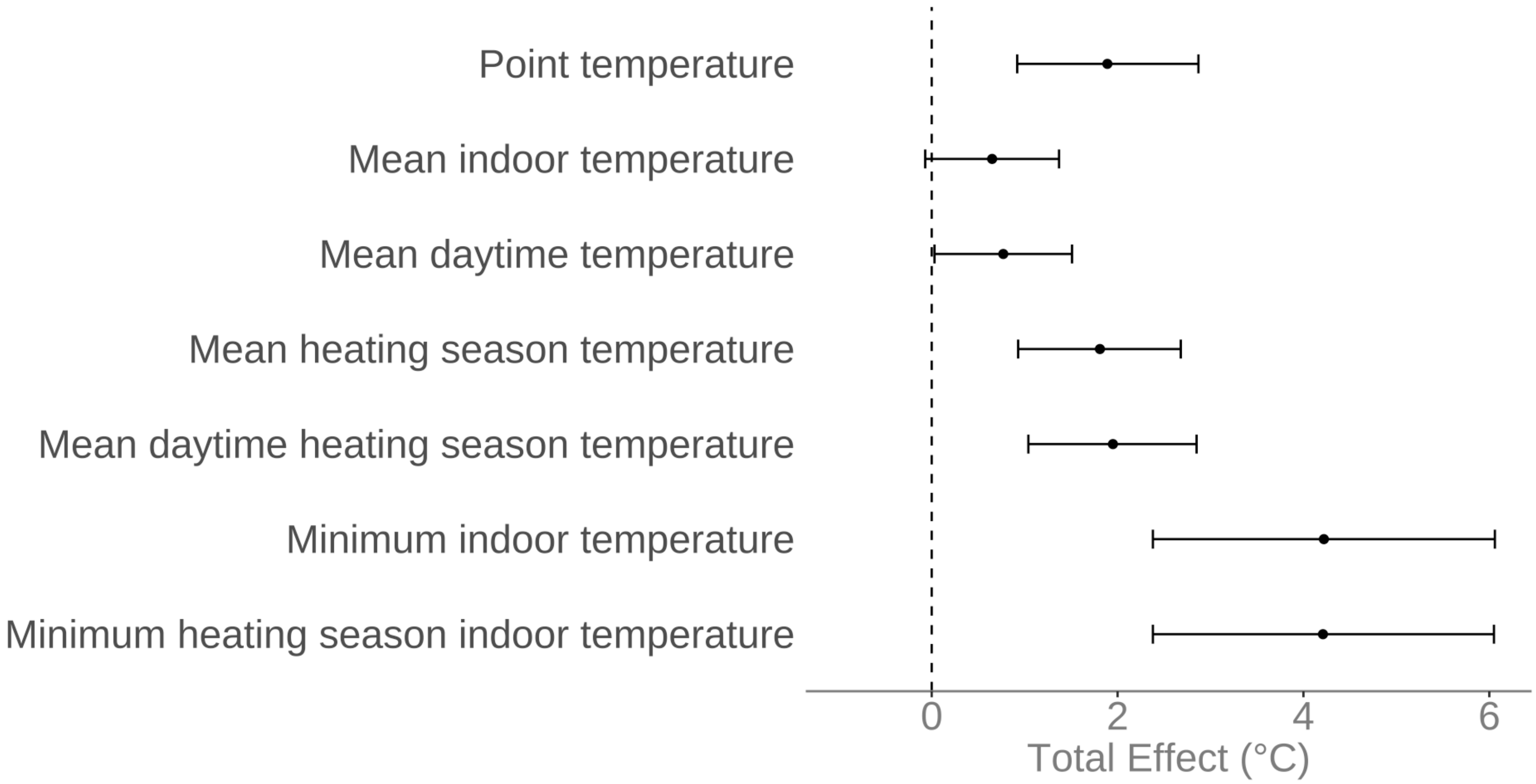




ETWFE models adjusted for household size, wealth index, smoking, outdoor temperature, and outdoor dewpoint.

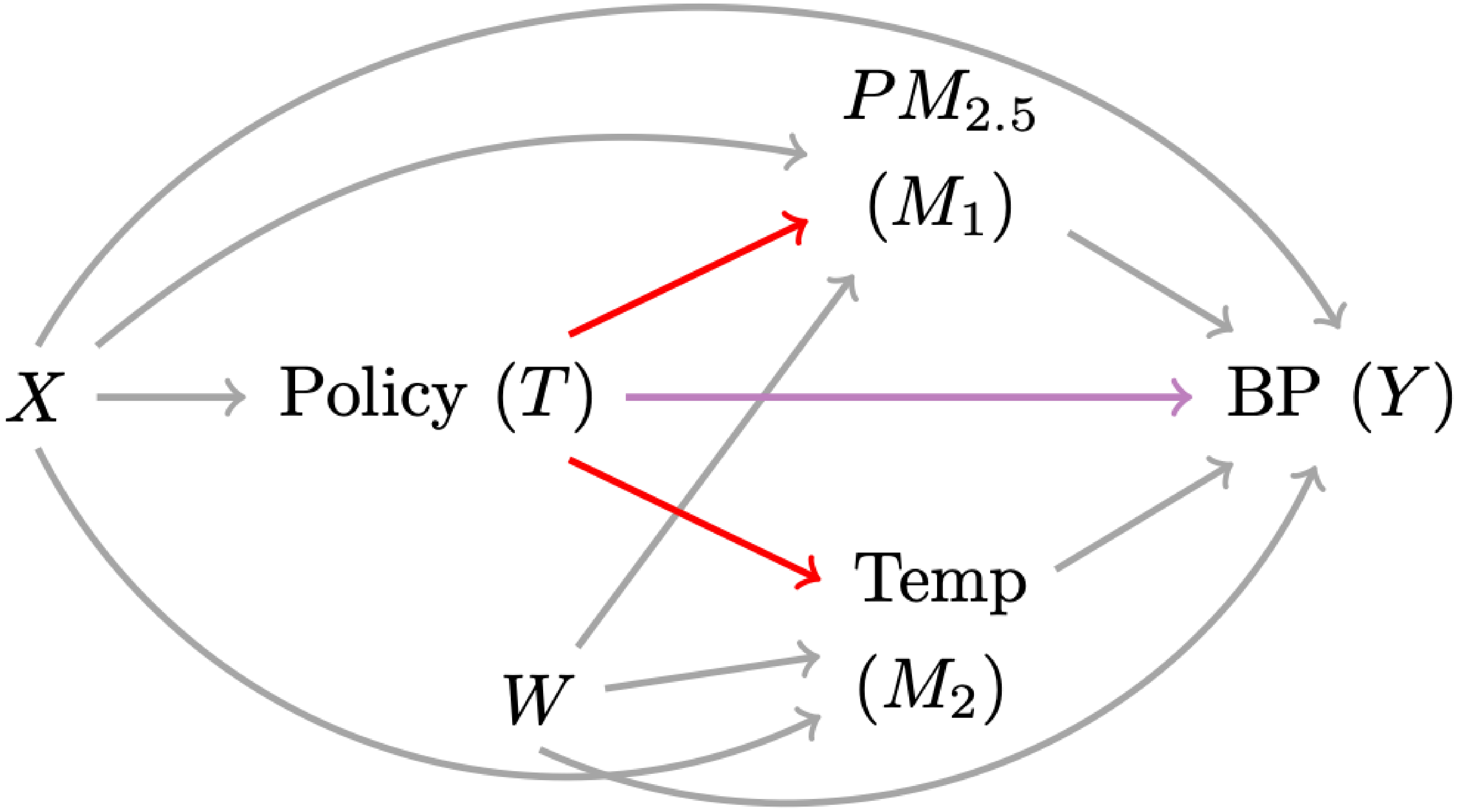
Policy increased indoor temperature



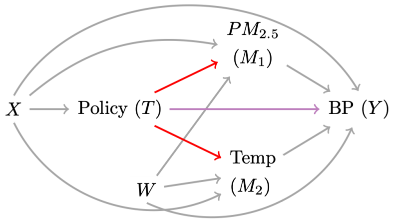


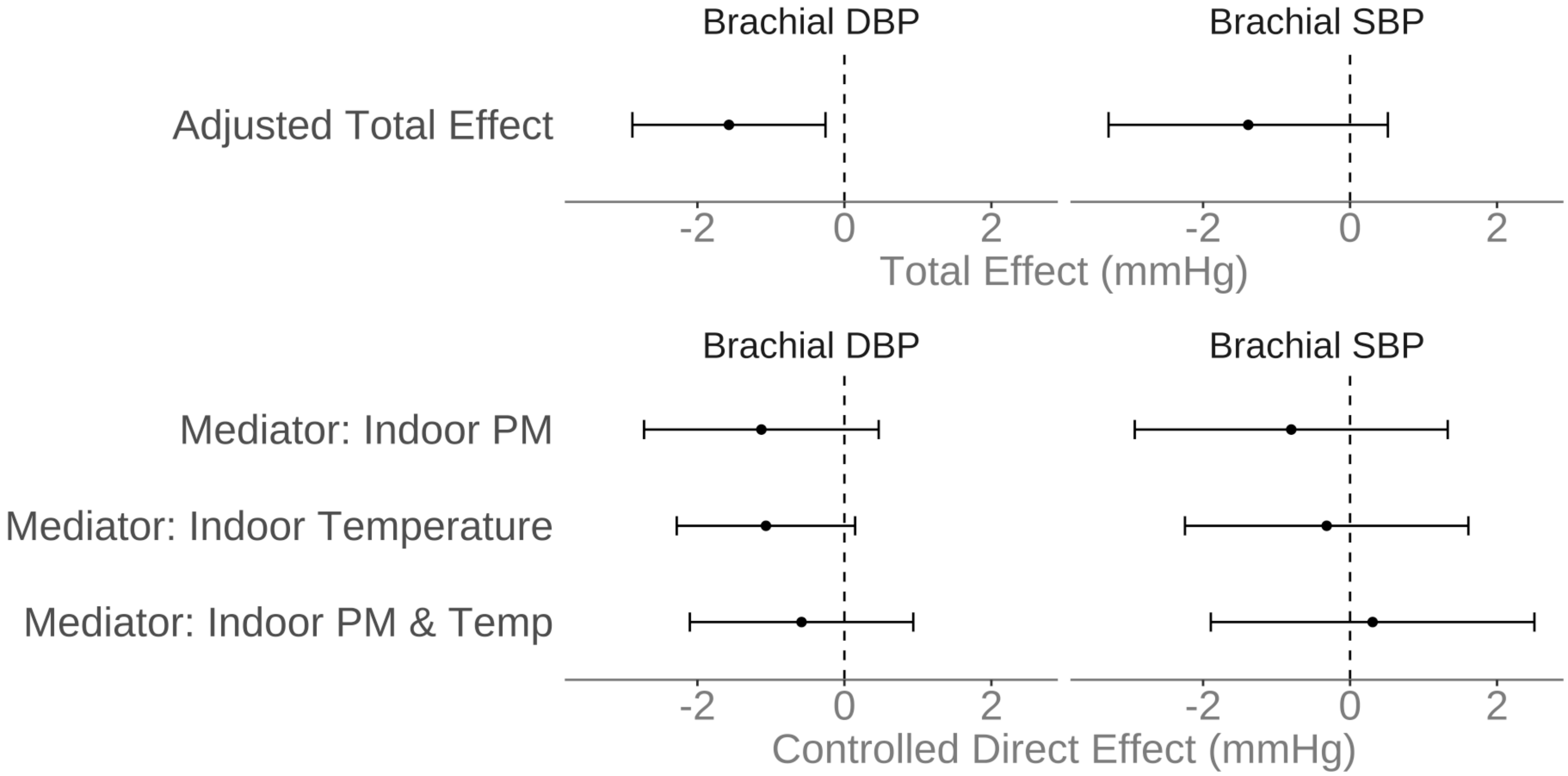
ETWFE models adjusted for the number of rooms and wintertime occupants in the household, age of the primary respondent, and wealth index.

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



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



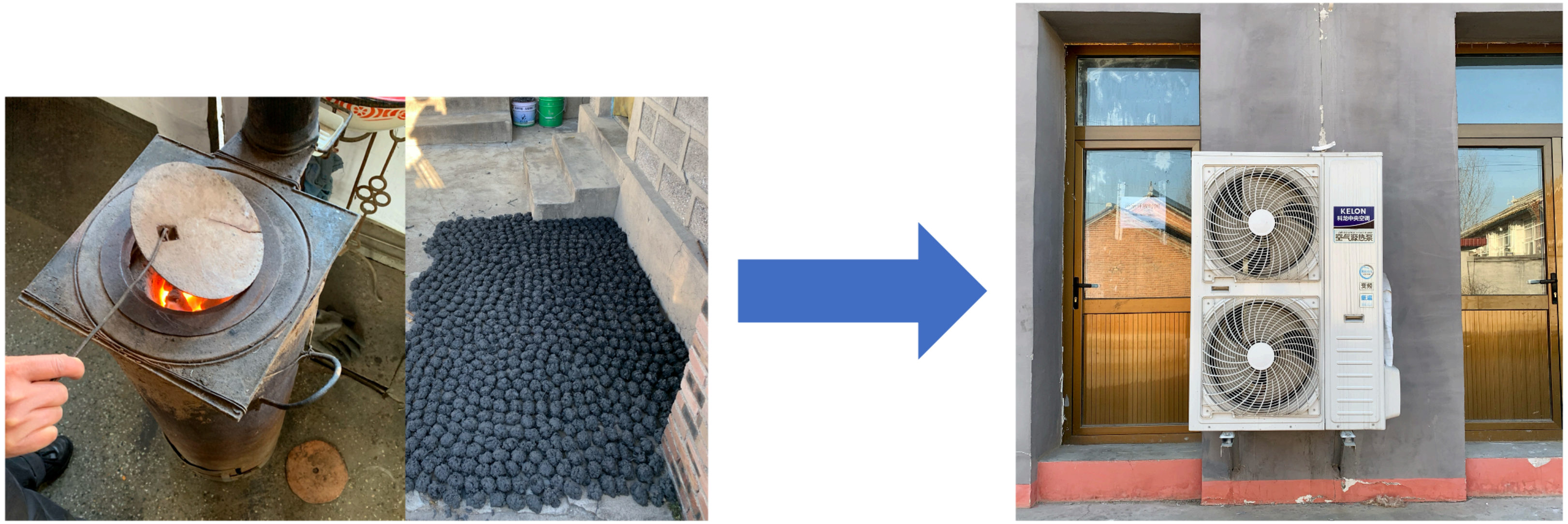


ETWFE model adjusted for time-varying covariates. Mediators set to untreated baseline.

Conclusions

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, moderate effects
- Some evidence of cohort heterogeneity
- BP impacts largely mediated by $PM_{2.5}$ and temperature

Imporant limitations

- No pre-trends for earliest treated group.
- Can't rule out other time-varying confounders.
- Strong assumptions required for mediated effects.

Going forward

- Sustainability: heat pumps remain 5–18 times higher than clean heaters at present, making them unaffordable for many households.
- More work on income and well-being impacts.

Zhou et al. (2022)

Questions?

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