# How does China's Clean Heating Policy affect blood pressure?

Talia Sternbach

PhD Candidate in Epidemiology

McGill University

# The Clean Heating Policy

- Implemented in 2016
- Coal to electric heating in northern China
- 36 million homes enrolled by 2021
- Village-by-village rollout
  - (1) Coal ban
  - (2) Subsidy for heat pumps and nighttime electricity
  - (3) Built out electricity grid

**COAL STOVE**

**HEAT PUMP**

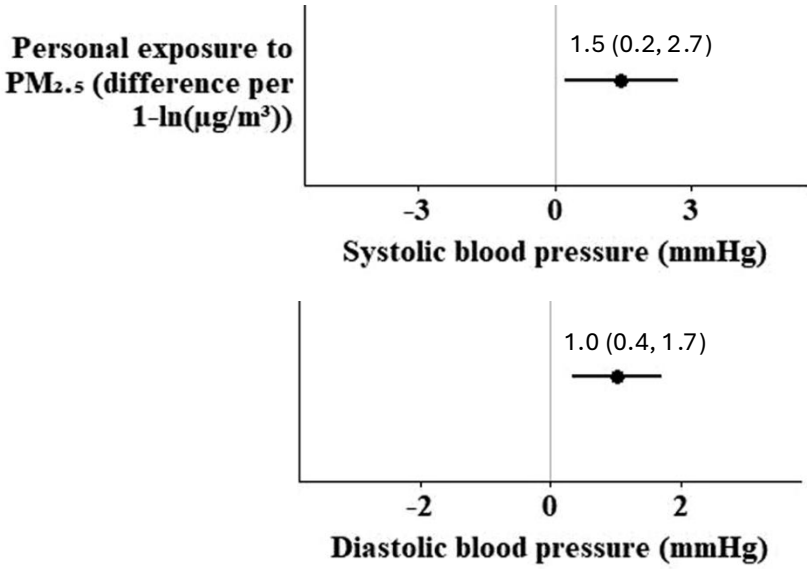
# How do clean energy interventions affect health?

- *Clean energy interventions can drive behavioral, environmental, and health-related changes that may affect health.*
  - Activity patterns
  - Household responsibilities
  - Diet
  - **Environmental exposures**

# The environment and blood pressure (BP)

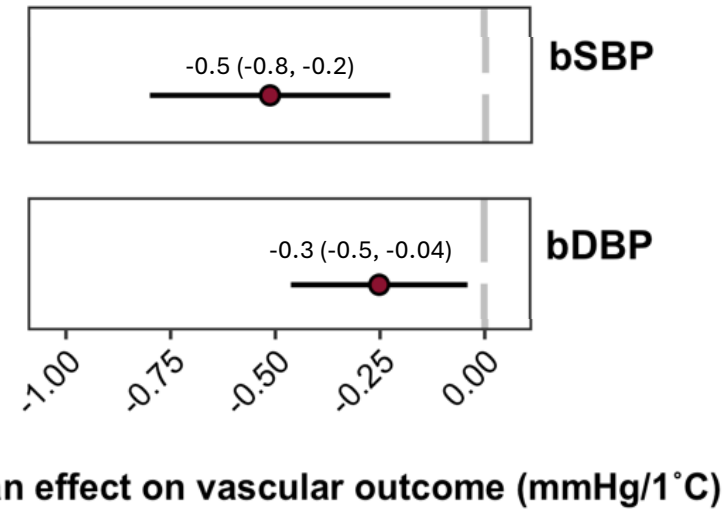
- Cardiovascular disease is the leading cause of mortality in China, and a CDC priority.
- BP is the leading risk for CVD.

**(A) Fine particulate air pollution & BP**




Kanagasabai et al. (2022)

**(B) Indoor temperature & BP**



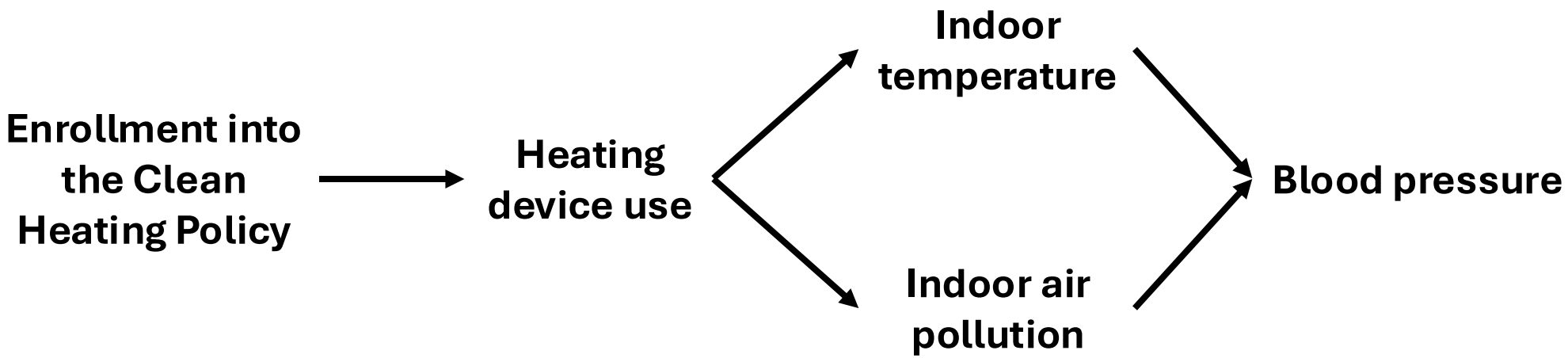

Sternbach et al. (2022)

# Study aims

(1) Estimate the policy's total effect on blood pressure.

(2) Estimate the policy's total effect on indoor temperature and $PM_{2.5}$.

(3) Mediation of the total effect by indoor temperature and $PM_{2.5}$.



# Sampling

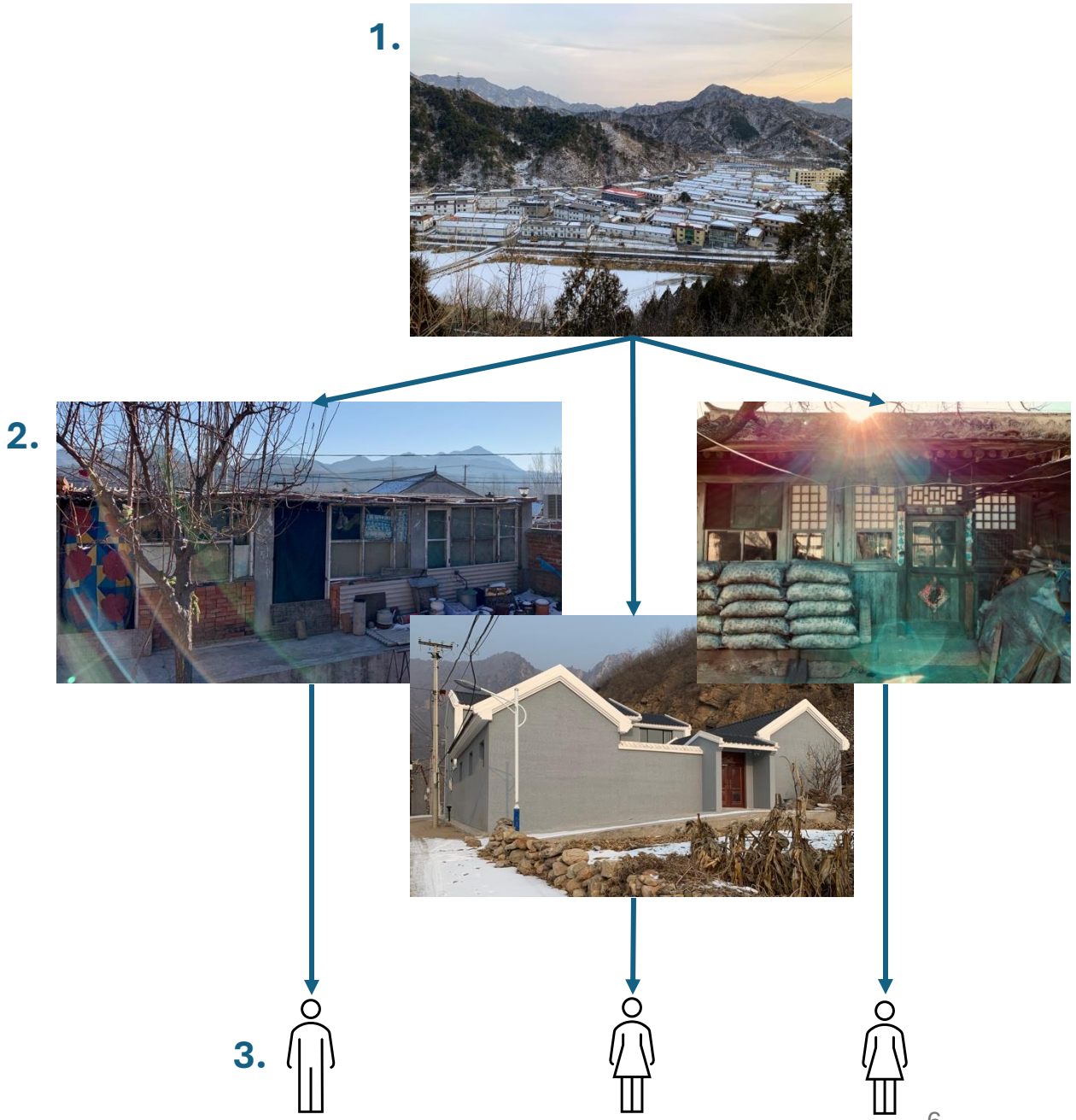
1. **Enrolled 50 villages** from 4 districts in peri-urban Beijing.

2. Sampled households in each village.

3. Randomly sampled 1 participant per household.

**Total of:**

- **1,438 participants**
- **1,236 households**



# Data Collection

**Wave 1 (2018-19)**

- Household questionnaire
- **Health measurements**
- **Indoor temperature**
- **---**
- Outdoor temperature
- Outdoor air pollution
- ---

**Wave 2 (2019-20)**

- Household questionnaire
- **Health measurements**
- **Indoor temperature**
- **Indoor air pollution**
- Outdoor temperature
- Outdoor air pollution
- Heating device use

**Wave 3 (2020-21)**

- ---
- **---**
- **Indoor temperature**
- **Indoor air pollution**
- Outdoor temperature
- Outdoor air pollution
- Heating device use

**Wave 4 (2021-22)**

- Household questionnaire
- **Health measurements**
- **Indoor temperature**
- **Indoor air pollution**
- Outdoor temperature
- Outdoor air pollution
- Heating device use

**Number of enrolled villages**

$$\frac{0}{50} \longrightarrow \frac{10}{50} \longrightarrow \frac{17}{50} \longrightarrow \frac{20}{50}$$

# Indoor $PM_{2.5}$

- Real-time (laser-based) monitor.
- $PM_{2.5}$ concentration measured every 1-min.
- Elevated surface in room where participant spent the most time.
- **Wintertime (Jan. 1 to Mar. 15) mean $PM_{2.5}$.**


# Indoor temperature

- **Measured with a digital thermometer in the 5-mins before BP.**
- Thermometer was held/placed at ~participant height.

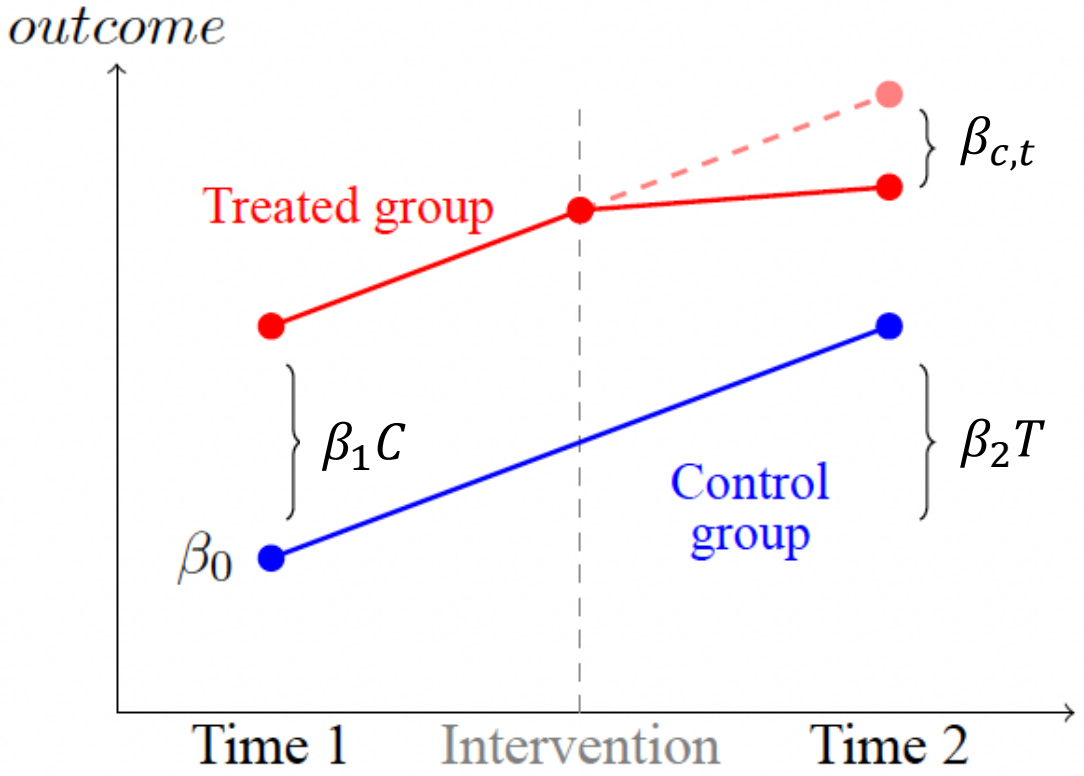
- **Long-term temperature (5-months)**, every 125-min.
- Thermochron iButton

# Blood pressure

- Home BP measurements.
- 3-5 times on participant's supported right arm.
- **Mean of final 2 measurements used in analysis.**
- Quality controls
    - 5-mins quiet, seated rest.
    - Proper posture, 2 feet on the floor
    - Proper cuff-size
    - Standards for home BPs recommended by most hypertension guidelines.

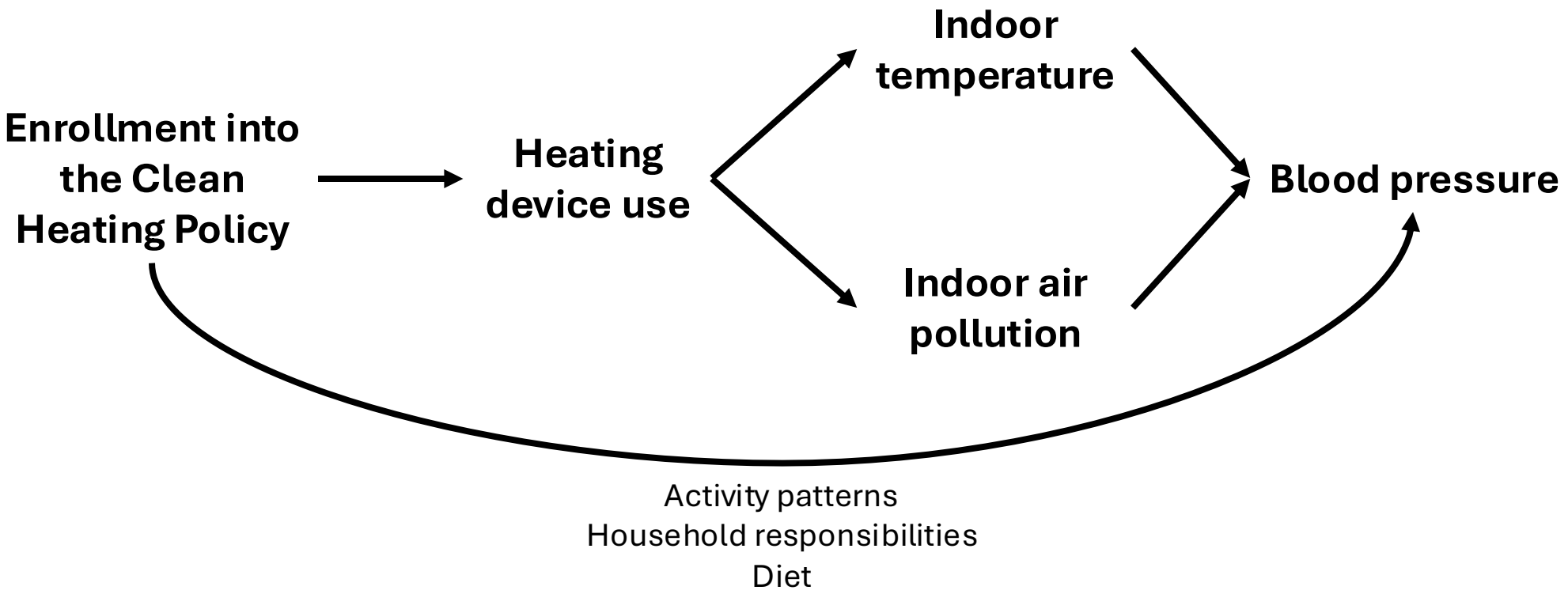
# Policy impacts with difference-in-differences

- Estimated policy impacts with difference-in-differences.
- $Y_{ict} = \beta_0 + \beta_1 C + \beta_2 T + \beta_{c,t}(C * T) + \varepsilon_{ict}$
- Assumptions:
  - Parallel outcome trends
  - No treatment anticipation
  - No co-interventions

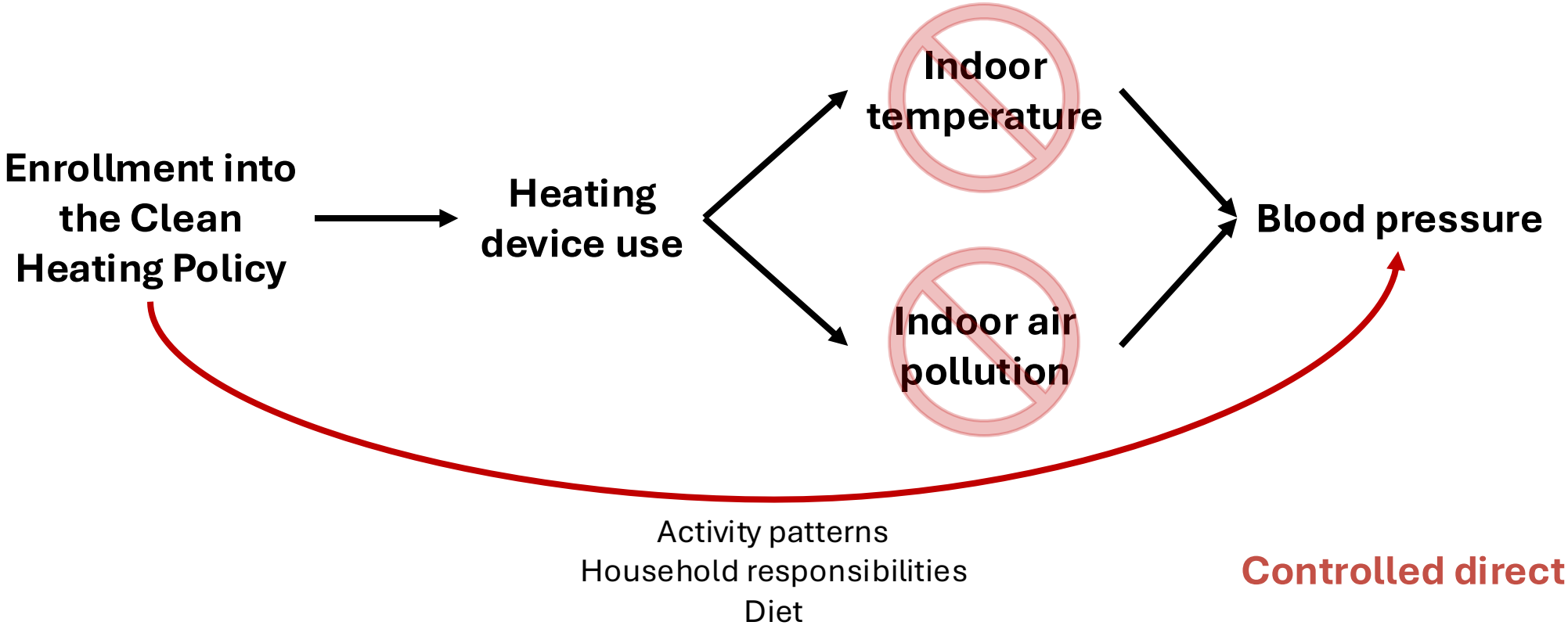



Wooldridge 2021

# Estimating the **total effect**



# How does mediation work?




**Controlled direct effect:**

*"Effect of the policy on BP through pathways other than the mediators."*

# Similar baseline characteristics by treatment status

| | Never Treated | Eventually Treated |
|---|---|---|
| **Number of villages** | 30 | 20 |
| **Number of participants** | 603 | 400 |
| **Age (years)** | 59.8 (9.3) | 60.3 (9.1) |
| **Sex (% female)** | 357 (59.2) | 240 (60) |
| **Tobacco smoke** | | |
| Current/former/second-hand smoke | 466 (77.3) | 322 (80.5) |
| No exposure to tobacco smoking | 130 (21.6) | 76 (19) |
| **Indoor temperature (˚C)** | 13.8 (3.6) | 13.5 (3.3) |
| **Personal exposure to $PM_{2.5}$ (μg/m³)** | 78.6 (2.9) | 63.6 (2.9) |
| **Waist circumference** | 87.7 (10.5) | 85.4 (9.5) |
| **Systolic brachial BP (mmHg)** | 131.4 (16.8) | 128.7 (14.3) |
| **Diastolic brachial (mmHg)** | 82.7 (11.6) | 82.1 (11.3) |
| **High BP (% with high BP)** | 370 (61.4) | 233 (58.2) |

# Treated homes reported less coal use

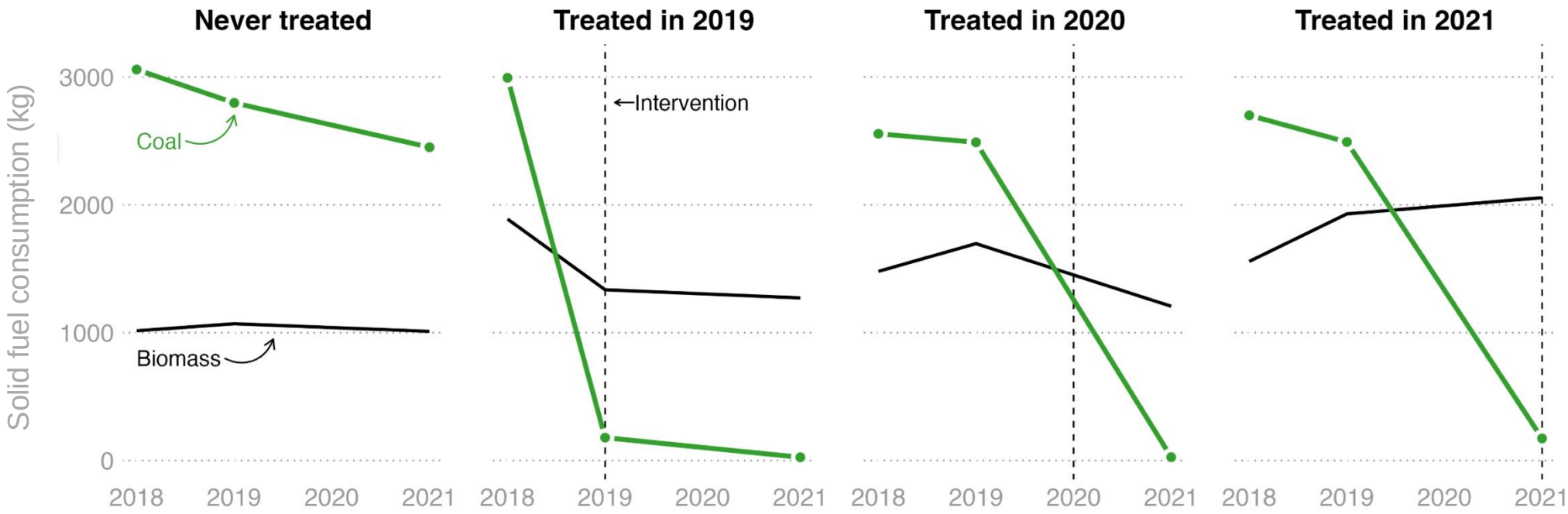
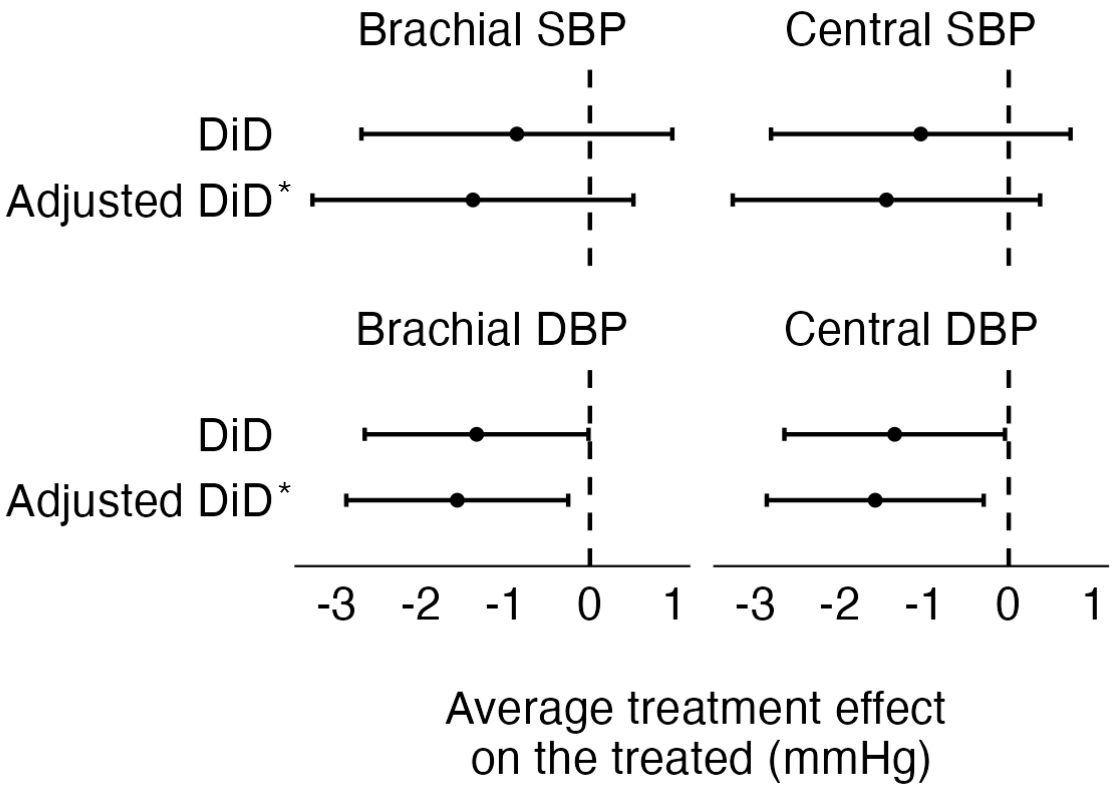



*Figure by Sam Harper, McGill University*

# The CHP modestly lowered blood pressure




ATT systolic BP

-1.4 mmHg (95% CI: -3.3, 0.5)

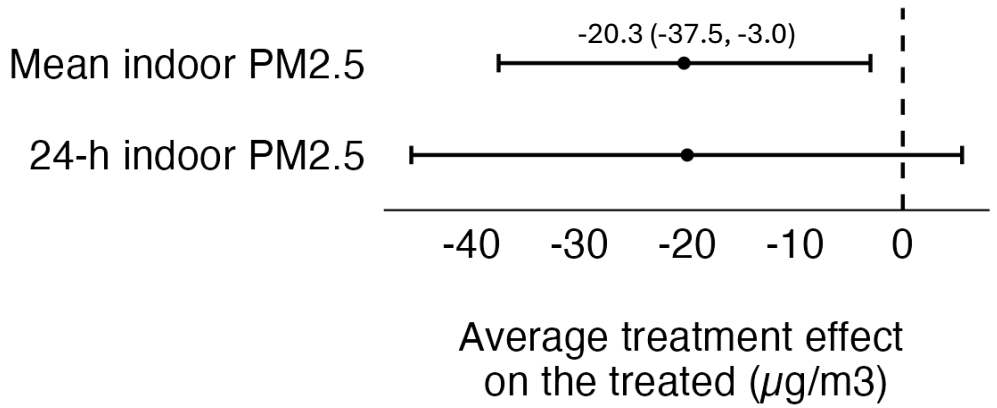
ATT diastolic BP

-1.6 mmHg (95%CI: -2.9, -0.3)

*Models included additional terms for sex, age, waist circumference, alcohol consumption, smoking, use of antihypertensive medication.

# Lower indoor $PM_{2.5}$ and warmer indoor temperature

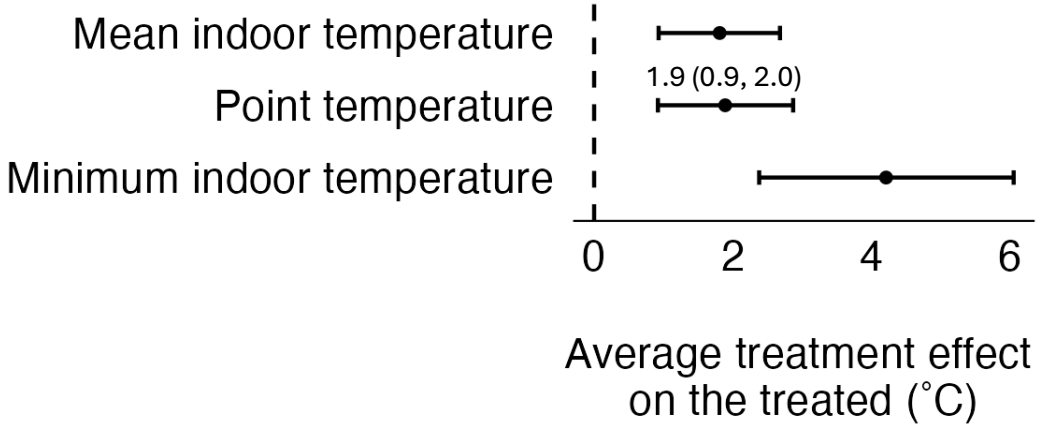
## Policy impacts on indoor $PM_{2.5}$




Note: Mean indoor $PM_{2.5}$ is a heating season (Jan. 15 to Mar. 15) average. The 24-h measure is averaged over the 24-h following device placement.

*Analysis by Xiaoying Li, Colorado State University*

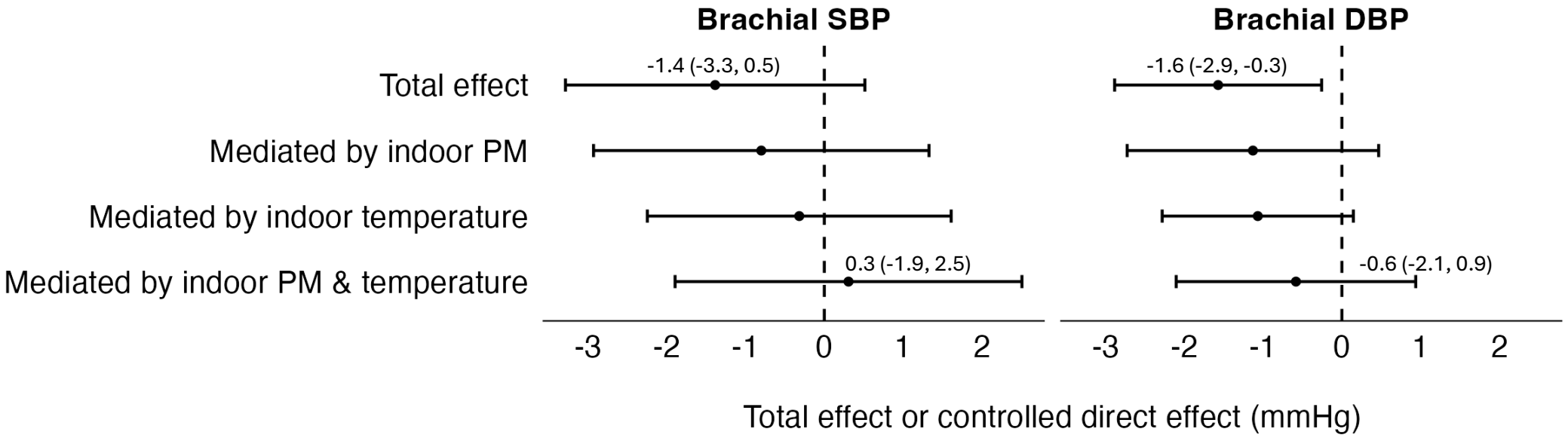
## Policy impacts on indoor temperature




Note: Mean and minimum indoor temperatures are the average and daily minimum values during the heating season (Nov. 15 to Mar. 15), respectively.

# Mediation by indoor temperature and $PM_{2.5}$

***Look for attenuation towards the null***




Note: All models included terms for sex, age, waist circumference, alcohol consumption, smoking, use of antihypertensive medi cation. Mediation models were additionally adjusted for the time of BP measurement (AM/PM).

# Conclusions

- The CHP provided a modest benefit to BP.
- Moderated (in part) through reduced indoor $PM_{2.5}$ and warmer indoor temperatures.
- Able to provide direct evidence of *how* a clean heating policy affected health.

# Thank you!

- **PIs/supervisors:** Jill Baumgartner, Sam Harper (McGill)
- **Co-investigators:**
  - Shu Tao, Guofeng Shen (Peking University)
  - Ellison Carter (Colorado State University)
  - Brian Robinson, Chris Barrington-Leigh (McGill University)
  - Yuanxun Zhang (University of Chinese Academy of Sciences)
- **Field leads:** Xiaoying Li, Xiang Zhang
- Field staff, village leaders, participants
- MSc and PhD students
- **Funding agencies:** Health Effects Institute, Canadian Institutes of Health Research

# References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- Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics*, *225*(2), 254–277. https://doi.org/10.1016/j.jeconom.2021.03.014
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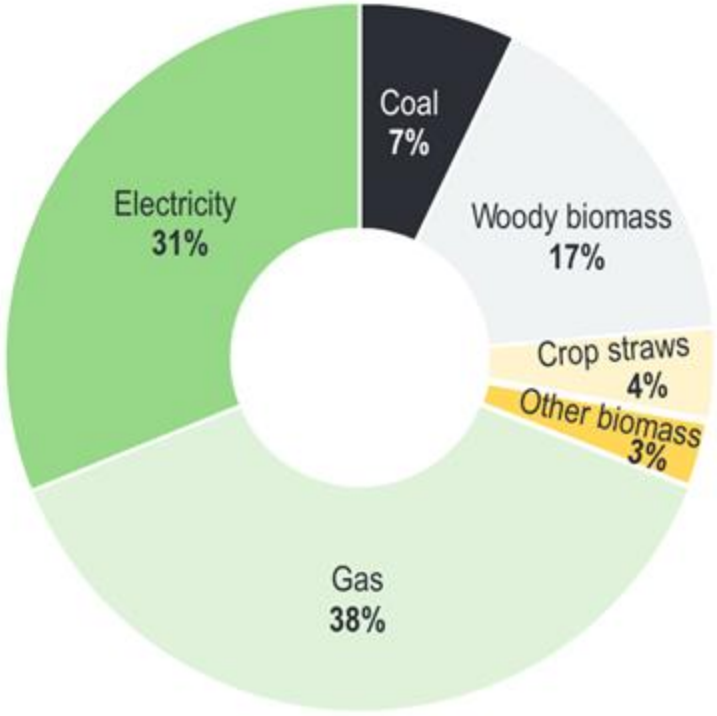
- Wooldridge, J. M. (2021). Two-Way Fixed Effects, the Two-Way Mundlak Regression, and Difference-in-Differences Estimators. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3906345

# Strengths, limitations, and next steps

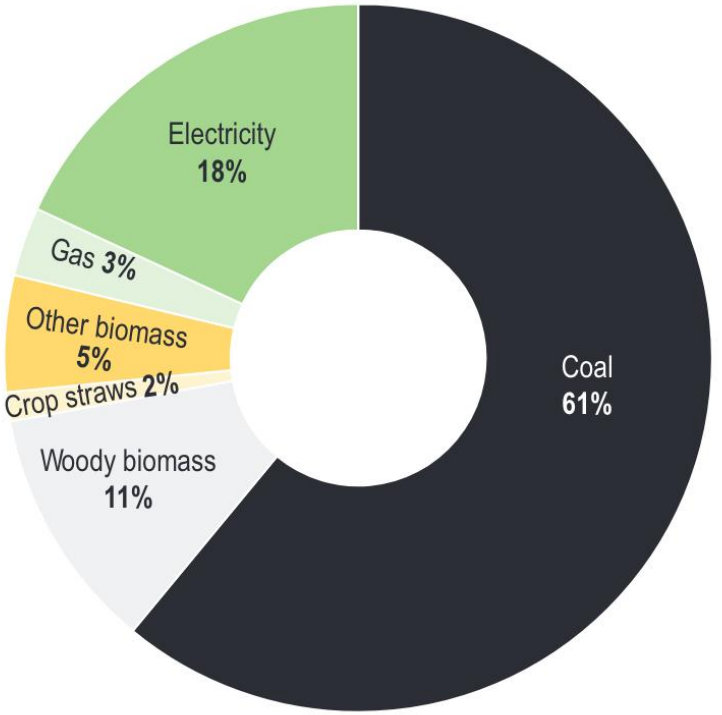
- Missing indoor $PM_{2.5}$ in wave 1 and 17% of waist circumference → imputation
- Continued biomass use, non-adherence to the intervention → underestimate ATT
- Confounding by time-varying factors that differ between treatment groups.

# Context for the Clean Heating Policy

- Decades of policies and programs to improve air quality in China.
- Transition to clean heating lagged cooking in 2017.




**(A) Time-share of fuels for cooking, 2017**



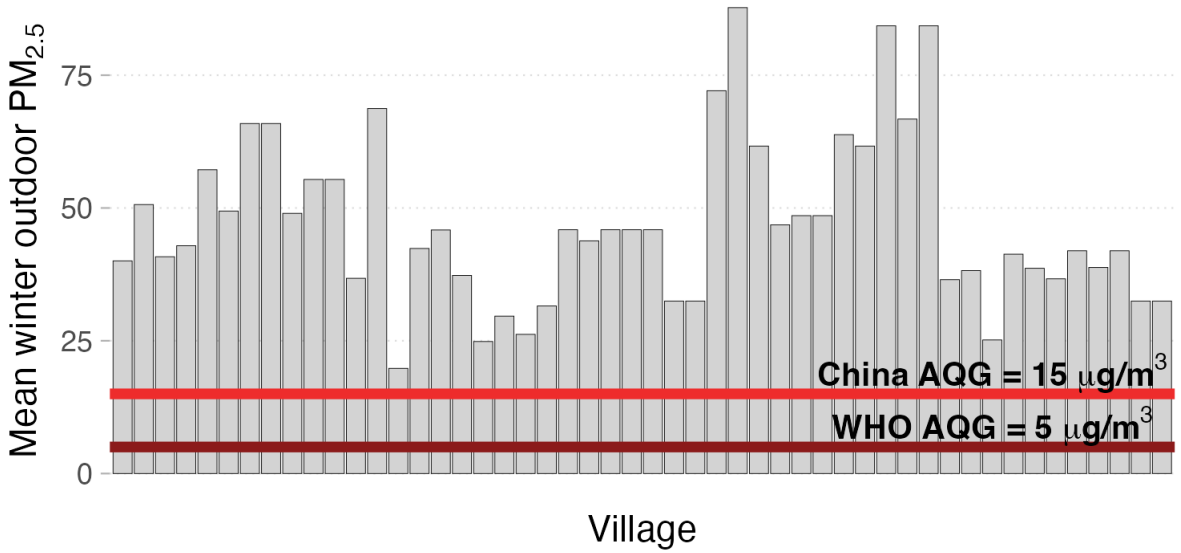

**(B) Time-share fuels for heating, 2017**

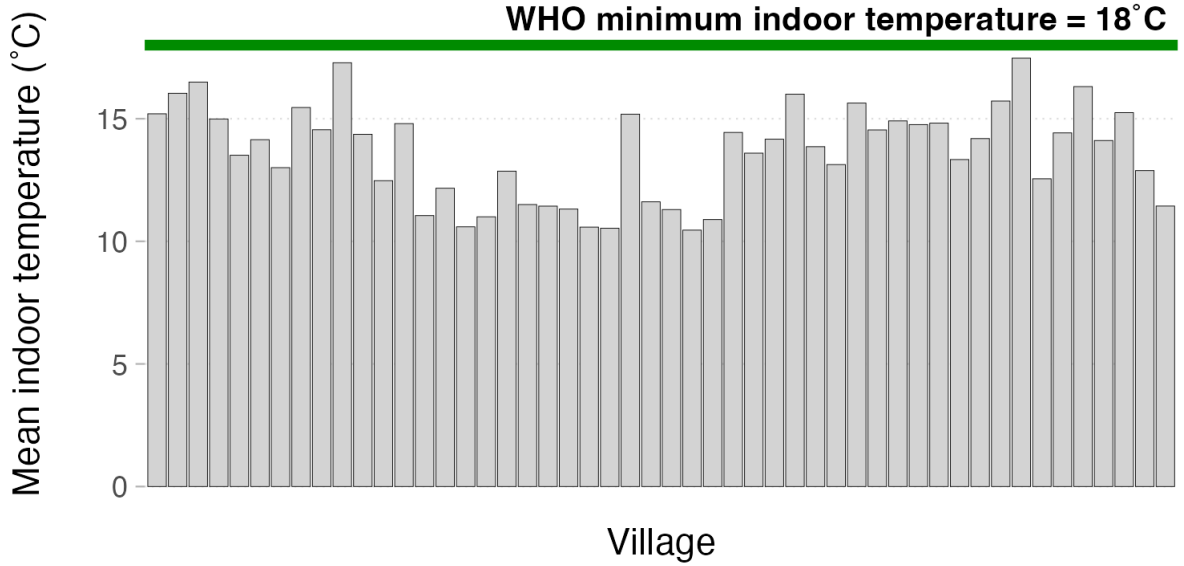


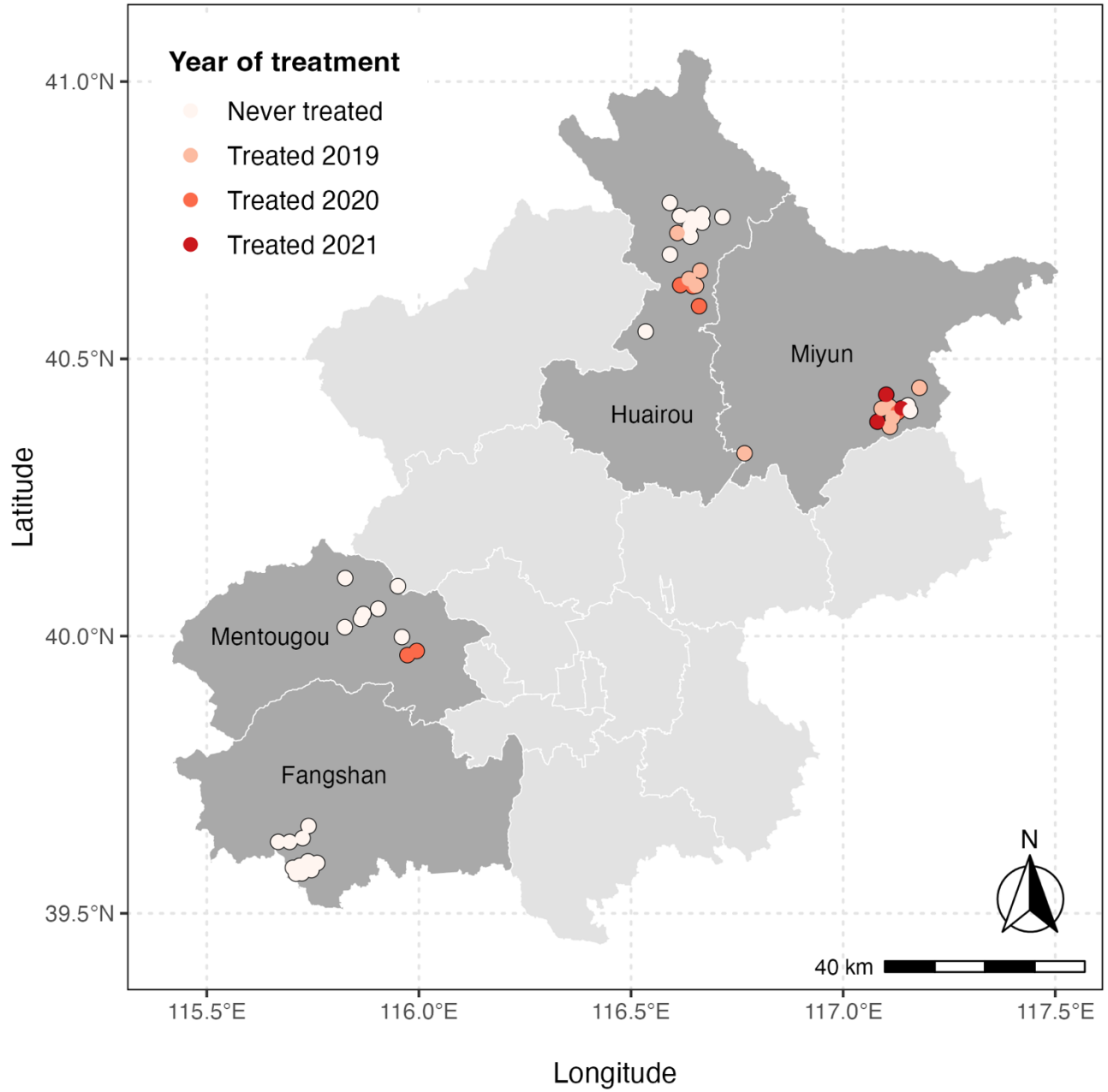
Shen et al. 2022

# Context for the Clean Heating Policy

- In 2018, wintertime $PM_{2.5}$ and indoor temperature don't meet health-motivated guidelines in rural Beijing.



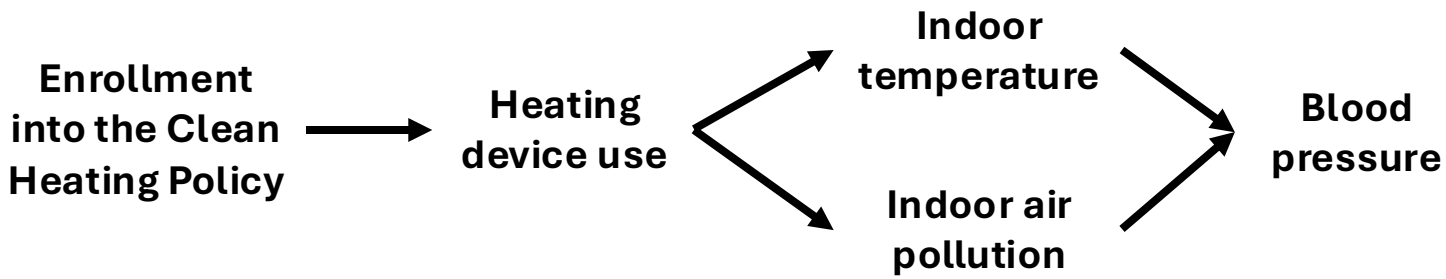




Year of treatment
Never treated
Treated 2019
Treated 2020
Treated 2021
Miyun
Huairou
Mentougou
Fangshan
N
40 km
41.0°N
40.5°N
40.0°N
39.5°N
Latitude
115.5°E
116.0°E
116.5°E
117.0°E
117.5°E
Longitude

# Kang = combined cooking and heating stove

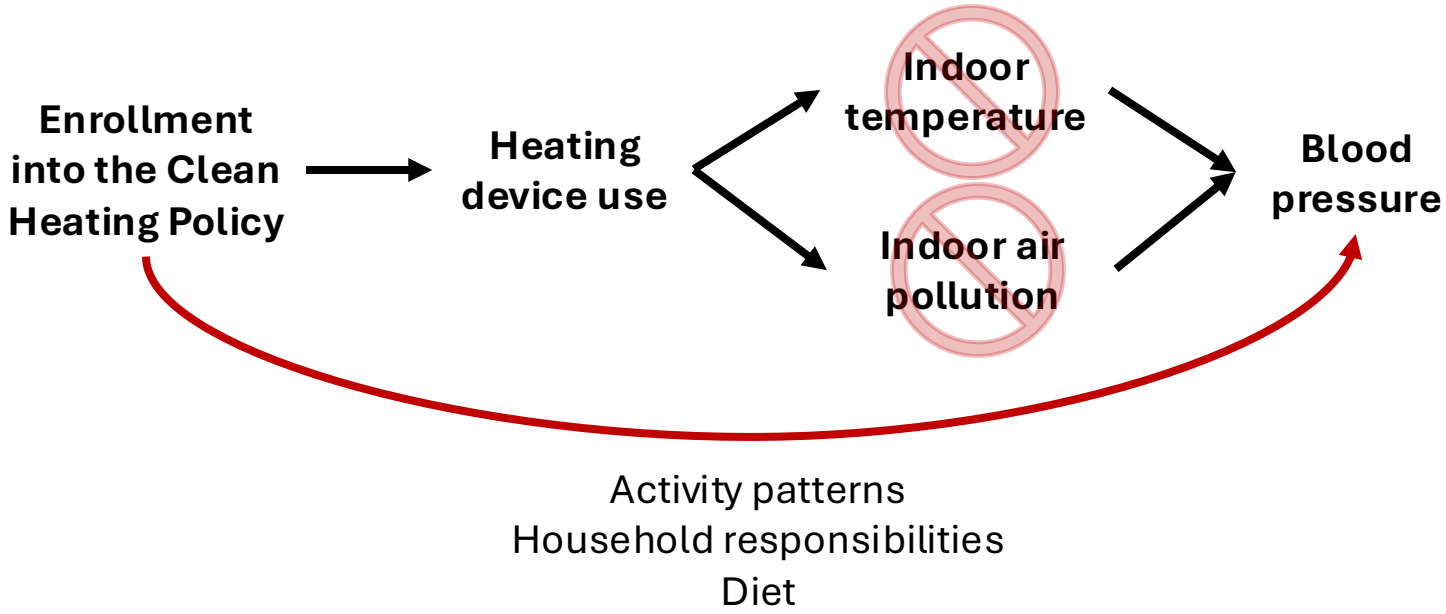
# How does mediation work?

**Total effect:**




**Controlled direct effect:**

*"Effect of the policy on BP through pathways other than the mediators."*



# Estimate mediator and outcome models

| Model | Definition | Regression specification |
|---|---|---|
| Total effect | Effect of exposure on outcome, including both direct and indirect effects | Y ~ a + time + cohort + policy*time*cohort + e |
| Direct effect | Effect of exposure on outcome through pathways other than the mediator(s). | Y ~ a + time + cohort + policy*time*cohort + mediators + e |

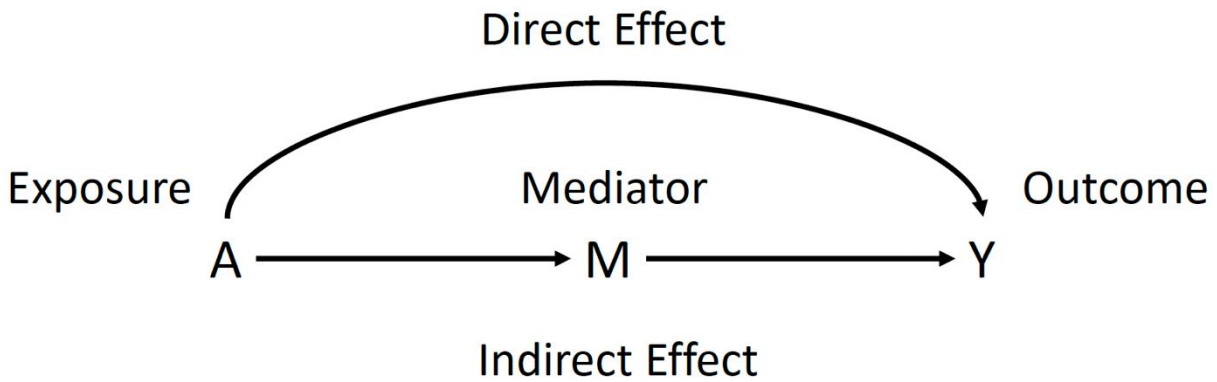





*Figure from Dr. Jonathan Chevrier's EBIP 705 slides

# Mediation

- Total effect of the policy on BP:
- $BP_{ict} = \beta_0 + \beta_1 C + \beta_2 T + \beta_{c,t}(C * T) + \beta_3 \boldsymbol{Z} + \varepsilon_{ict}$

- Mediation model:
- $BP_{ict} = \beta_0 + \beta_1 C + \beta_2 T + \beta_{c,t}(C * T) + \beta_3 PM + \beta_4 temp + \varepsilon_{ict}$

- Mediator models:
- $temp_{ict} = \beta_0 + \beta_1 C + \beta_2 T + \beta_{c,t}(C * T) + \varepsilon_{ict}$
- $PM_{ict} = \beta_0 + \beta_1 C + \beta_2 T + \beta_{c,t}(C * T) + \varepsilon_{ict}$

**BP** = blood pressure

**i** = individual

**C** = cohort (group of villages treated at the same time)

**T** = time (study year)

**PM** = indoor $PM_{2.5}$

**temp** = indoor temperature

**Z** = vector of covariates

# Controlled direct effect (CDE)

- Effect of the policy on BP through pathways *other than* the mediator.

- Fix levels of mediator:

| | Indoor $PM_{2.5}$ ug/$m^3$ | Indoor temperature ˚C |
|---|---|---|
| Mean baseline values | 65.3 | 13.7 |

- $CDE_M = \beta_{c,t} + [\beta_M * interactions]$
- Marginal effect of mediator model, after fixing mediator values

# Participation

| | Total villages | Enrolled villages | Total participants | Participants with ≥1 BP measurement* |
|---|---|---|---|---|
| **Year 1 (2018-19)** | 50 | 0 | 1,003 | 975 (97%) |
| **Year 2 (2019-20)** | 50 | 10 | 1,110 | 1,103 (99%) |
| **Year 3 (2020-21)** | 41 | 17 | 531 | *NA* |
| **Year 4 (2021-22)** | 50 | 20 | 1,011 | 1,006 (99%) |

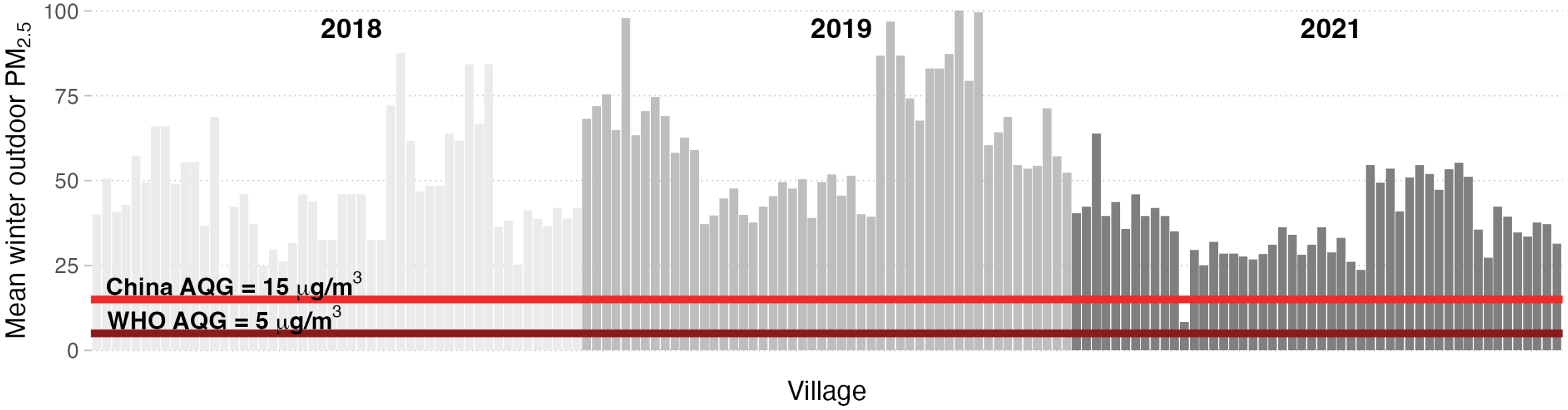
*621 participants in Years 1 +2 + 4

| Period | Program |
|---|---|
| 1949-1977 | **Era of central planning:**<br>• Electricity shortages<br>• Electricity use restricted to lighting |
| 1978–1997 | **Era of market reforms:**<br>• Electricity for irrigation, lighting, small household appliances (e.g., TVs, fans) |
| 1997-(2012) | **Move to market economy:**<br>• De-centralization of electricity regulation<br>• Electricity used for energy-intensive appliances (e.g., fridge, AC unit, washing machine) |

| Year | Program |
|---|---|
| 1996 | The Brightness Programme |
| 2002 | The Township Electrification programme |
| 2008 | Beijing Olympics |
| 2013 | Air Pollution Prevention and Control Action Plan |
| 2017 | Clean Winter Heating Plan for Northern China |

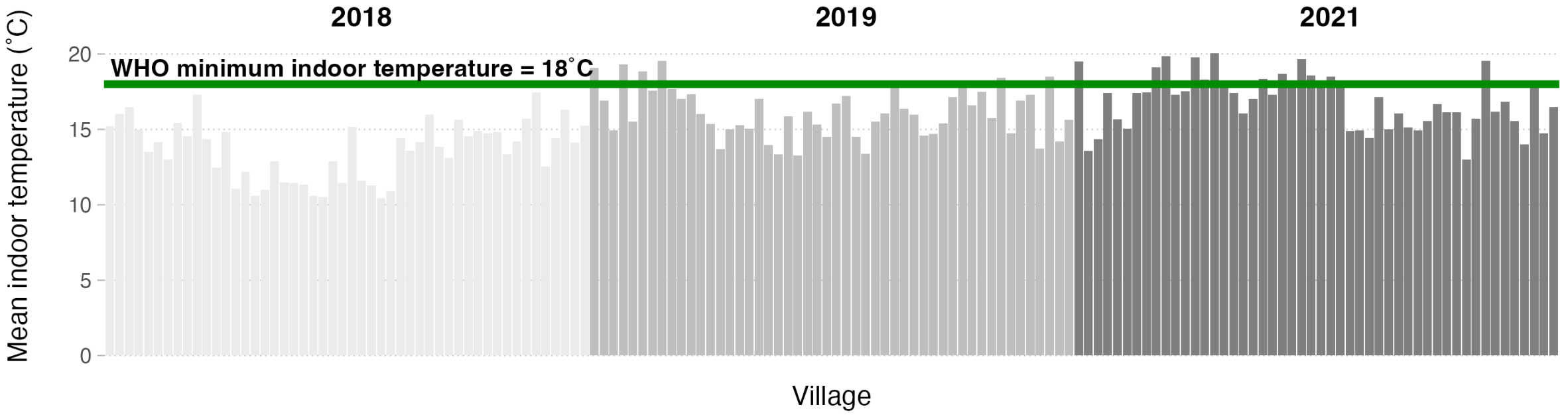
# Context for the Clean Heating Policy

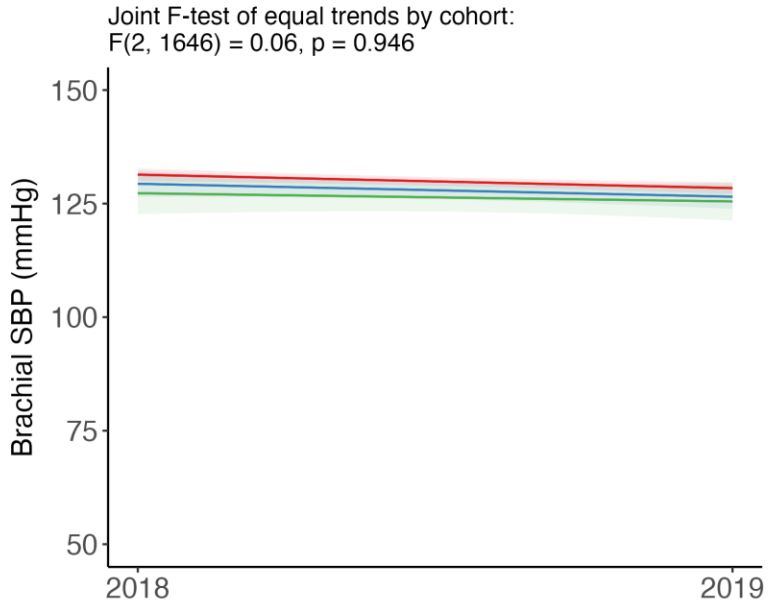
- Winter $PM_{2.5}$ still above air quality guidelines (AQG) in rural Beijing.

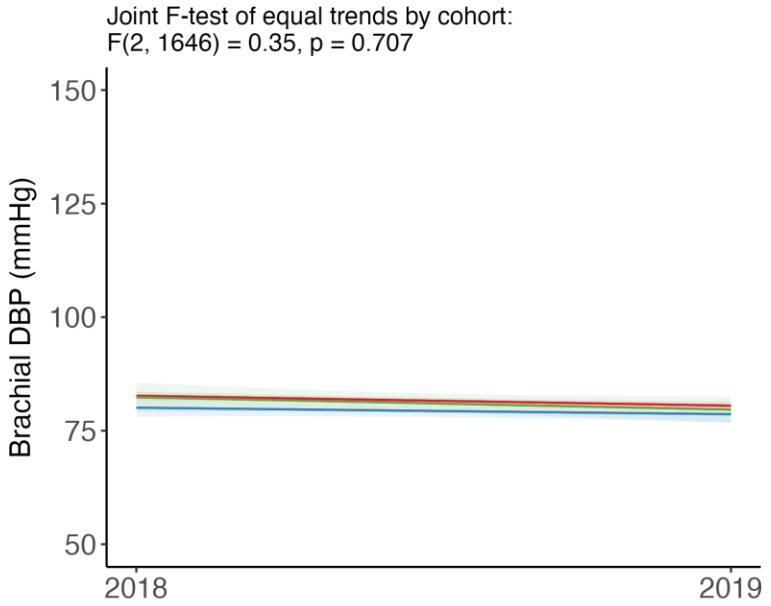


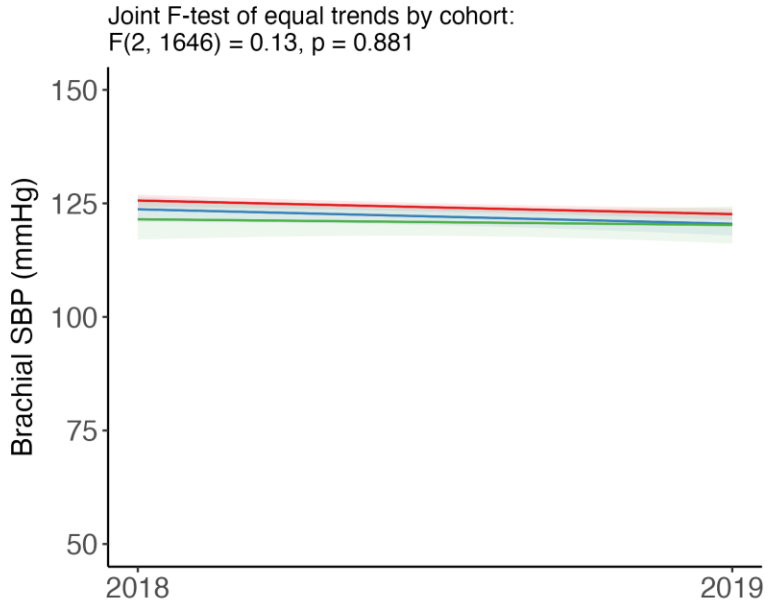
# Context for the Clean Heating Policy

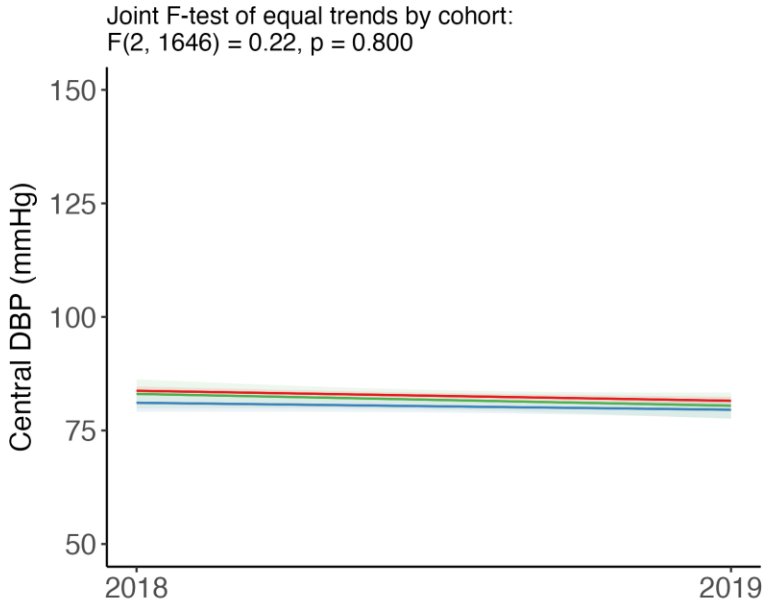
- Indoor temperatures below WHO guidelines in rural Beijing.



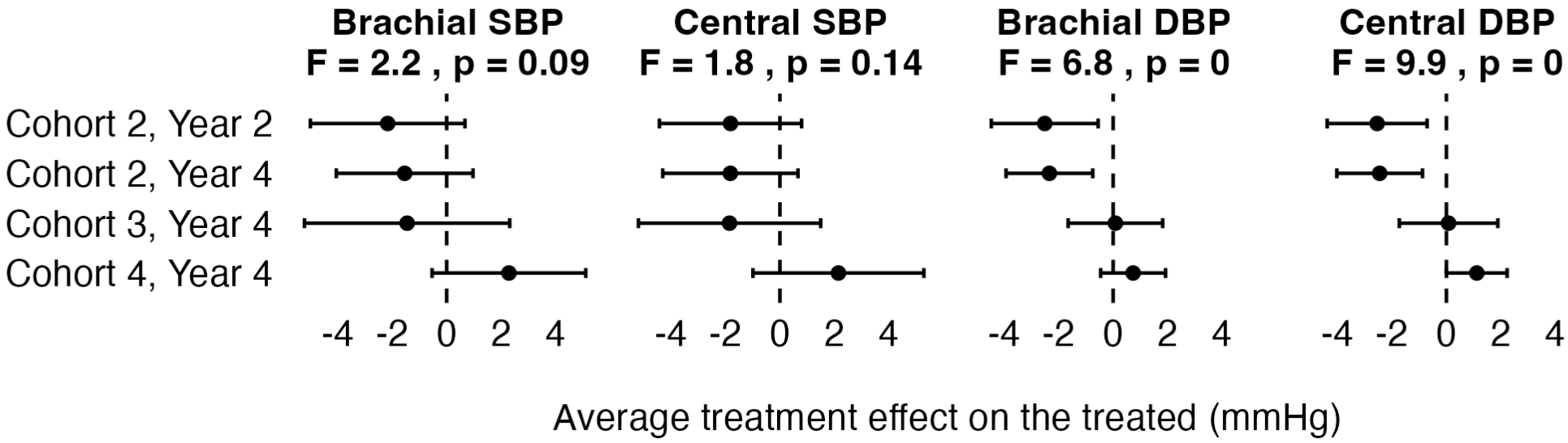

Joint F-test of equal trends by cohort:
F(2, 1646) = 0.06, p = 0.946
Brachial SBP (mmHg)
150
125
100
75
50
2018
2019
Treatment cohort
Never
2020
2021


Joint F-test of equal trends by cohort:
F(2, 1646) = 0.35, p = 0.707
Brachial DBP (mmHg)
150
125
100
75
50
2018
2019
Treatment cohort
Never
2020
2021


Joint F-test of equal trends by cohort:
F(2, 1646) = 0.13, p = 0.881
Brachial SBP (mmHg)
150
125
100
75
50
2018
2019
Treatment cohort
Never
2020
2021


Joint F-test of equal trends by cohort:
F(2, 1646) = 0.22, p = 0.800
Central DBP (mmHg)
150
125
100
75
50
2018
2019
Treatment cohort
Never
2020
2021

# Heterogeneity of the total effects



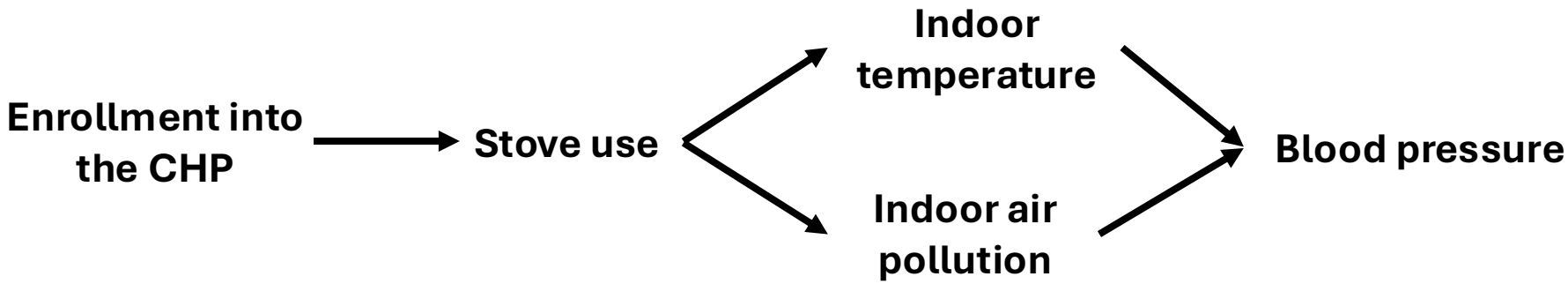
# Studies of clean energy interventions

- Randomized trials, observational studies, natural experiments
- Increase the accessibility and affordability of less-polluting energy sources (i.e., providing clean fuels, improved stoves)
- Smaller sample size (*n* = 28 to 605)
- Few population-based evaluations
    - Pre-post studies
    - Couldn’t account for secular trends

# Assumptions for mediation

**ID Assumptions for CDE and PE:**

1. No exposure-outcome confounding
2. No mediator-outcome confounding
3. No exposure-mediator confounding



# Heating with coal stove vs. electric heat pump