Cooking, health, and daily exposure to transient air pollution peaks

Susanna B. Berkouwer[1] (they/them) Joshua T. Dean[2] (he/him)

[1]The Wharton School, University of Pennsylvania and NBER
[2]The Booth School of Business, University of Chicago

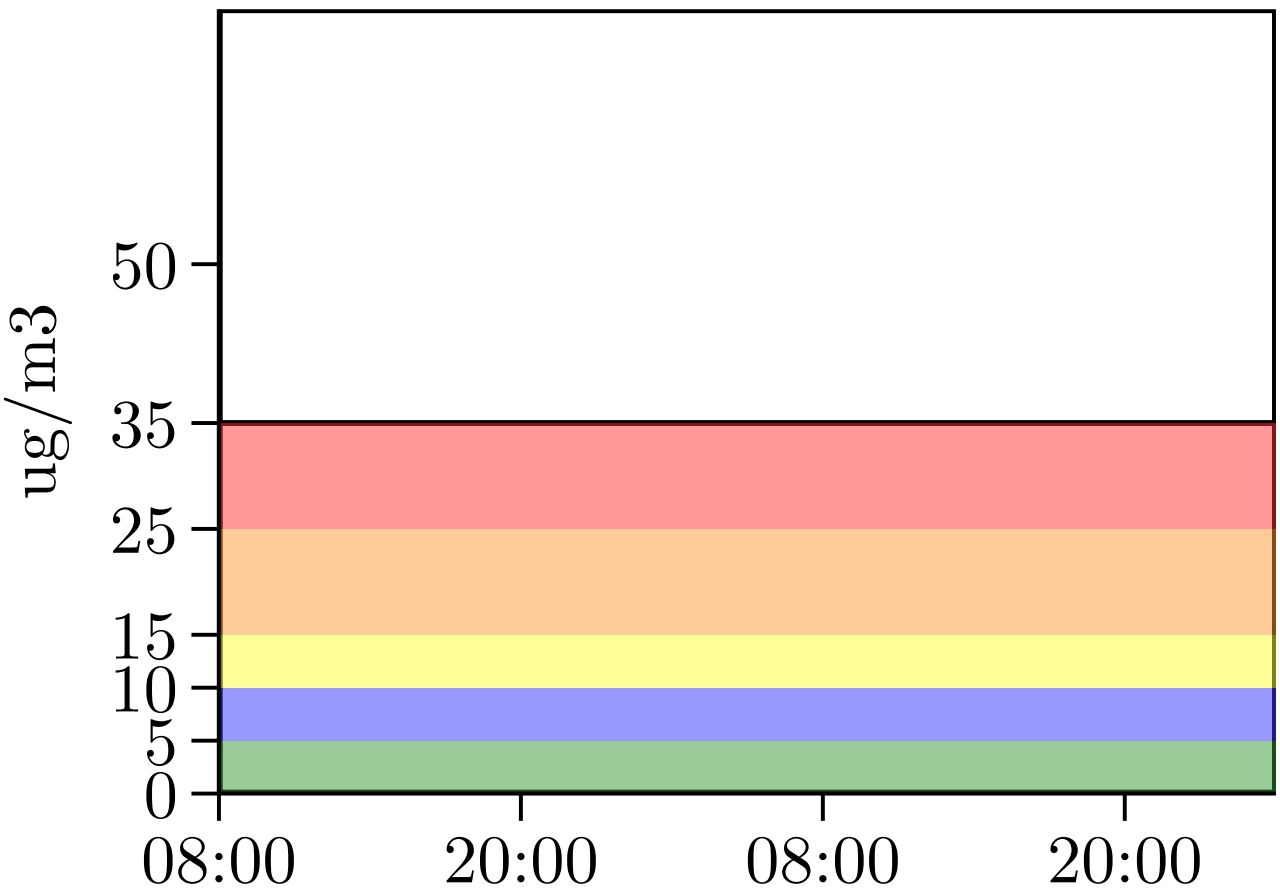
June 2024

What causes pollution peaks? Routine daily activities:

What causes pollution peaks? Routine daily activities:

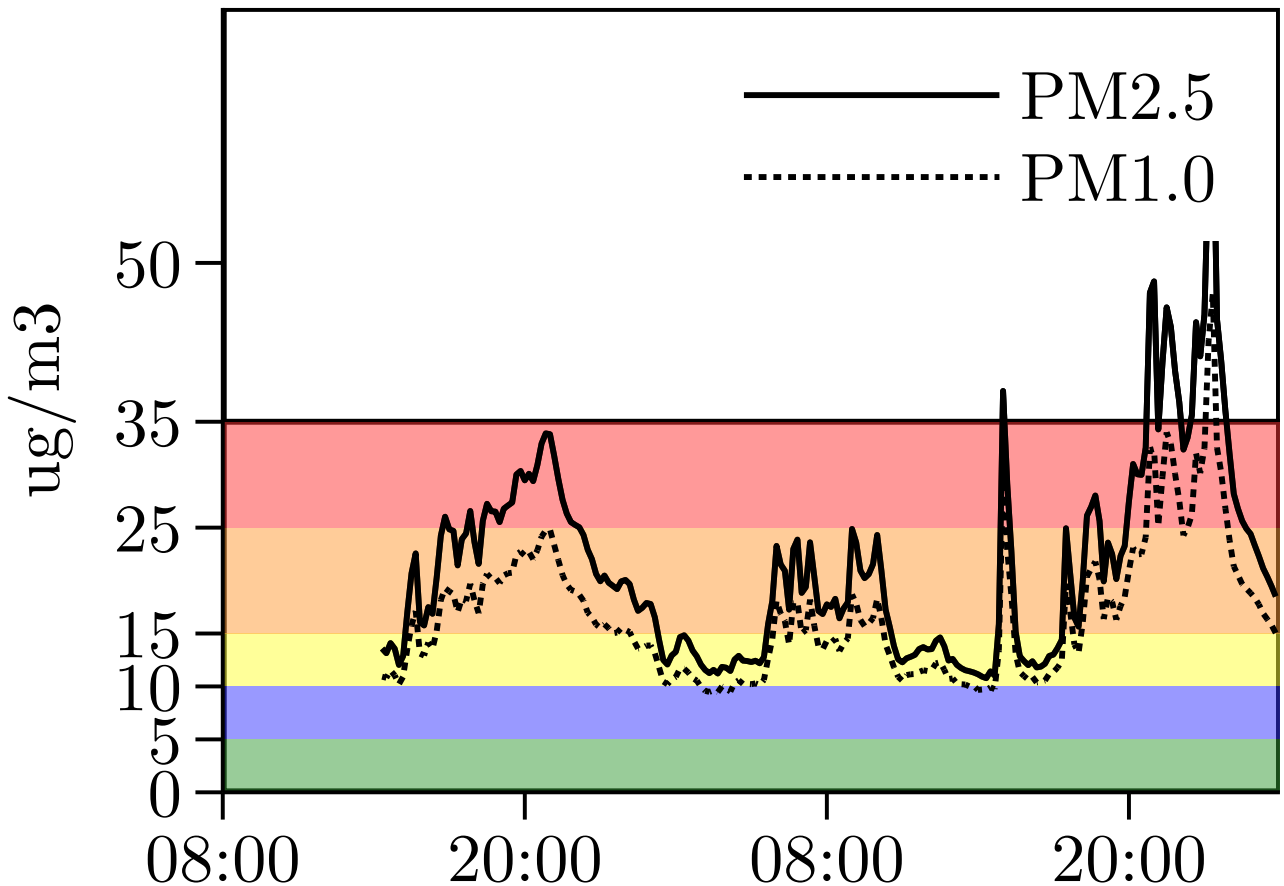
Daily air pollution patterns

- WHO pollution standards: $<5\mu g/m^3$ (AQI 21) to $<35\mu g/m^3$ (AQI 100)



Daily air pollution patterns

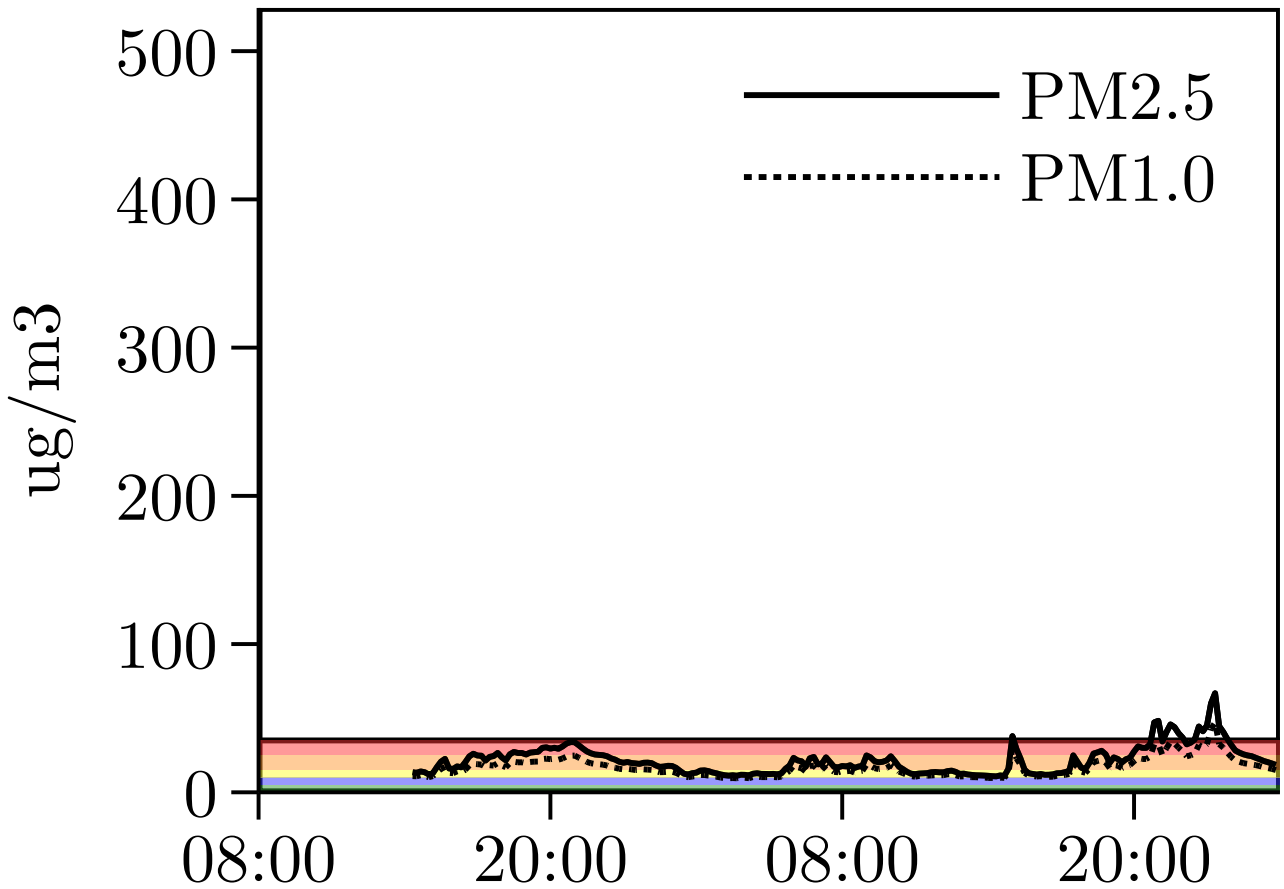
- WHO pollution standards: $<5\mu g/m^3$ (AQI 21) to $<35\mu g/m^3$ (AQI 100)



Source: Individual carrying an Purple Air device in Nairobi

Daily air pollution patterns

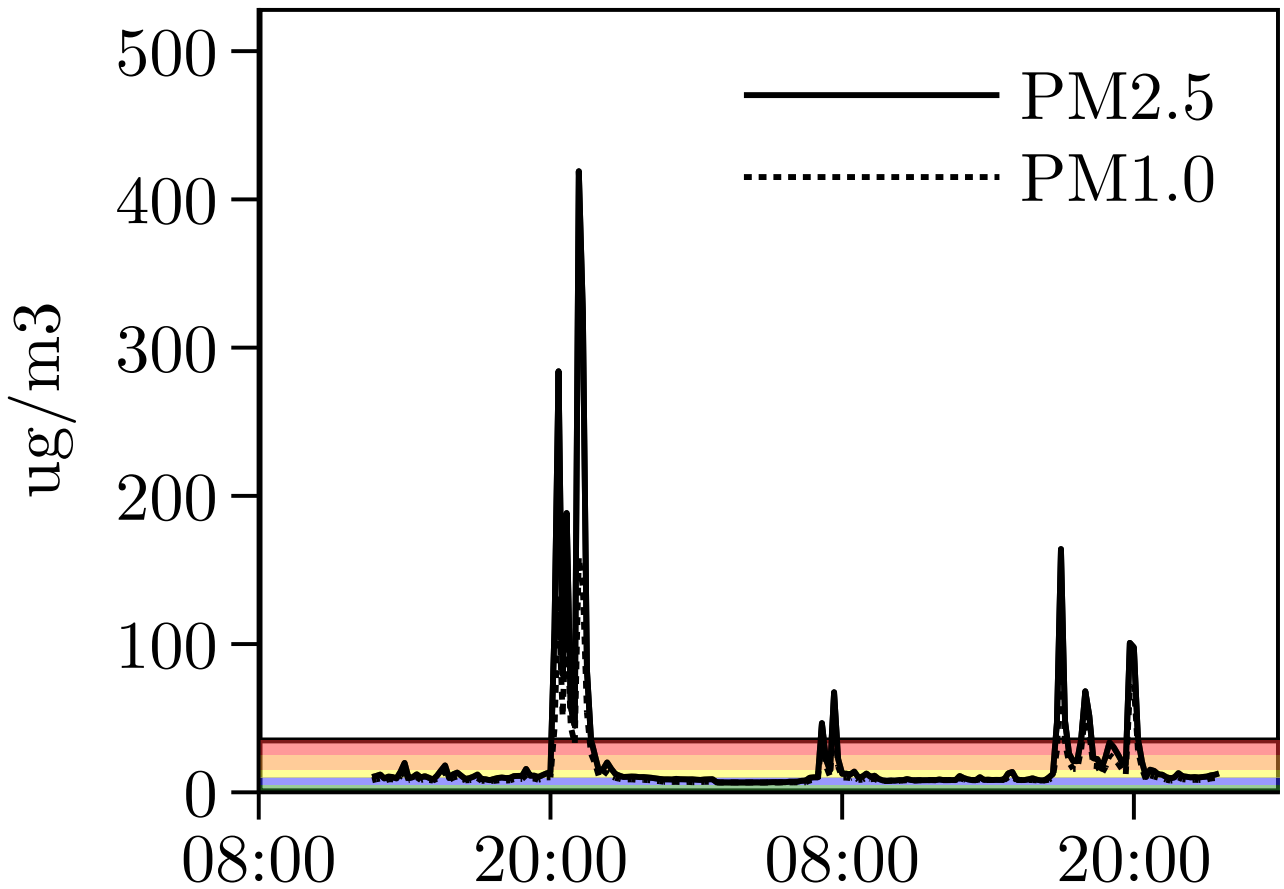
- WHO pollution standards: $<5\mu g/m^3$ (AQI 21) to $<35\mu g/m^3$ (AQI 100)



Source: Individual carrying an Purple Air device in Nairobi

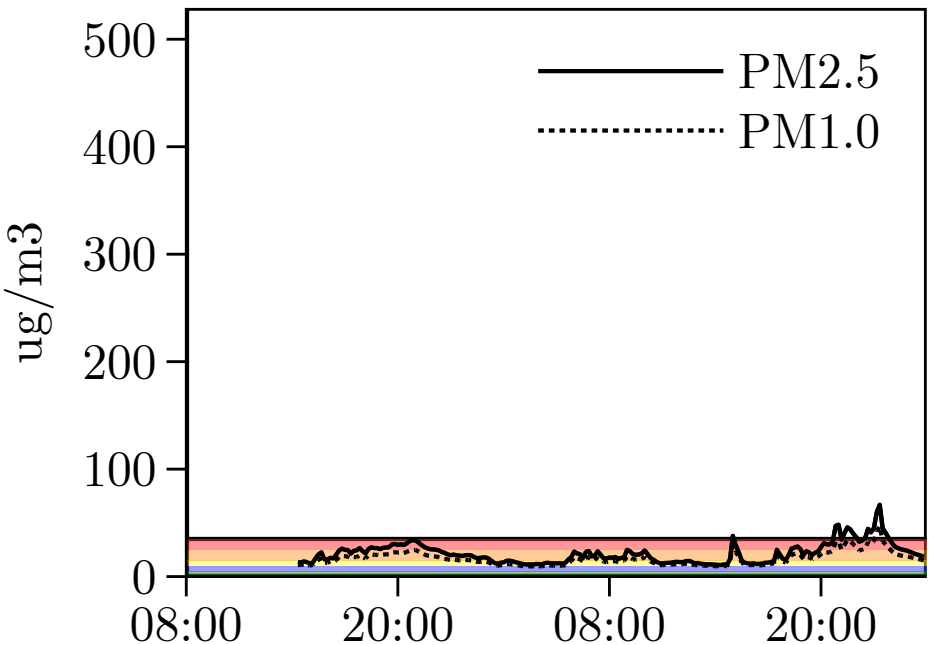
Daily air pollution patterns

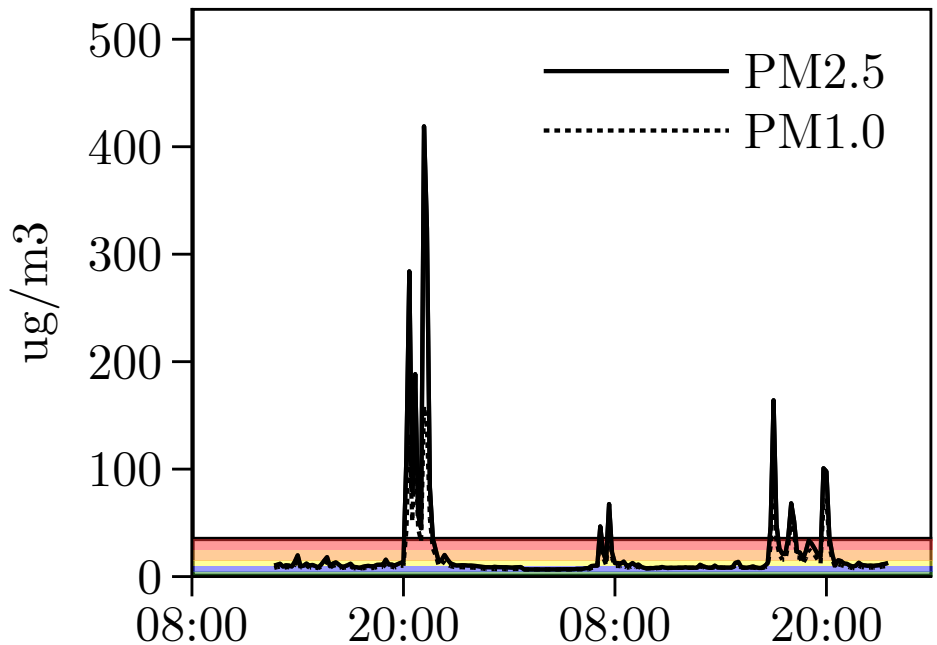
- WHO pollution standards: $<5\mu g/m^3$ (AQI 21) to $<35\mu g/m^3$ (AQI 100)



Source: Individual carrying an Purple Air device in Nairobi

Same daily average (21μg/m^3, AQI 70):





Source: Individuals carrying Purple Air devices in Nairobi

Existing research on air pollution impacts

- Impact of **daily average** TSP/PM2.5 concentrations
  Chay, Greenstone (2003); Currie, Walker (2011); Schlenker, Walker (2016); Chang, Graff Zivin, Gross, Neidell (2016); Ebenstein, Fan, Greenstone, He, Zhou (2017); Isen, Rossin-Slater, Walker (2017); Deryugina, Heutel, Miller, Molitor, Reif (2018); Shapiro, Walker (2020); Simeonova, Currie, Nilsson, Walker (2021); Clay, Lewis, Severnini (2022); Gong, Li, Sanders, Shi (2023)

Existing research on air pollution impacts

- Impact of **daily average** TSP/PM2.5 concentrations
  Chay, Greenstone (2003); Currie, Walker (2011); Schlenker, Walker (2016); Chang, Graff Zivin, Gross, Neidell (2016); Ebenstein, Fan, Greenstone, He, Zhou (2017); Isen, Rossin-Slater, Walker (2017); Deryugina, Heutel, Miller, Molitor, Reif (2018); Shapiro, Walker (2020); Simeonova, Currie, Nilsson, Walker (2021); Clay, Lewis, Severnini (2022); Gong, Li, Sanders, Shi (2023)

- Short-term impacts of a **single** transient spike
  Kubesch et al. (2015); Adhvaryu, Kala, and Nyshadham (2022); Künn, Palacios, and Pestel (2023); Ebenstein, Lavy, and Roth (2016); Archsmith, Heyes, and Saberian (2018)

Health impacts of daily transient peaks:

The Washington Post

What can you do?

First, don't panic.

Cooking once in a smoky kitchen isn't particularly dangerous. It's the cumulative exposure that matters. The daily, weekly and monthly cadence of elevated pollutants increases the risk of disease down the line.

Studying causal impacts of daily transient peaks requires:

Studying causal impacts of daily transient peaks requires:

1. High-frequency data on how individual activities generate (exposure to) pollution peaks

Studying causal impacts of daily transient peaks requires:

1. High-frequency data on how individual activities generate (exposure to) pollution peaks

2. High-frequency, individual-level data on realized exposure during pollution peaks
   - Not captured by (even high-frequency) stationary monitors

Studying causal impacts of daily transient peaks requires:

1. High-frequency data on how individual activities generate (exposure to) pollution peaks

2. High-frequency, individual-level data on realized exposure during pollution peaks
   - Not captured by (even high-frequency) stationary monitors

3. Plausibly-random reduction in pollution spikes

Studying causal impacts of daily transient peaks requires:

1. High-frequency data on how individual activities generate (exposure to) pollution peaks

2. High-frequency, individual-level data on realized exposure during pollution peaks
   - Not captured by (even high-frequency) stationary monitors

3. Plausibly-random reduction in pollution spikes

4. For several years

Limited evidence complicates environmental regulations

1. Most concentration limits address annual or 24-hour averages
   - 99th percentile standards only regulate outlier days
   - Only 1 country regulates any sub-24 hour average

Limited evidence complicates environmental regulations

1. Most concentration limits address annual or 24-hour averages
   - 99th percentile standards only regulate outlier days
   - Only 1 country regulates any sub-24 hour average

2. **EPA reconsideration of the PM NAAQS (2023):** Discussions about potential sub-daily average concentration caps only reference research on one-off peaks

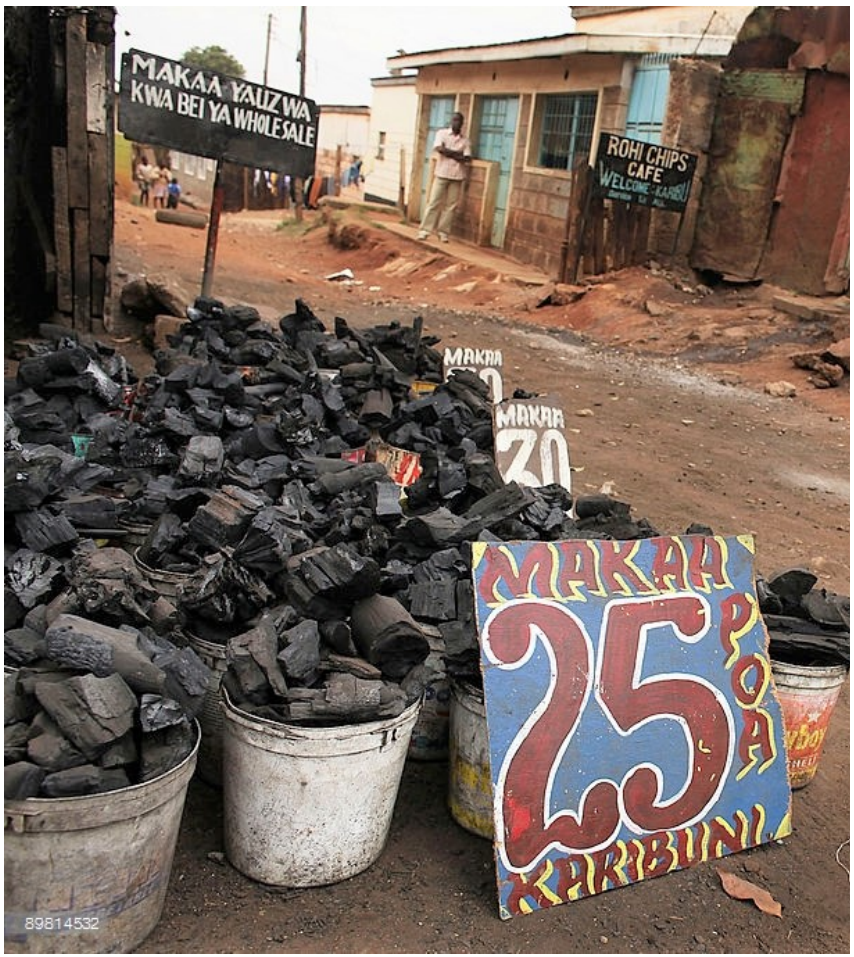
Limited evidence complicates environmental regulations

1. Most concentration limits address annual or 24-hour averages
   - 99th percentile standards only regulate outlier days
   - Only 1 country regulates any sub-24 hour average

2. **EPA reconsideration of the PM NAAQS (2023):**
   Discussions about potential sub-daily average concentration caps only reference research on one-off peaks

3. **WHO Bulletin (2021):**
   "Jurisdictions with a high temporal variability of PM2.5 concentration, such as in India and China, should consider short-term averaging (20 minutes or 1 hour)"

In low- and middle income countries, biomass cooking causes large daily transient peaks:



The urban poor experience high means and higher peaks

- In Africa, >80% of urban households use biomass cooking (FAO)
- 3bn to live in slums in Africa and Asia by 2050 (WHO, UN)

Can clean cookstoves improve health? The evidence is far from conclusive:

1. Many RCTs focus on **adoption** and do not measure health impacts
   - Mobarak et al. (2012), Bensch et al. (2015), Levine et al. (2018), Bensch and Peters (2019), Chowdhury et al. (2019), Pattanayak et al. (2019), Berkouwer and Dean (2022)

Can clean cookstoves improve health? The evidence is far from conclusive:

1. Many RCTs focus on **adoption** and do not measure health impacts
   - Mobarak et al. (2012), Bensch et al. (2015), Levine et al. (2018), Bensch and Peters (2019), Chowdhury et al. (2019), Pattanayak et al. (2019), Berkouwer and Dean (2022)

2. Lancet Global Health (2020) reviews 437 papers:
   - Mostly **correlational**: **6** were RCTs (3 from 1 RCT) (RESPIRE, HAPIN)

Can clean cookstoves improve health? The evidence is far from conclusive:

1. Many RCTs focus on **adoption** and do not measure health impacts
   - Mobarak et al. (2012), Bensch et al. (2015), Levine et al. (2018), Bensch and Peters (2019), Chowdhury et al. (2019), Pattanayak et al. (2019), Berkouwer and Dean (2022)

2. Lancet Global Health (2020) reviews 437 papers:
   - Mostly **correlational**: **6** were RCTs (3 from 1 RCT) (RESPIRE, HAPIN)
   - RESPIRE, HAPIN, and almost all other research **rural**

Can clean cookstoves improve health? The evidence is far from conclusive:

1. Many RCTs focus on **adoption** and do not measure health impacts
   - Mobarak et al. (2012), Bensch et al. (2015), Levine et al. (2018), Bensch and Peters (2019), Chowdhury et al. (2019), Pattanayak et al. (2019), Berkouwer and Dean (2022)

2. Lancet Global Health (2020) reviews 437 papers:
   - Mostly **correlational**: **6** were RCTs (3 from 1 RCT) (RESPIRE, HAPIN)
   - RESPIRE, HAPIN, and almost all other research **rural**
   - **None** measure non-kitchen exposure $\Rightarrow$ no estimates of daily averages

This study: How do persistent reductions in transient peaks affect health?

This study: How do persistent reductions in transient peaks affect health?

- Leverage experiment where we randomized subsidies for stoves that reduced charcoal use by 40% (Berkouwer & Dean, 2022)

This study: How do persistent reductions in transient peaks affect health?

- Leverage experiment where we randomized subsidies for stoves that reduced charcoal use by 40% (Berkouwer & Dean, 2022)
- **3.5 year** follow-up (86% concordance with initial take-up)

This study: How do persistent reductions in transient peaks affect health?

- Leverage experiment where we randomized subsidies for stoves that reduced charcoal use by 40% (Berkouwer & Dean, 2022)
- **3.5 year** follow-up (86% concordance with initial take-up)

1. Pollution data (backpacks with PA and LASCAR devices)
2. Clinical health outcomes
3. Self-reported health outcomes
4. Time use data
5. Cognitive function

Preview of results

1. Improved stove ownership reduces peak cooking pollution by $52\mu g/m^3$ (**42%**)

Preview of results

1. Improved stove ownership reduces peak cooking pollution by $52\mu g/m^3$ (**42%**)
2. **0.24 SD reduction** in self-reported respiratory symptoms (sore throat, cough, headache, fatigue)

Preview of results

1. Improved stove ownership reduces peak cooking pollution by $52\mu g/m^3$ (**42%**)
2. **0.24 SD reduction** in self-reported respiratory symptoms (sore throat, cough, headache, fatigue)
3. **No impact on clinical outcomes**: blood pressure, blood oxygen, medical diagnoses

Preview of results

1. Improved stove ownership reduces peak cooking pollution by $52\mu g/m^3$ (**42%**)
2. **0.24 SD reduction** in self-reported respiratory symptoms (sore throat, cough, headache, fatigue)
3. **No impact on clinical outcomes**: blood pressure, blood oxygen, medical diagnoses
4. Why? **High pollution** for 22 non-cooking hours per day $\Rightarrow$ Negligible impact ($-0.8\mu g/m^3$) on **daily mean** ($37\mu g/m^3$)

Preview of results

1. Improved stove ownership reduces peak cooking pollution by $52\mu g/m^3$ (**42%**)
2. **0.24 SD reduction** in self-reported respiratory symptoms (sore throat, cough, headache, fatigue)
3. **No impact on clinical outcomes**: blood pressure, blood oxygen, medical diagnoses
4. Why? **High pollution** for 22 non-cooking hours per day $\Rightarrow$ Negligible impact ($-0.8\mu g/m^3$) on **daily mean** ($37\mu g/m^3$)

   Evidence is consistent with:
   - Transient peaks in pollution cause short-term symptoms
   - Average concentrations drive chronic health

Today

Background

Study design

Data & descriptive statistics

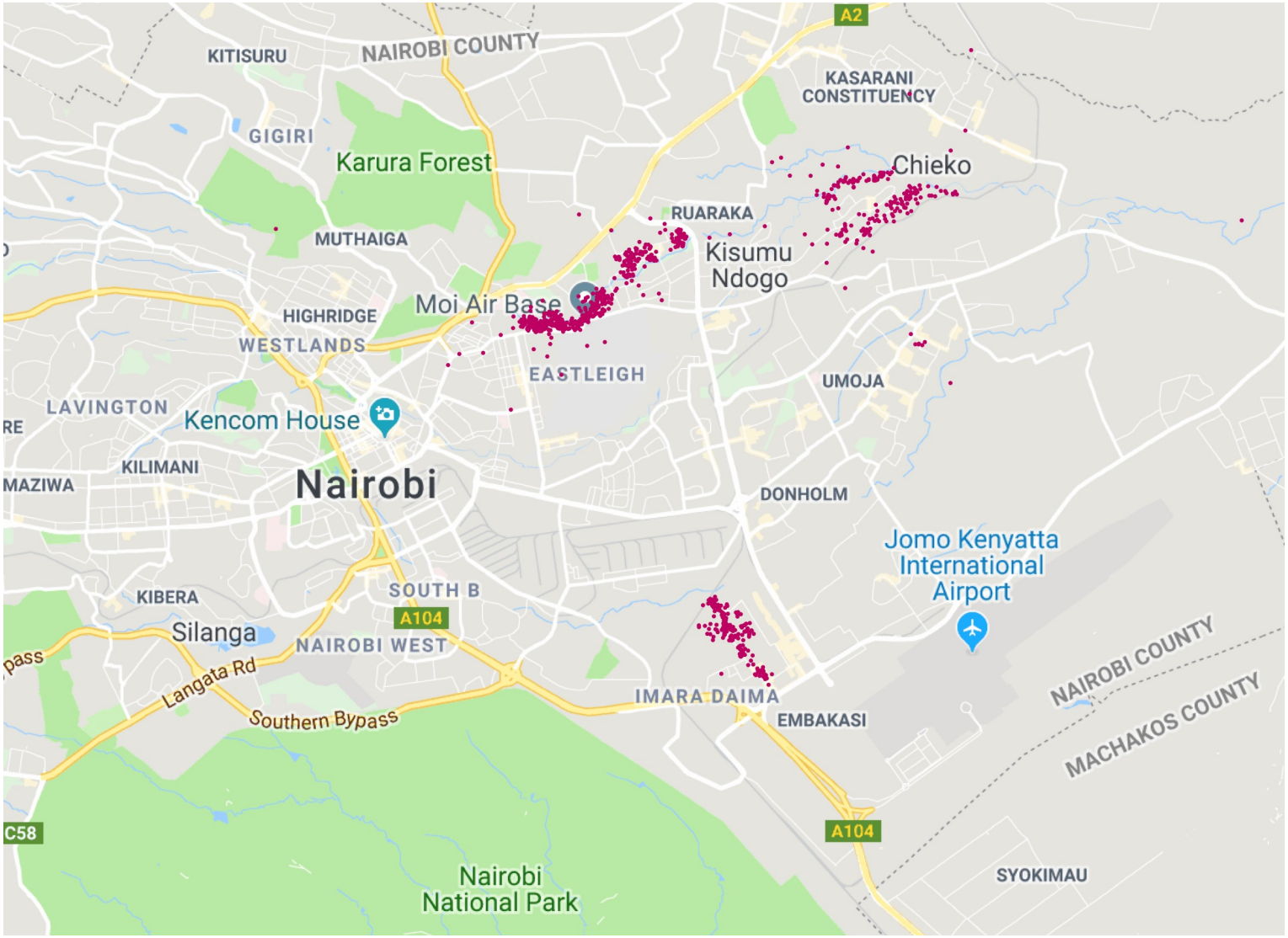
Pollution impacts

Health impacts

Impacts on poverty & climate

RCT in 2019 with 955 respondents (96% women)

Berkouwer & Dean (2022)



Houses in the study areas in Nairobi (Kenya):

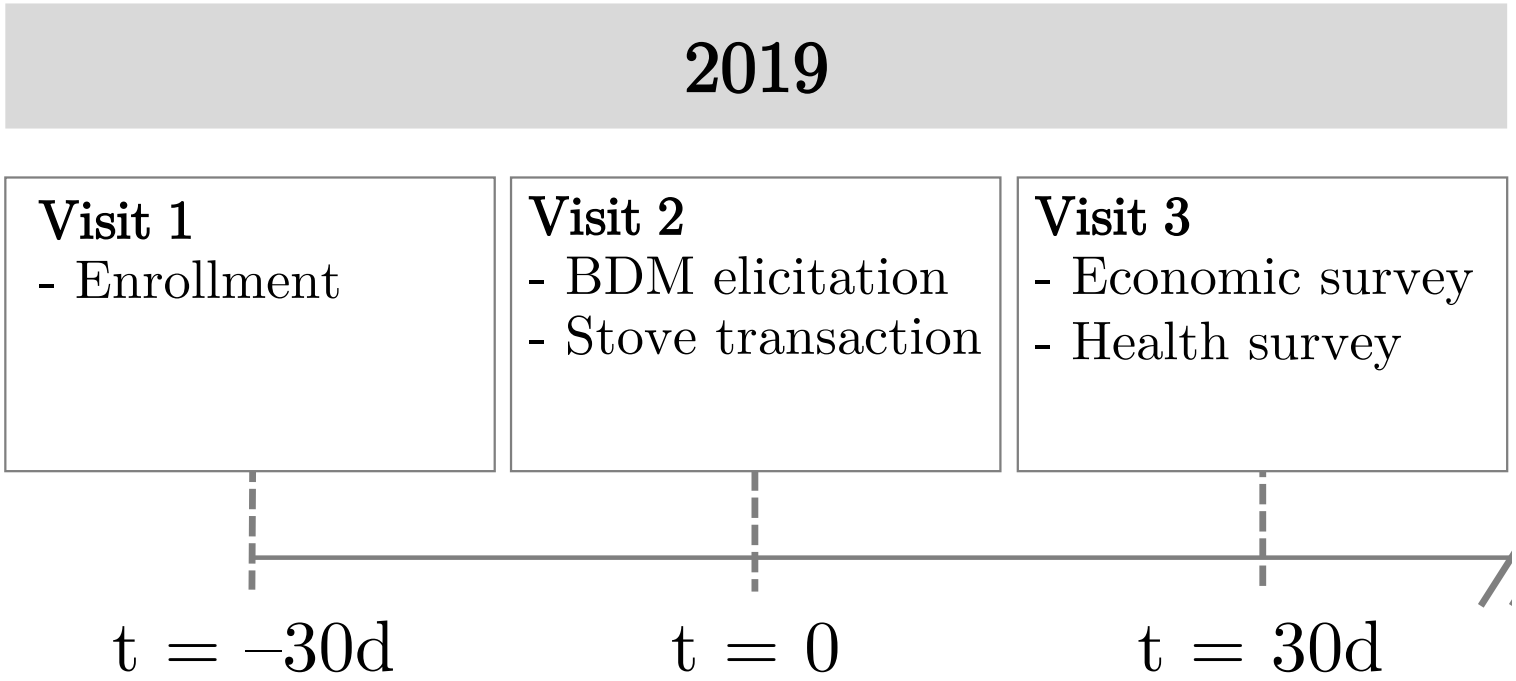
Traditional and energy efficient charcoal cookstoves

Traditional Stove
$2-$5

Jikokoa Stove
$40 (now $30)

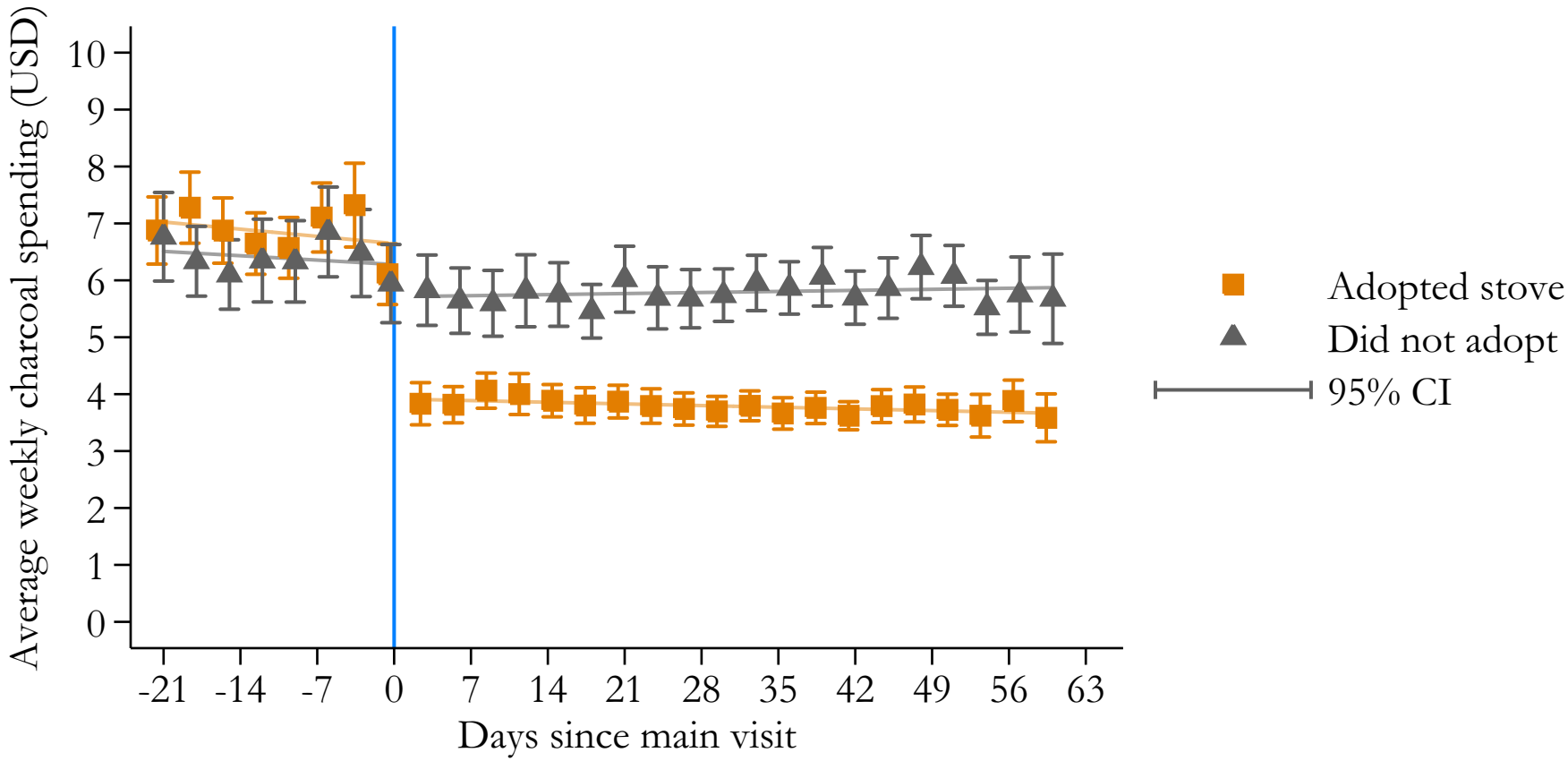
- Identical inputs: same charcoal
- Identical usage: almost no learning or behavior change
- Improved insulation materials

Experiment Overview *Berkouwer & Dean (2022)*



Stove reduces charcoal spending 40% ($2/week)

- Randomized stove subsidies
- 576 out of 962 respondents bought stove (60%)
- High-frequency charcoal expenditure SMS survey



(Berkouwer & Dean, 2022)

Stove reduces charcoal spending by 40% ($2.24 per week)

- Outcome is weekly charcoal spending from SMS survey
- 576 out of 962 respondents (60%) bought stove
- Instrumental Variables: BDM price is instrument for adoption

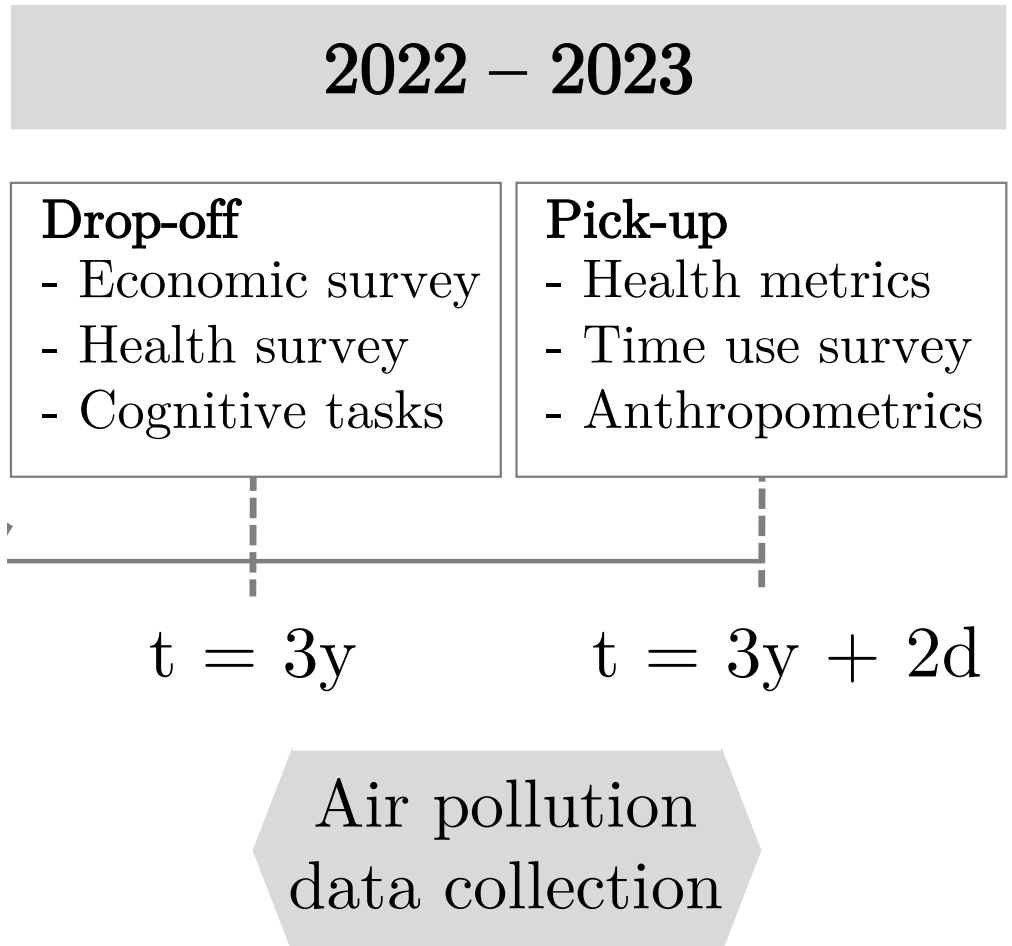
	OLS	First Stage	IV Estimate	
	USD	Bought Stove	USD	IHS(USD)
BDM Price (USD)	0.004	-0.029***		
	(0.013)	(0.001)		
WTP (USD)	-0.003	0.025***	-0.003	-0.001
	(0.010)	(0.001)	(0.011)	(0.003)
Bought Cookstove (=1)	-1.926***		-2.279***	-0.496***
	(0.293)		(0.296)	(0.072)
Observations	7923	920	7923	7923
Control Mean	5.716		4.960	2.154
Socioeconomic controls	Yes	Yes	Yes	Yes
Data Source	SMSes	Midline	SMSes	SMSes
F-statistic:		183.47		

Stove reduces charcoal spending by 40% ($2.24 per week)

- Outcome is weekly charcoal spending from SMS survey
- 576 out of 962 respondents (60%) bought stove
- Instrumental Variables: BDM price is instrument for adoption

	OLS	First Stage	IV Estimate	
	USD	Bought Stove	USD	IHS(USD)
BDM Price (USD)	0.004	-0.029***		
	(0.013)	(0.001)		
WTP (USD)	-0.003	0.025***	-0.003	-0.001
	(0.010)	(0.001)	(0.011)	(0.003)
Bought Cookstove (=1)	-1.926***		-2.279***	-0.496***
	(0.293)		(0.296)	(0.072)
Observations	7923	920	7923	7923
Control Mean	5.716		4.960	2.154
Socioeconomic controls	Yes	Yes	Yes	Yes
Data Source	SMSes	Midline	SMSes	SMSes
F-statistic:		183.47		

Follow-up surveys **3.4–3.8 years** later:



Today

Background

Study design

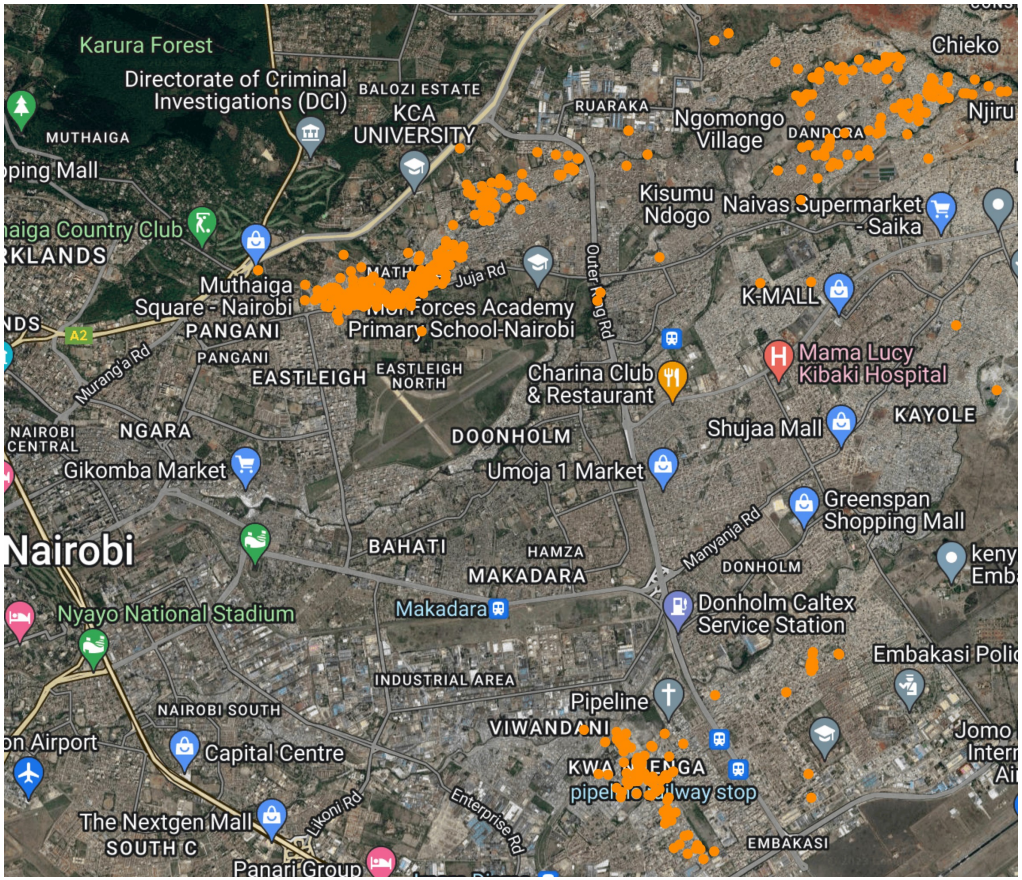
Data & descriptive statistics

Pollution impacts

Health impacts

Impacts on poverty & climate

Follow-up population: 702 households (74%)



- 639 still reside in primary study areas
- 10 respondents reside elsewhere in Nairobi
- 53 respondents reside elsewhere in Kenya
- Attrition is balanced on observables

Jikokoa ownership is persistent

Instrumental variables regression, instrumenting for improved stove ownership with 3 instruments:

- Randomly assigned price
- Randomly assigned credit treatment
- Interaction

Jikokoa ownership is persistent

Instrumental variables regression, instrumenting for improved stove ownership with 3 instruments:

- Randomly assigned price
- Randomly assigned credit treatment
- Interaction

	Control Mean	TE of 2019 Jikokoa Ownership	N
Owns other wood/charcoal stove in 2022	0.88	-0.54***	702
	[0.33]	(0.05)	
Owns Jikokoa in 2022	0.10	0.74***	702
	[0.31]	(0.04)	
Owns LPG stove in 2022	0.57	0.05	702
	[0.50]	(0.06)	
Owns bio-ethanol stove in 2022	0.15	0.01	702
	[0.36]	(0.04)	
Owns electric stove in 2022	0.00	0.02*	702
	[0.06]	(0.01)	

Five data sources

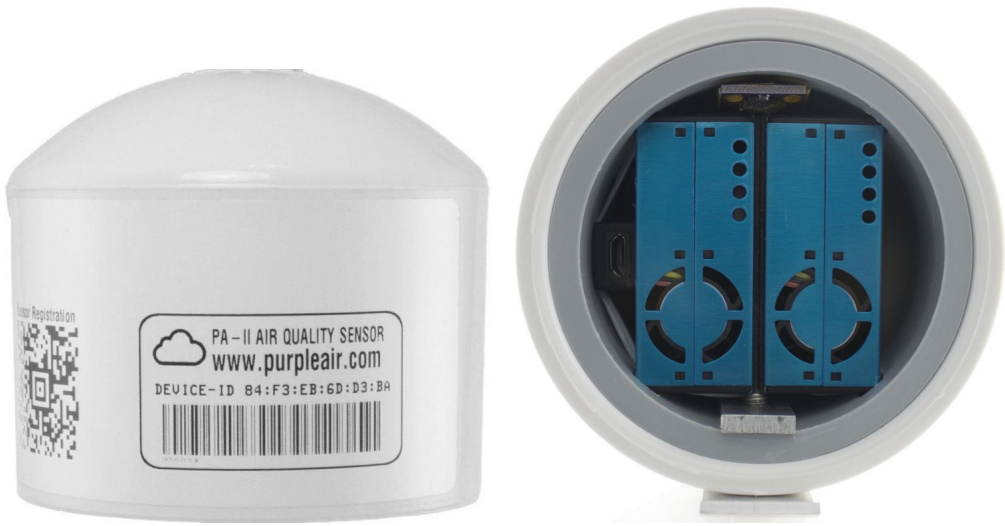
1. Air pollution
2. Clinical health outcomes
3. Self-reported health outcomes
4. Time-use
5. Cognitive function

1. Air pollution

Particulate Matter (PM)

- Purple Air device
- One reading every 2 minutes
- Calibrated using Ward et al. (AGU 2021)

PM1.0: Any particles $< 1.0\mu m$ *diameter*
PM2.5: Any particles $< 2.5\mu m$ *diameter*

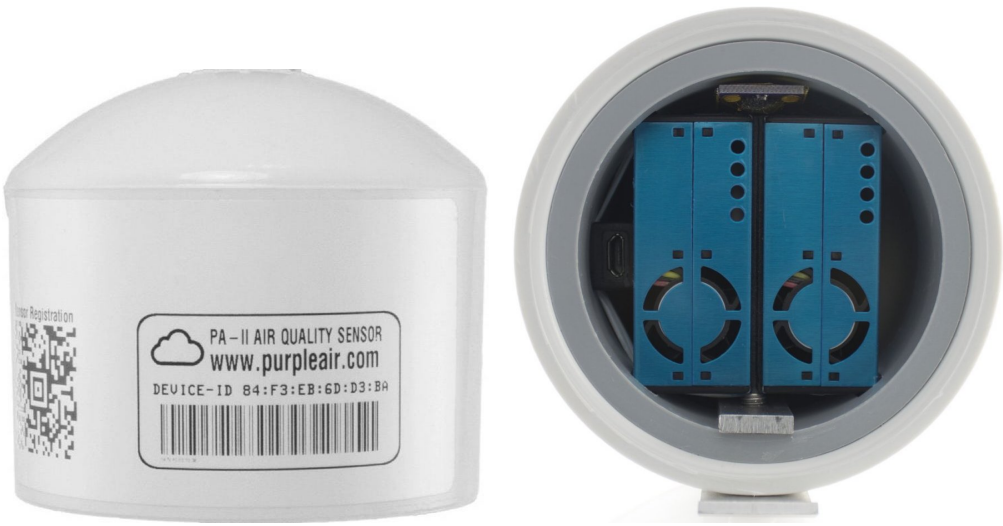


1. Air pollution

Particulate Matter (PM)

- Purple Air device
- One reading every 2 minutes
- Calibrated using Ward et al. (AGU 2021)

PM1.0: Any particles $< 1.0\mu m$ *diameter*
PM2.5: Any particles $< 2.5\mu m$ *diameter*



Carbon Monoxide (CO)

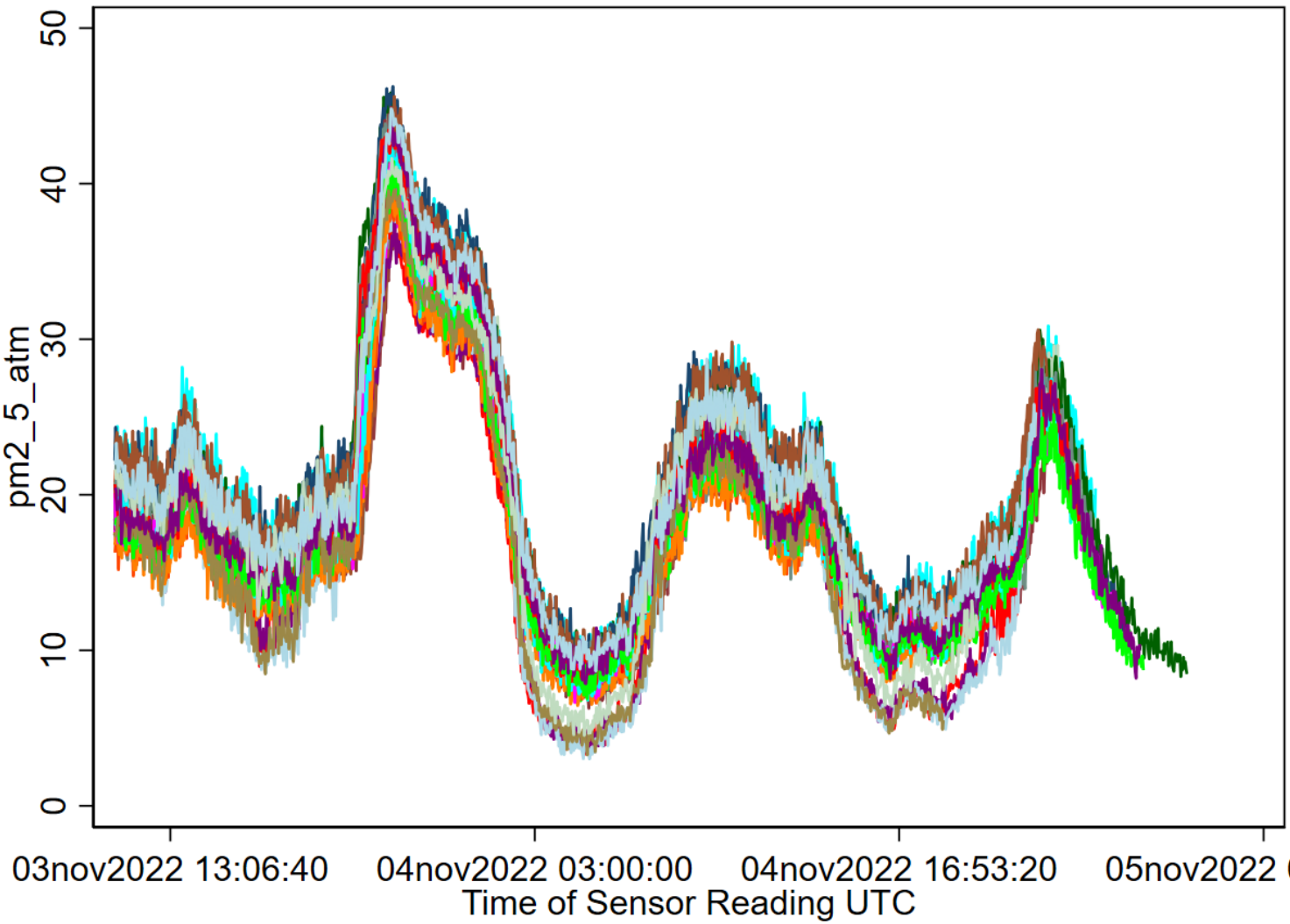
- Lascar Electronics device
- One reading every minute
- Calibrated every 2 months

1. Air pollution measurements

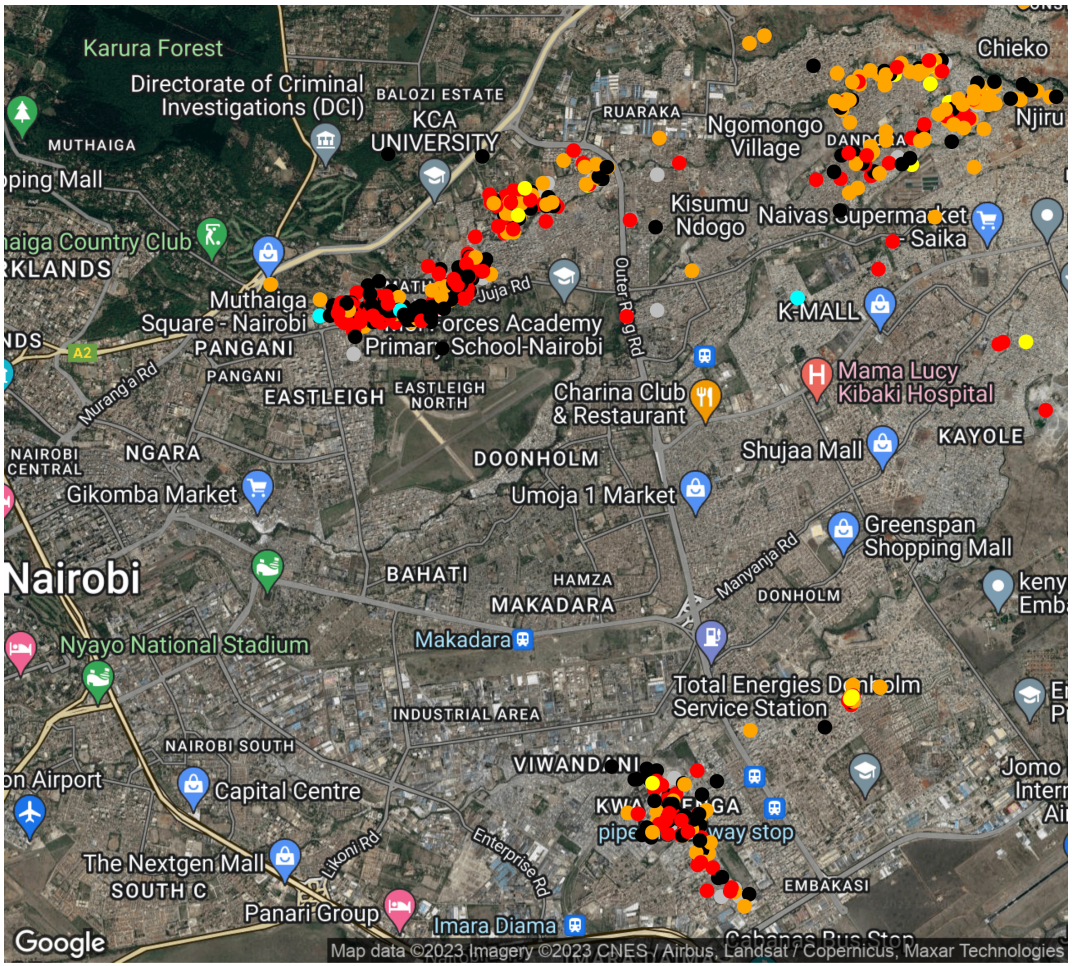
- Methodology and design developed by Berkeley Air Johnson et al 2021
- Best practices Chillrud et al 2021; Burrowes 2019; Gordon et al 2014; Gould et al 2022
- Each backpack contains 2 devices and a battery
- Dropped off during visit 1, picked up ∼48 hours later

Co-located PM2.5 readings for 30 devices

- We include device fixed effects where relevant



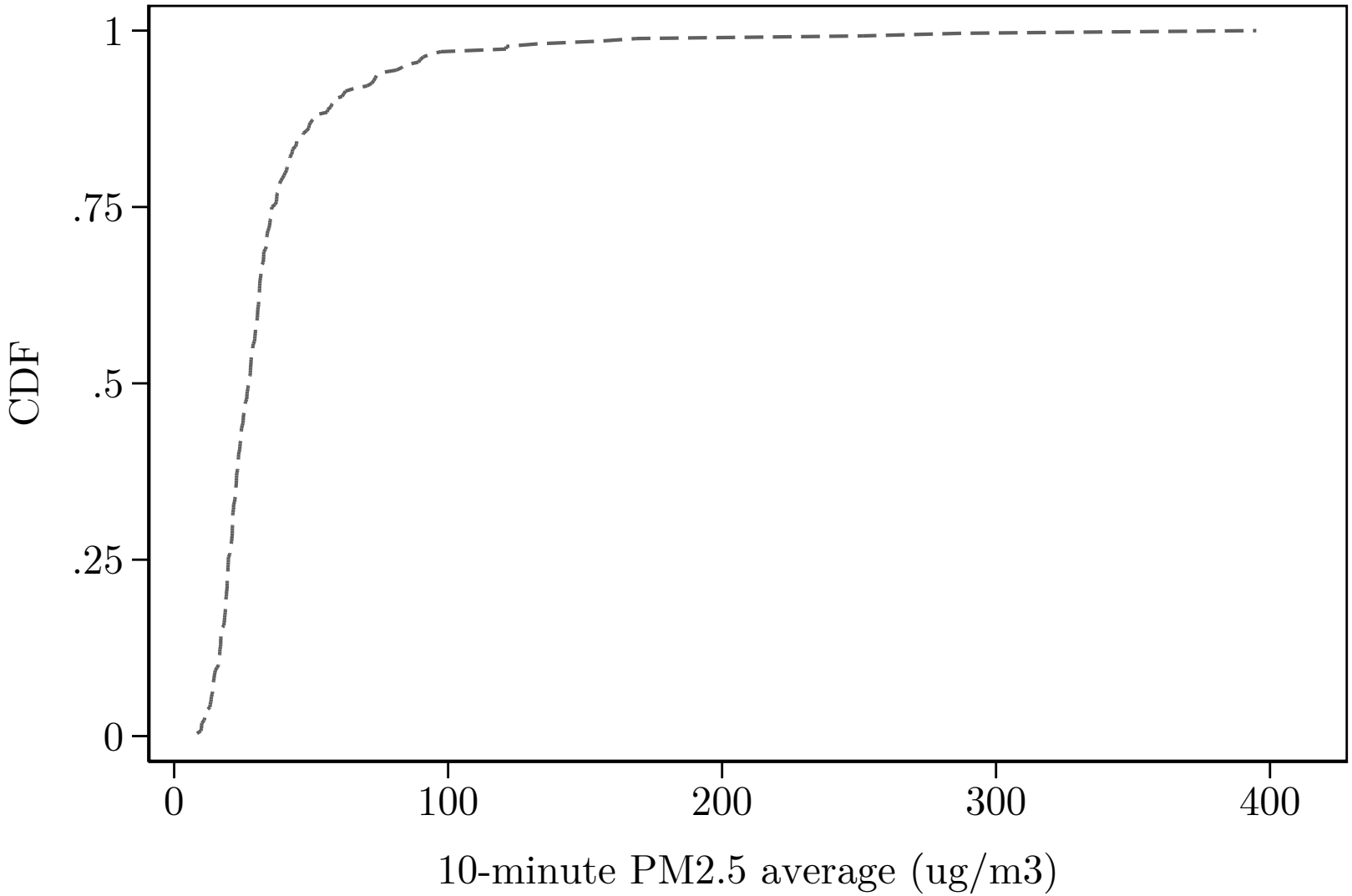
Average PM2.5 concentrations far exceed WHO guidelines



PM2.5 ($\mu g/m^3$):

- 0 – 5
- 5 – 10
- 10 – 15
- 15 – 25
- 25 – 35
- 35+

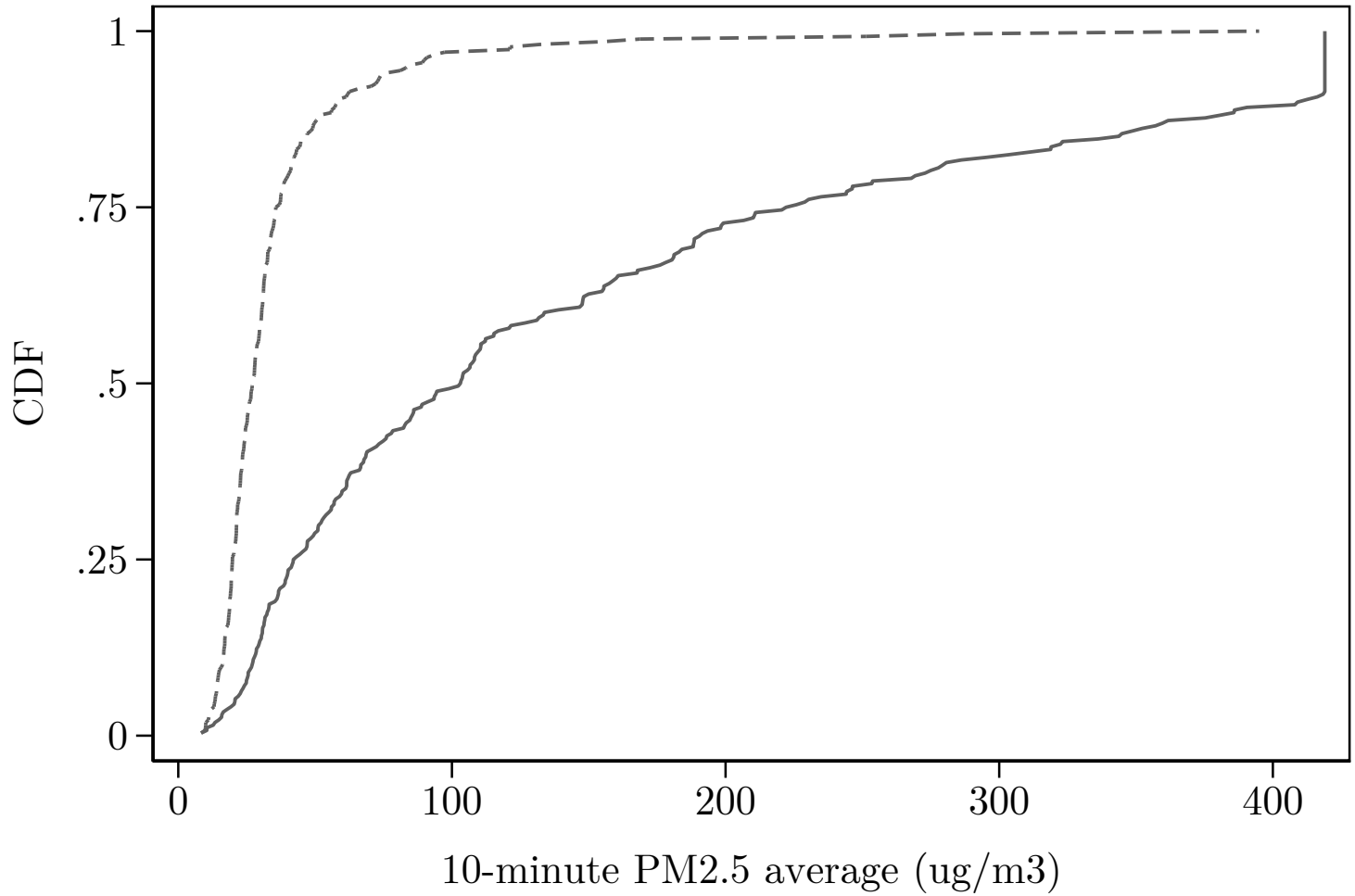
Each respondent's median 10-minute PM2.5:



$35 \mu g/m^3 = \text{AQI } 100$

Each respondent's 99th percentile of 10-minute PM2.5:

(99th percentile is approx. 15 minutes per day)

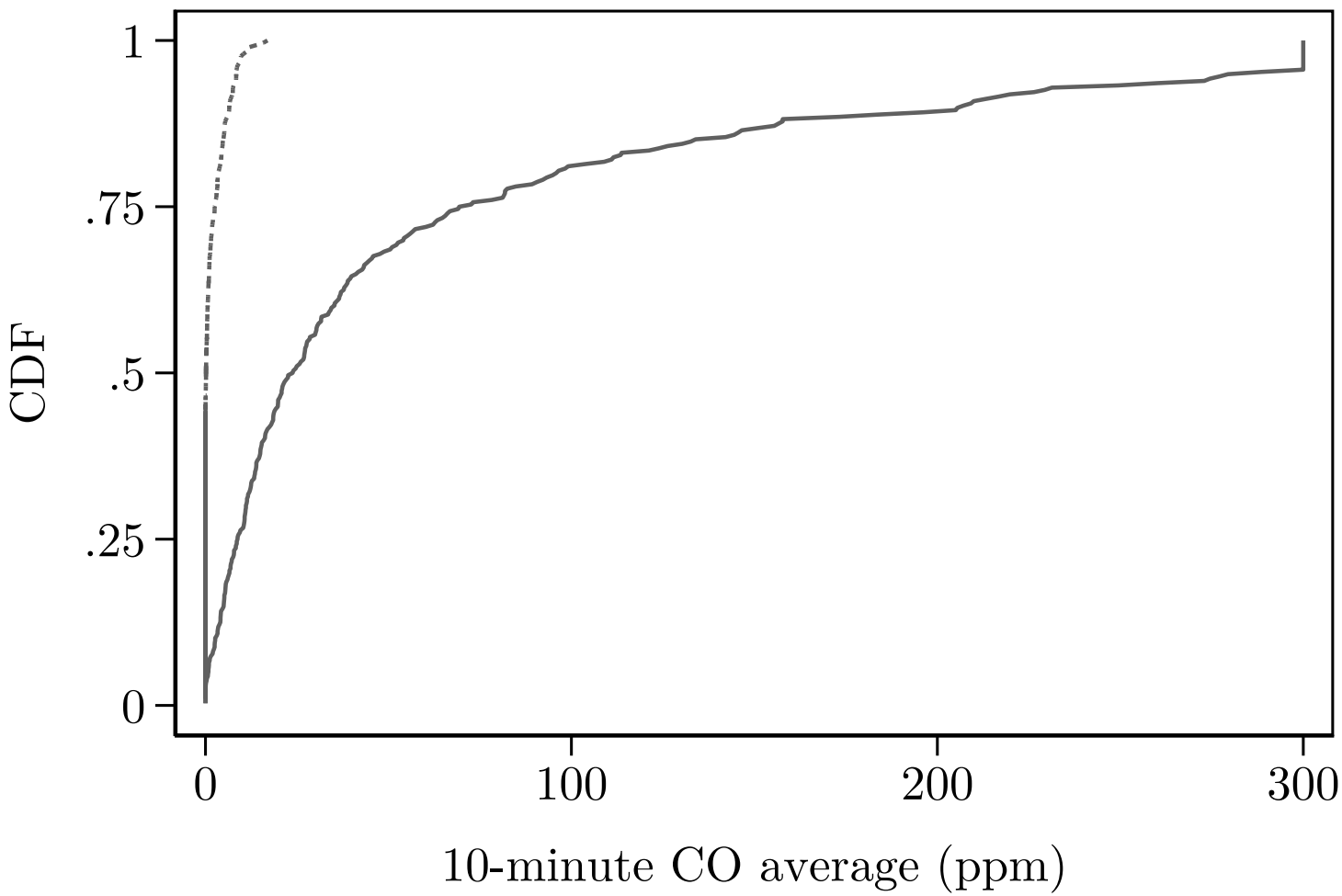


$100\mu g/m^3$ = AQI 174
$200\mu g/m^3$ = AQI 250

50th & 99th percentile of 10-minute CO average:

>10ppm: "Significant increase in heart disease deaths and hospital admissions for congestive heart failure"

>100ppm: "Headache, tiredness, dizziness, nausea, damage to hearts and brains within 2–5 hours" (EPA)



2. Clinical health outcomes

Following methodology from public health Tielsch et al., 2016; Smith-Sivertsen et al., 2009; Checkley et al., 2021

1. **Blood pressure** using a sphygmomanometer
   - Following procedures set out by CDC NHANES (2019)
   - Average of 3 measurements of systolic and diastolic BP
   - Respondent to sit on a chair, straight back, feet flat on the floor, etc.
2. **Blood oxygen saturation** using pulse oximeter

2. Clinical health outcomes

Following methodology from public health Tielsch et al., 2016; Smith-Sivertsen et al., 2009; Checkley et al., 2021

1. **Blood pressure** using a sphygmomanometer
   - Following procedures set out by CDC NHANES (2019)
   - Average of 3 measurements of systolic and diastolic BP
   - Respondent to sit on a chair, straight back, feet flat on the floor, etc.
2. **Blood oxygen saturation** using pulse oximeter
3. **Child anthropometrics**
   - Weight
   - Height
   - Arm circumference

2. Clinical health outcomes

Following methodology from public health Tielsch et al., 2016; Smith-Sivertsen et al., 2009; Checkley et al., 2021

1. **Blood pressure** using a sphygmomanometer
   - Following procedures set out by CDC NHANES (2019)
   - Average of 3 measurements of systolic and diastolic BP
   - Respondent to sit on a chair, straight back, feet flat on the floor, etc.
2. **Blood oxygen saturation** using pulse oximeter
3. **Child anthropometrics**
   - Weight
   - Height
   - Arm circumference
4. **Have you been diagnosed by a medical professional with...**
   - Asthma, pneumonia, COPD, hypertension, diabetes, TB, COVID, etc.
5. **Pneumonia diagnosis** using UNICEF MICS6 (2020) methodology

3. Self-reported health outcomes

Following methodology from public health Tielsch et al., 2016; Smith-Sivertsen et al., 2009; Checkley et al., 2021

In the past two weeks, have you experienced...
(split defined in pre-analysis plan)

- **Self-reported respiratory symptoms:** Headache, fatigue, cough, runny nose, sore throat, etc.
- **Self-reported non-respiratory symptoms:** Fever, stomach pain, malaria, worms, myalgia, etc.

3. Self-reported health outcomes

Following methodology from public health Tielsch et al., 2016; Smith-Sivertsen et al., 2009; Checkley et al., 2021

In the past two weeks, have you experienced...
(split defined in pre-analysis plan)

- **Self-reported respiratory symptoms:** Headache, fatigue, cough, runny nose, sore throat, etc.
- **Self-reported non-respiratory symptoms:** Fever, stomach pain, malaria, worms, myalgia, etc.

Child outcomes: ask parents about any symptoms or diagnoses in children under 10

4. Time-use survey

For each hour during which the respondent had the device:

- Whether they were indoor or outdoors
- Their primary activity(ies)
- If the primary activitiy was cooking, which cookstove(s) they used

Adoption does not affect cooking behavior

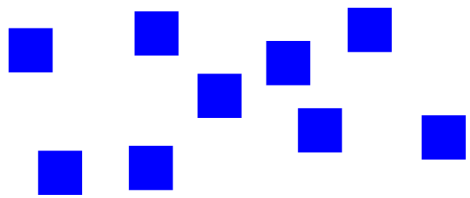
	Minutes per day	Cooking (=1)		Cooking indoors (=1)	
	(1)	(2)	(3)	(4)	(5)
Own Jikokoa	4.131	0.013	0.014	-0.026	-0.065
	(9.025)	(0.010)	(0.010)	(0.047)	(0.061)
Control Mean	137.013	0.101	0.101	0.889	0.872
HOD FE	N/A	N/A	Yes	N/A	Yes
Weak IV F-Stat	51	51	69	46	47
Observations	697	697	31887	649	3068

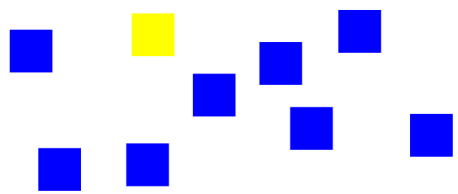
5. Cognition

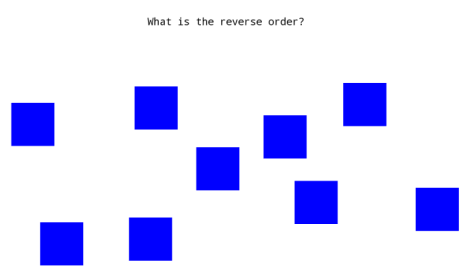
Working memory

Ability to store and manipulate information in your mind

Reverse Corsi Blocks:





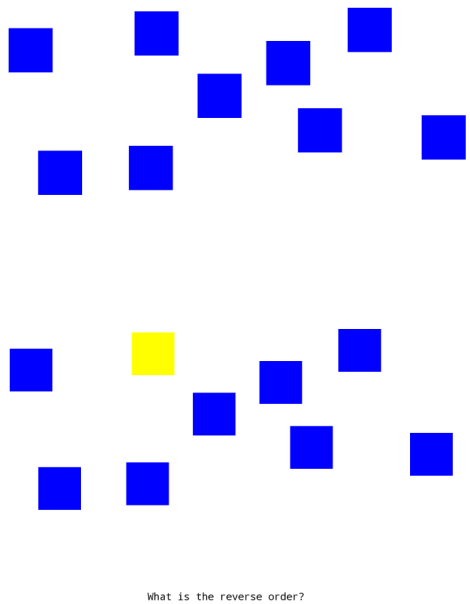


5. Cognition

Working memory

Ability to store and manipulate information in your mind

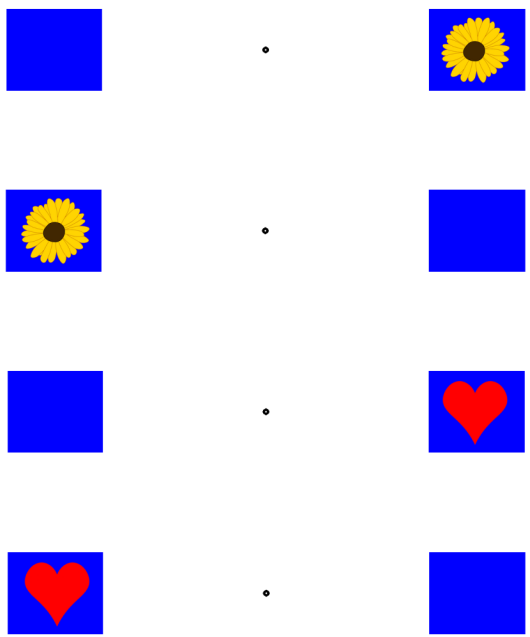
Reverse Corsi Blocks:



Inhibitory control

Ability to resist tempting impulses

Hearts and Flowers:

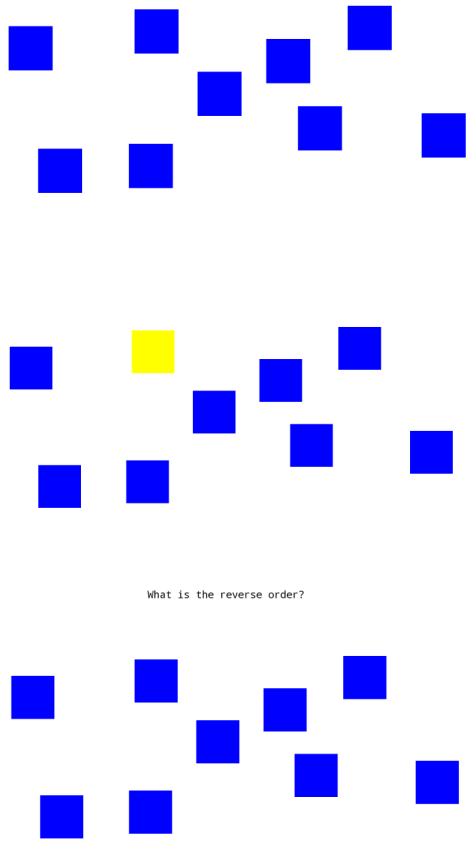


5. Cognition

Working memory

Ability to store and manipulate information in your mind

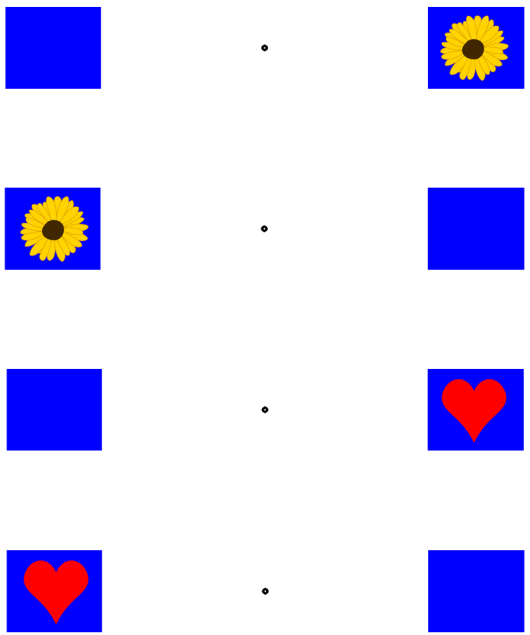
Reverse Corsi Blocks:



Inhibitory control

Ability to resist tempting impulses

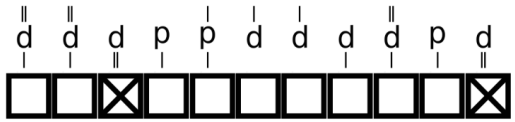
Hearts and Flowers:



Attention

Ability to ignore distractions

d2 task:



Today

Background

Study design

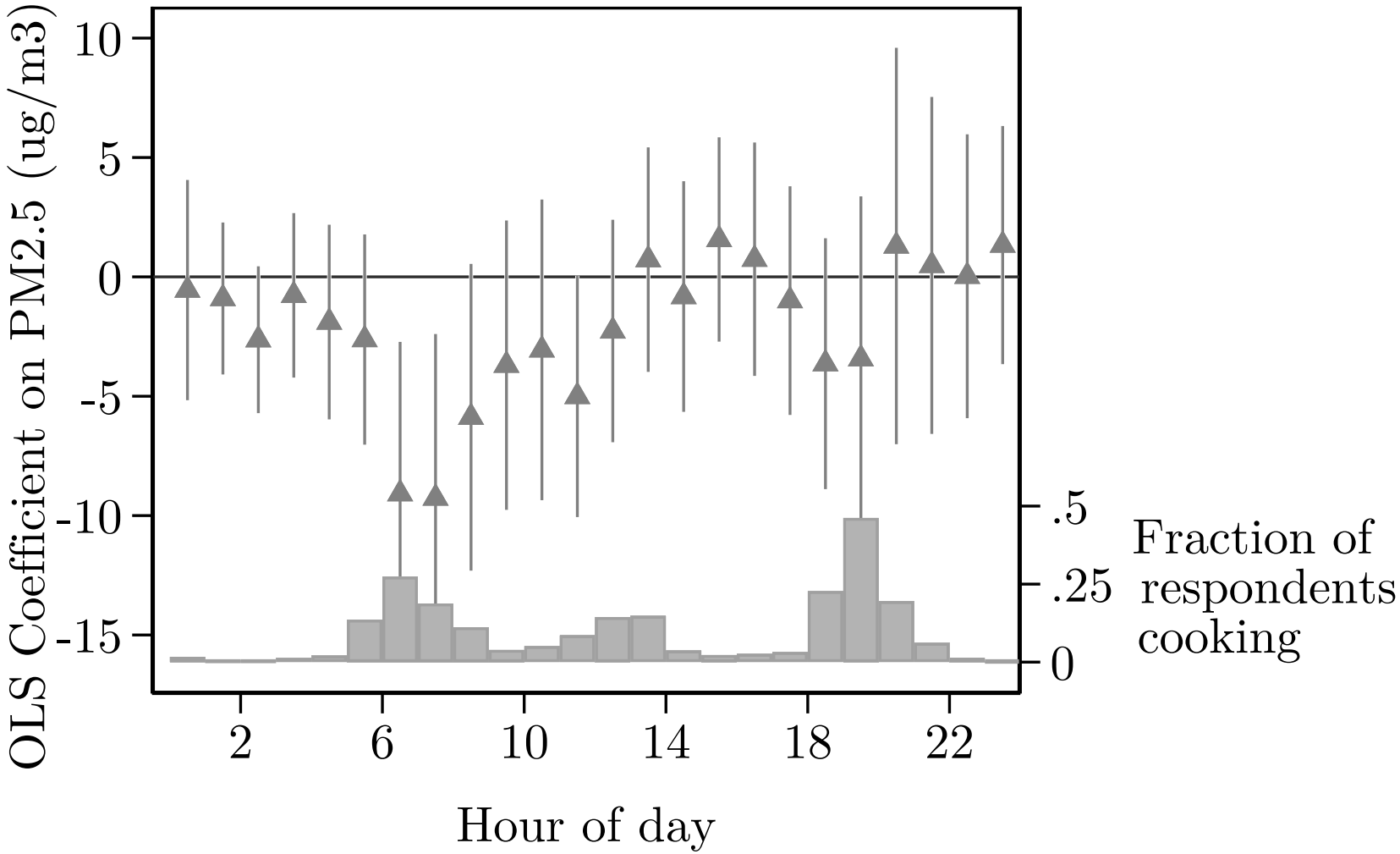
Data & descriptive statistics

Pollution impacts

Health impacts

Impacts on poverty & climate

PM2.5 decreases during cooking times:



Respondent-level pollution metrics

- As before: subsidy and credit instrument for Jikokoa ownership

Panel A) All hours

	Median	Mean	Max Hour	99th
Own Jikokoa	0.1	-0.8	-16.4	-8.3
	(1.7)	(3.4)	(19.0)	(23.0)
Control Mean	25.2	37.8	153.3	200.3
Weak IV F-Statistic	53	53	53	53
Observations	651	651	651	651

Panel B) Hours when self-reporting cooking

	Median	Mean	Max Hour	99th
Own Jikokoa	-11.0**	-16.6***	-31.0**	-52.0**
	(5.2)	(6.4)	(15.4)	(22.5)
Control Mean	35.9	49.7	92.6	150.3
Weak IV F-Statistic	48	48	48	48
Observations	598	598	595	598

Cooking increases PM2.5 by $125 \mu g/m^3$

- As before: subsidy and credit instrument for Jikokoa ownership

Panel A) All hours

	Median	Mean	Max Hour	99th
Own Jikokoa	0.1	-0.8	-16.4	-8.3
	(1.7)	(3.4)	(19.0)	(23.0)
Control Mean	25.2	37.8	153.3	200.3
Weak IV F-Statistic	53	53	53	53
Observations	651	651	651	651

Panel B) Hours when self-reporting cooking

	Median	Mean	Max Hour	99th
Own Jikokoa	-11.0**	-16.6***	-31.0**	-52.0**
	(5.2)	(6.4)	(15.4)	(22.5)
Control Mean	35.9	49.7	92.6	150.3
Weak IV F-Statistic	48	48	48	48
Observations	598	598	595	598

Adoption reduces peak emissions by $52\mu g/m^3$ (42%)

Panel A) All hours

	Median	Mean	Max Hour	99th
Own Jikokoa	0.1	-0.8	-16.4	-8.3
	(1.7)	(3.4)	(19.0)	(23.0)
Control Mean	25.2	37.8	153.3	200.3
Weak IV F-Statistic	53	53	53	53
Observations	651	651	651	651

Panel B) Hours when self-reporting cooking

	Median	Mean	Max Hour	99th
Own Jikokoa	-11.0**	-16.6***	-31.0**	-52.0**
	(5.2)	(6.4)	(15.4)	(22.5)
Control Mean	35.9	49.7	92.6	150.3
Weak IV F-Statistic	48	48	48	48
Observations	598	598	595	598

No detectable change in daily average

- –0.8$\mu g/m^3$ is around 2%
- 95% CI: -7.5, 5.9 $\mu g/m^3$

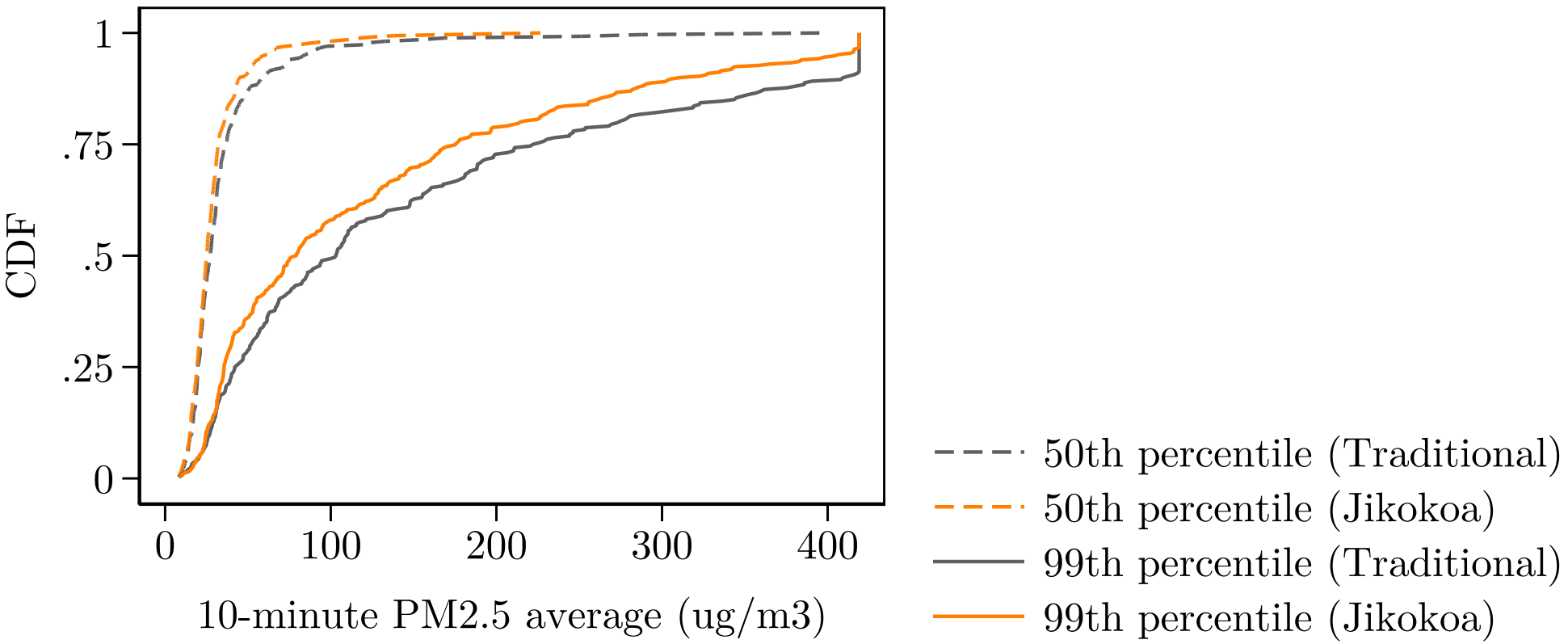
Panel A) All hours

	Median	Mean	Max Hour	99th
Own Jikokoa	0.1	-0.8	-16.4	-8.3
	(1.7)	(3.4)	(19.0)	(23.0)
Control Mean	25.2	37.8	153.3	200.3
Weak IV F-Statistic	53	53	53	53
Observations	651	651	651	651

Panel B) Hours when self-reporting cooking

	Median	Mean	Max Hour	99th
Own Jikokoa	-11.0**	-16.6***	-31.0**	-52.0**
	(5.2)	(6.4)	(15.4)	(22.5)
Control Mean	35.9	49.7	92.6	150.3
Weak IV F-Statistic	48	48	48	48
Observations	598	598	595	598

Impact on 50th and 99th percentiles



How big of an effect could private fuel switching have on **average** exposure?

- Respondents cook for 9% of the day (2 hours) on average
- Average PM2.5 is $38 \mu g/m^3$ (AQI: 100)
  - $52 \mu g/m^3$ when cooking
  - $36 \mu g/m^3$ when not cooking
- Even if treatment consisted of a perfectly clean stove (e.g. electric), then treatment would still only reduce average exposure by $1.9 \mu g/m^3$ (4%)

How big of an effect could private fuel switching have on **average** exposure?

- Respondents cook for 9% of the day (2 hours) on average
- Average PM2.5 is $38\mu g/m^3$ (AQI: 100)
  - $52\mu g/m^3$ when cooking
  - $36\mu g/m^3$ when not cooking
- Even if treatment consisted of a perfectly clean stove (e.g. electric), then treatment would still only reduce average exposure by $1.9\mu g/m^3$ (4%)
- **In rural areas:**
  - Background is $9\mu g/m^3$ (Pope et al, 2018)
  - Suppose cooking twice as long
  - **28%** reduction in aggregate exposure

Summarizing pollution impacts:

- Median concentration: $25\mu g/m^3$ (AQI 75)
- Cooking increases peak pollution by $125\mu g/m^3$ among control
- Jikokoa reduces this by $52\mu g/m^3$: **42%** of the increase
- Impacts persist for 3.5+ years

Summarizing pollution impacts:

- Median concentration: $25\mu g/m^3$ (AQI 75)
- Cooking increases peak pollution by $125\mu g/m^3$ among control
- Jikokoa reduces this by $52\mu g/m^3$: **42%** of the increase
- Impacts persist for 3.5+ years
- Still, respondents cook only 9% of the day (2 hours): no detectable impact on average pollution

Summarizing pollution impacts:

- Median concentration: $25\mu g/m^3$ (AQI 75)
- Cooking increases peak pollution by $125\mu g/m^3$ among control
- Jikokoa reduces this by $52\mu g/m^3$: **42%** of the increase
- Impacts persist for 3.5+ years
- Still, respondents cook only 9% of the day (2 hours): no detectable impact on average pollution

How does pollution affect health?

A 0.24SD reduction in self-reported respiratory symptoms

- Split pre-specified in analysis plan

	Control Mean	Treatment Effect	N
Health symptoms index (z-score)	0.00	-0.15	702
	[1.00]	(0.16)	
Number of health symptoms	2.78	-0.72*	702
	[2.93]	(0.42)	
Non-respiratory health symptom index	-0.00	-0.03	702
	[1.00]	(0.19)	
Number of non-respiratory health symptoms	1.09	-0.24	702
	[1.54]	(0.25)	
Respiratory health symptom index	-0.00	-0.24*	702
	[1.00]	(0.13)	
Number of respiratory health symptoms	1.70	-0.48**	702
	[1.76]	(0.23)	

Reductions in sore throat, headache, cough, fatigue

	Control Mean	Treatment Effect	N
Respiratory health symptom index	-0.00	-0.24*	702
	[1.00]	(0.13)	
Number of respiratory health symptoms	1.70	-0.48**	702
	[1.76]	(0.23)	
Persistent cough	0.24	-0.09	702
	[0.43]	(0.07)	
Always feeling tired	0.30	-0.07	702
	[0.46]	(0.07)	
Breathlessness at night	0.08	-0.01	702
	[0.27]	(0.04)	
Frequent diarrhea	0.02	-0.02	702
	[0.15]	(0.03)	
Difficulty breathing / Chest tightness	0.07	-0.01	702
	[0.26]	(0.04)	
Runny nose	0.23	-0.05	702
	[0.42]	(0.07)	
Sore throat	0.16	-0.12*	702
	[0.37]	(0.06)	
Headache	0.52	-0.12	702
	[0.50]	(0.08)	
Wheezing	0.03	0.01	702
	[0.17]	(0.03)	
Persistent mucus problems	0.04	-0.01	702
	[0.19]	(0.02)	

No detectable impact on clinical health outcomes

	Control Mean	Treatment Effect	N
Blood oxygen	96.61	0.31	696
	[2.53]	(0.37)	
Average systolic blood pressure	122.16	0.49	696
	[18.97]	(3.30)	
Average diastolic blood pressure	81.32	0.58	696
	[11.73]	(2.15)	
Hypertension: Stage 1 or higher (>130/80)	0.51	0.02	696
	[0.50]	(0.09)	
Hypertension: Stage 2 or higher (>140/90)	0.27	-0.02	696
	[0.44]	(0.08)	

No detectable impact on clinical health outcomes

- We can rule out a 0.14 SD or greater reduction in health diagnoses
- We can rule out a 6 mmHg or greater reduction in systolic BP
- Smoking acutely increases systolic BP by 20 mmHg (Cohen and Townsend, 2009); limited evidence on long-term impact on BP
- Comparing our cardiovascular impacts with the medical literature we can reject a 12% or greater decrease in major cardiovascular events

No detectable impact on clinical health outcomes

- We can rule out a 0.14 SD or greater reduction in health diagnoses
- We can rule out a 6 mmHg or greater reduction in systolic BP
- Smoking acutely increases systolic BP by 20 mmHg (Cohen and Townsend, 2009); limited evidence on long-term impact on BP
- Comparing our cardiovascular impacts with the medical literature we can reject a 12% or greater decrease in major cardiovascular events
- No heterogeneity by baseline health, beliefs about health, age, WTP, or background pollution

No impact on diagnoses by healthcare professionals

	Control Mean	Treatment Effect	N
Number of health diagnoses	0.30	0.13	702
	[0.58]	(0.09)	
Asthma	0.01	-0.01	702
	[0.08]	(0.01)	
Pneumonia	0.13	0.02	702
	[0.34]	(0.05)	
Chronic Pulmonary Disease	0.00	0.01	702
	[0.06]	(0.01)	
Tuberculosis	0.01	0.02	702
	[0.08]	(0.01)	
COVID	0.01	-0.01	702
	[0.08]	(0.01)	
Other lung disease	0.01	-0.01	702
	[0.08]	(0.01)	
Stroke or cardiovascular disease	0.01	-0.00	702
	[0.08]	(0.01)	
Diabetes	0.02	-0.00	702
	[0.14]	(0.02)	
Other	0.04	0.01	702
	[0.19]	(0.03)	

No impact on children's outcomes (ages <10, <5)

	Control Mean	Treatment Effect	N
Child weight (kg)	17.73	-1.02	224
	[7.57]	(1.80)	
Child height (cm)	98.59	6.02	199
	[31.07]	(6.08)	
Child arm circumference (cm)	16.37	1.24	220
	[7.26]	(1.41)	
Number of child health symptoms	1.19	0.34	343
	[1.50]	(0.40)	
Child health symptom index	0.00	0.32	343
	[1.00]	(0.29)	
Fever	0.18	-0.01	343
	[0.38]	(0.09)	
Vomiting	0.10	-0.01	343
	[0.30]	(0.06)	
Cough	0.40	0.03	343
	[0.49]	(0.12)	
Diarrhea	0.10	0.00	343
	[0.30]	(0.07)	
Breathlessness	0.04	0.08	343
	[0.19]	(0.06)	
Persistent headache	0.08	0.05	343
	[0.27]	(0.05)	
Very bad cough	0.25	0.10	343
	[0.43]	(0.09)	
Pneumonia - DHS	0.03	0.03	343
	[0.18]	(0.05)	

No impact on cognitive function

	Control Mean	Treatment Effect	N
Cognitive index	-0.00	-0.01	587
	[1.00]	(0.15)	
Working memory (Corsi)	-0.00	-0.48**	305
	[1.00]	(0.22)	
Attention (d2)	0.00	-0.09	564
	[1.00]	(0.15)	
Inhibitory control (HF - % correct)	-0.00	0.18	516
	[1.00]	(0.16)	
Inhibitory control (HF - reaction time)	0.00	0.14	516
	[1.00]	(0.19)	

Sample size here is smaller due to technical issues with the tablets. Since the order of follow-up surveys was randomized, it is unlikely that this biased the results.

Evidence against measurement error, experimenter demand

Evidence against measurement error, experimenter demand

1. Medical diagnoses correlate with blood pressure

	Mean (1)	Blood Pressure (2)	N (4)
Health diagnoses index	-0.00	0.11***	696
	[1.00]	(0.04)	
Number of health diagnoses	0.28	0.06***	696
	[0.55]	(0.02)	

Evidence against measurement error, experimenter demand

1. Medical diagnoses correlate with blood pressure
2. Impact on **respiratory** but not **non-respiratory** symptoms

	Control Mean	Treatment Effect	N
Non-respiratory health symptom index	-0.00	-0.03	702
	[1.00]	(0.19)	
Number of non-respiratory health symptoms	1.09	-0.24	702
	[1.54]	(0.25)	
Respiratory health symptom index	-0.00	-0.24*	702
	[1.00]	(0.13)	
Number of respiratory health symptoms	1.70	-0.48**	702
	[1.76]	(0.23)	

Evidence against measurement error, experimenter demand

1. Medical diagnoses correlate with blood pressure
2. Impact on **respiratory** but not **non-respiratory** symptoms
3. No difference by size of subsidy (25% to 90%)

	Respiratory			Non-respiratory		
	(1)	(2)	(3)	(4)	(5)	(6)
Owns Jikokoa	-0.45***	-0.29	-0.30	-0.39***	-0.40	-0.38
	(0.12)	(0.28)	(0.28)	(0.11)	(0.26)	(0.27)
Price (10 USD)	-0.00	0.05	0.05	-0.06	-0.07	-0.06
	(0.07)	(0.11)	(0.11)	(0.06)	(0.10)	(0.10)
Owns Jikokoa		-0.09	-0.09		0.00	0.01
X Price (10 USD)		(0.14)	(0.14)		(0.13)	(0.13)
WTP (10 USD)			0.02			-0.02
			(0.05)			(0.05)

Today

Background

Study design

Data & descriptive statistics

Pollution impacts

Health impacts

Impacts on poverty & climate

Reduction in charcoal expenditures persists

- Persistent **40% reduction** in charcoal expenditures

	(1) 2022	(2) 2019
Own Jikokoa	-1.50***	-1.12***
	(0.47)	(0.35)
Own Jikokoa (Urban)		
Own Jikokoa (Rural)		
Rural	-1.05***	-1.08***
	(0.36)	(0.38)
Control Mean	3.84	3.65
Weak IV F-Statistic	64.22	217.30
Observations	702	702

Regressions use the randomly assigned subsidy, offer of credit and their interaction as instruments for Jikokoa adoption

Reduction in charcoal expenditures persists – concentrated in urban areas

- Persistent **40% reduction** in charcoal expenditures
- Charcoal and wood often gathered (not purchased) in rural areas

	(1) 2022	(2) 2019	(3) 2022	(4) 2019
Own Jikokoa	-1.50***	-1.12***		
	(0.47)	(0.35)		
Own Jikokoa (Urban)			-1.64***	-1.20***
			(0.51)	(0.37)
Own Jikokoa (Rural)			-0.45	-0.40
			(1.05)	(0.98)
Rural	-1.05***	-1.08***	-1.74**	-1.58*
	(0.36)	(0.38)	(0.85)	(0.82)
Control Mean	3.84	3.65	3.84	3.65
Weak IV F-Statistic	64.22	217.30	26.75	96.17
Observations	702	702	702	702

Regressions use the randomly assigned subsidy, offer of credit and their interaction as instruments for Jikokoa adoption

This is a very cost-effective CO_2 abatement opportunity

- No crowding in/out of other stoves (e.g. LPG, electric)
- To calculate **additionality:**
  - 98% of stoves sold are used for >1 year; 83% for 3 years
  - Low subsidy group ($13-15): 37% adopted
  - High subsidy group ($28-30): 77% adopted
  - Every $100 in subsidies incentivizes 5.8 stove-years

This is a very cost-effective CO_2 abatement opportunity

- No crowding in/out of other stoves (e.g. LPG, electric)
- To calculate **additionality:**
  - 98% of stoves sold are used for >1 year; 83% for 3 years
  - Low subsidy group ($13-15): 37% adopted
  - High subsidy group ($28-30): 77% adopted
  - Every $100 in subsidies incentivizes 5.8 stove-years
- Adoption reduces emissions by 3.5 tCO_2e/yr
  - 2 tCO_2e/yr with more conservative fNRB assumptions

This is a very cost-effective CO_2 abatement opportunity

- No crowding in/out of other stoves (e.g. LPG, electric)
- To calculate **additionality:**
  - 98% of stoves sold are used for >1 year; 83% for 3 years
  - Low subsidy group ($13-15): 37% adopted
  - High subsidy group ($28-30): 77% adopted
  - Every $100 in subsidies incentivizes 5.8 stove-years
- Adoption reduces emissions by 3.5 tCO_2e/yr
  - 2 tCO_2e/yr with more conservative fNRB assumptions
- **Abatement cost: $4.9 per tCO_2e**

Conclusion

- Reductions in peak exposure can generate short-term health benefits with meaningful quality-of-life improvements
- Chronic, clinical health improvements may require reductions in average concentrations

Conclusion

- Reductions in peak exposure can generate short-term health benefits with meaningful quality-of-life improvements
- Chronic, clinical health improvements may require reductions in average concentrations
- The stove's large **climate & financial benefits** persist:
  - CO_2 mitigation at \$5–\$10 per ton
  - Private savings of \$86–\$120 per year

Thank you!

sberkou@wharton.upenn.edu
joshua.dean@chicagobooth.edu