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

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March 2024

What causes pollution peaks? Routine daily activities:

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The Washington Post

CLIMATE COACH

Are induction stoves that much safer than gas? We tested them.

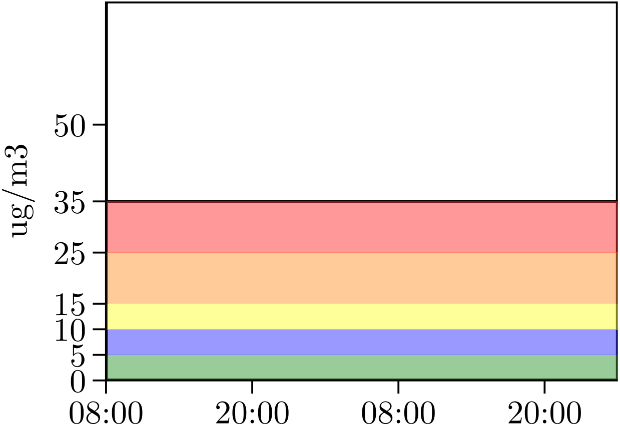
Scientists' best answer, at the moment, to whether you should ditch your gas stove is: We're not sure yet

Advice by Michael J. Coren, John Farrell and Alice Li

January 16, 2024 at 6:30 a.m. EST

Daily air pollution patterns

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



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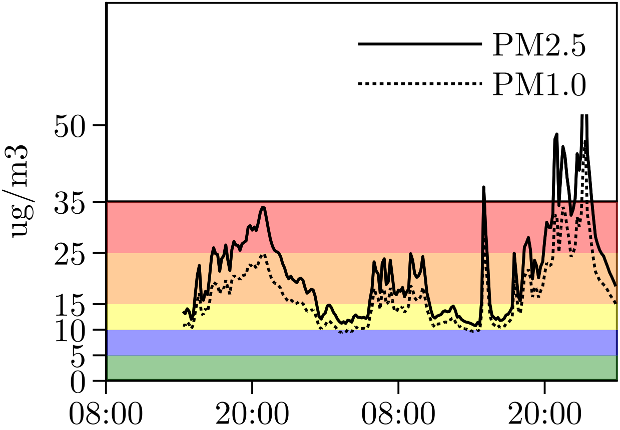

Source: Individual carrying an Purple Air device in Nairobi

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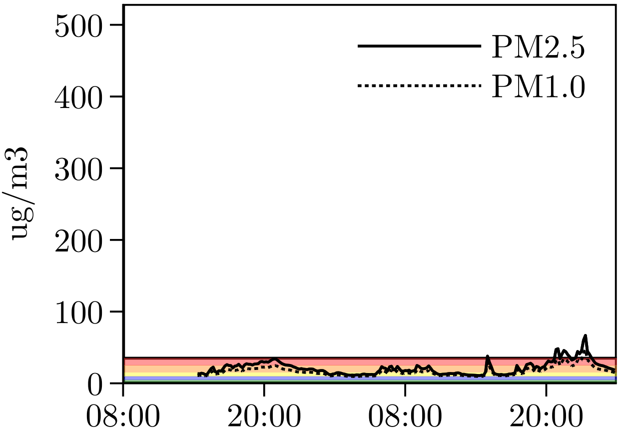

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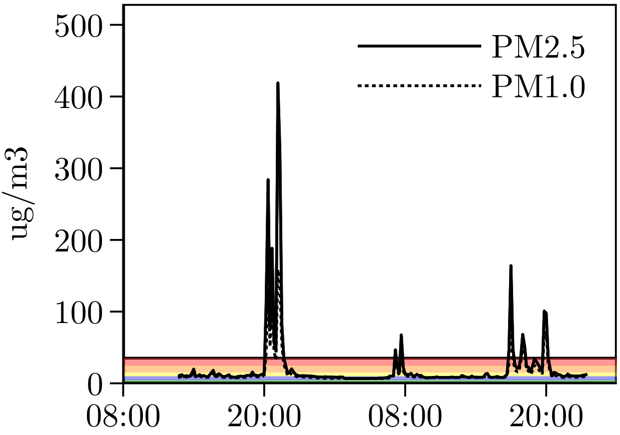

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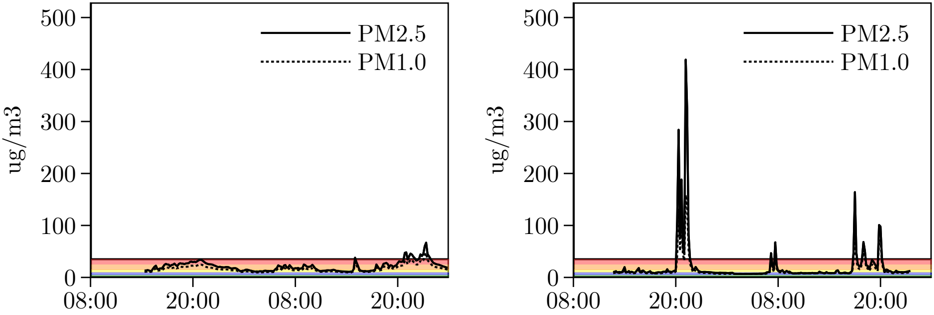
Same daily average (21μg/m^3, AQI 70):



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- WHO and *Lancet* Global Burden of Disease Study (2019): Air pollution causes 7–9 million premature deaths (10–15%) annually
- These estimates might lead some to conclude that by adopting cleaner technologies, households can substantially improve their health outcomes

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)

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   - RESPIRE, HAPIN, and almost all other research **rural**
   - **None** measure non-kitchen exposure ⇒ no estimates of daily averages

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)

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- 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.

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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

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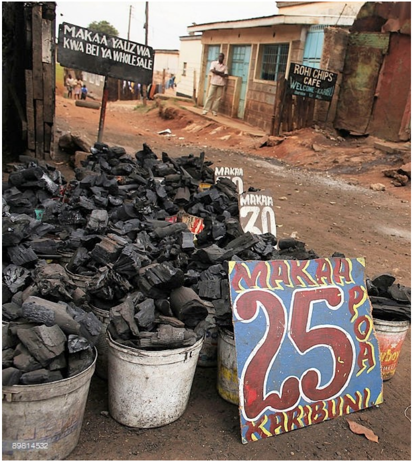
3. **WHO Bulletin (2021):**
   "Jurisdictions with a high temporal variability of PM2.5 concentration, such as in India and China, should consider short-term averaging (20 minutes or 1 hour)"

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)

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- 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: Large reduction in transient peaks

1. Median PM2.5 when not cooking: $\underline{25\mu g/m^3}$ (AQI 100)

2. Cooking increases control group peak pollution by $\underline{125\mu g/m^3}$, to $150\mu g/m^3$ (AQI 187)

Preview of results: Large reduction in transient peaks

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2. Cooking increases control group peak pollution by $\underline{125 \mu g/m^3}$, to $150 \mu g/m^3$ (AQI 187)

3. Improved stove ownership reduces peak cooking pollution by $\underline{52 \mu g/m^3}$: **42%** of the cooking increase

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Evidence against measurement error, experimenter demand:

- Medical diagnoses correlate with blood pressure and blood oxygen measurements
- Impact on **respiratory** symptoms but not **non-respiratory** symptoms
- No change by size of subsidy (25% to 90%)
- Correlation between self-reported health symptoms and max pollution persists **among non-adopters**

How does pollution affect health?

1. **42%** reduction for 2 cooking hours per day
2. **No change** for 22 non-cooking hours per day
3. Negligible impact ($-0.8\mu g/m^3$) on **daily mean** ($37\mu g/m^3$)

How does pollution affect health?

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<u>Evidence is consistent with:</u>

- Transient peaks in pollution cause short-term symptoms
- Average concentrations drive chronic health

Poverty and climate

This does **not** imply the \$40 cookstove is not effective:

1. **Large private benefits:** \$86 reduction in annual charcoal expenditures (1 month of income)
2. **Large social benefits:** Subsidies cost \$5–\$10 per tCO_2e avoided (depending on fNRB value; Gill-Wiehl, Kammen, Haya; 2024)

Today

Background

Study design

Data & descriptive statistics

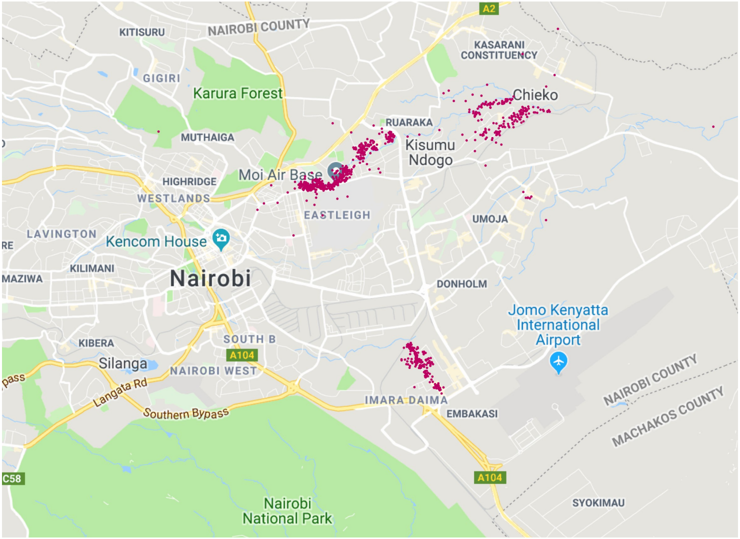
Pollution impacts

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):

These are similar to other urban informal settlements

Jakarta

Mumbai

Lagos

Traditional and energy efficient charcoal cookstoves

KCJ stove
$4

Jikokoa stove
$40

Energy efficient Jikokoa 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)*

2019

Visit 1	Visit 2	Visit 3
- Enrollment	- BDM elicitation - Stove transaction	- Economic survey - Health survey
t = –30d	t = 0	t = 30d

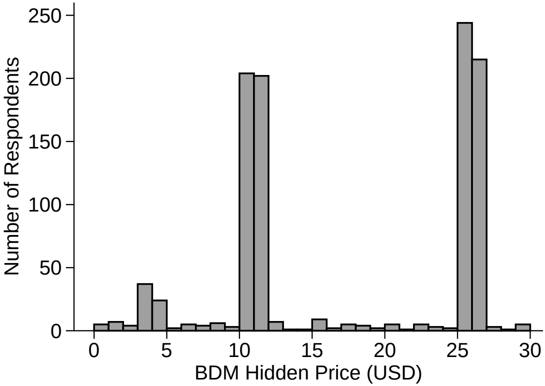
Eliciting Willingness to Pay (WTP):

We use Becker-DeGroot-Marschak (BDM) mechanism

- Guide WTP_i elicitation using binary search
- Reveal random price $P_i \in (0, 30)$ USD
- WTP is binding: adopt *iff* $WTP_i \geq P_i$

Distribution of randomized BDM Prices

- Positive probability everywhere: incentive-compatible
- Concentration to increase first stage
- Discount >$10 for everyone

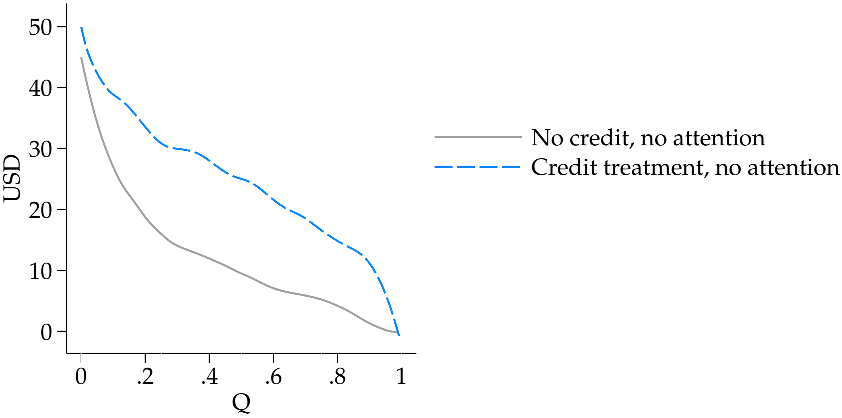


Back

We cross-randomize credit and attention treatments

		Credit Control	Credit Treatment	
			Weekly Deadlines	Monthly Deadlines
Attention Control		96	98	98
Attention Treatment	Energy Savings	96	97	96
	Energy Savings – Costs	145	146	146

Credit increases WTP by $13 (104% increase)



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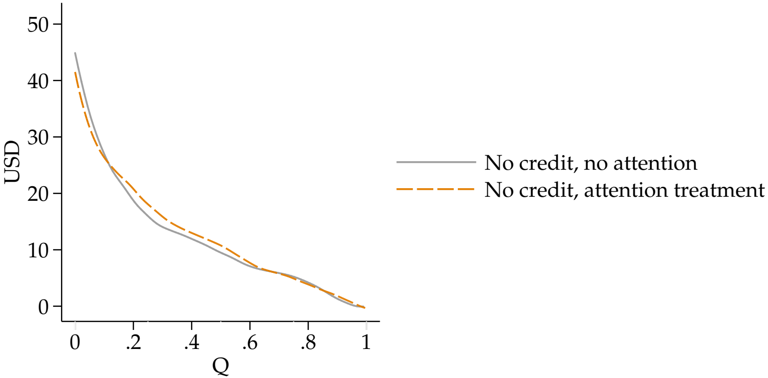
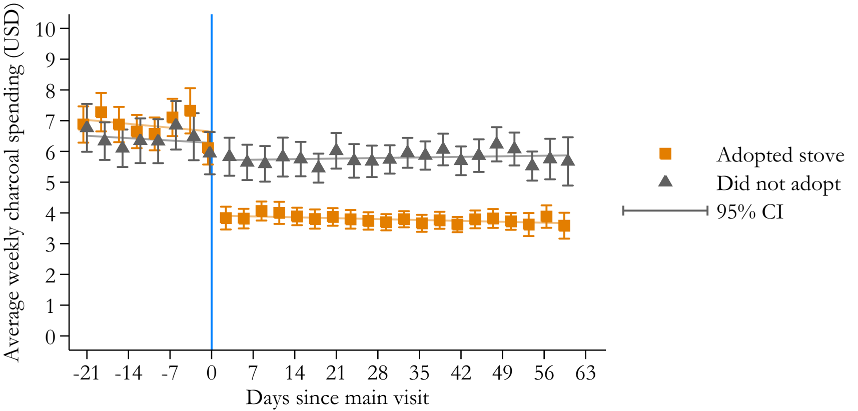
Original study: Attention intervention does nothing



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

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



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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***		$\boxed{-2.279^{***}}$	$\boxed{-0.496^{***}}$
	(0.293)		$\boxed{(0.296)}$	$\boxed{(0.072)}$
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		

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Hawthorne Effect or **Experimenter Demand Effect**?

We weigh KG ash output from 1 month of charcoal use

Original study: Stove reduces charcoal ash output by 40%

	First Stage	IV Estimate		
	Bought Stove	USD	IHS(USD)	IHS(KG)
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Bought Cookstove (=1)		-2.279***	-0.496***	-0.490***
		(0.296)	(0.072)	(0.083)
Observations	920	7923	7923	803
Control Mean		4.960	2.154	1.546
Socioeconomic controls	Yes	Yes	Yes	Yes
Data Source	Midline	SMSes	SMSes	Buckets

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

2022 – 2023

Drop-off	**Pick-up**
- Economic survey	- Health metrics
- Health survey	- Time use survey
- Cognitive tasks	- Anthropometrics

$t = 3y$ $t = 3y + 2d$

Air pollution
data collection

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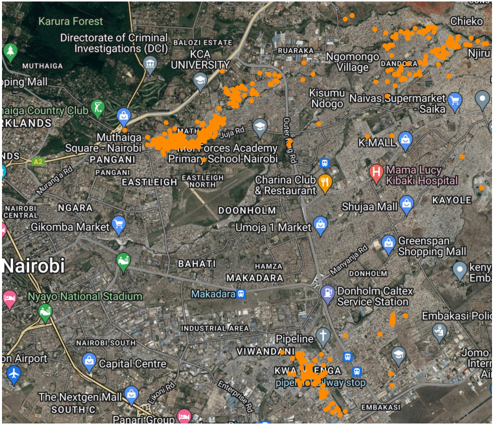
Follow-up population: 702 households (74%)



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

Demographic and socio-economic information

	N	Mean	SD	25^{th}	50^{th}	75^{th}
Female respondent	702	0.96				
Completed primary education	702	0.70				
Completed secondary education	702	0.26				
Age	702	41.46	11.8	33.0	40.0	48.0
Children under 5 in home	702	0.50	0.7	0.0	0.0	1.0
Daily earnings (USD)	563	2.77	5.8	1.0	1.7	3.1
Daily charcoal expenditure (USD)	702	0.48	0.6	0.2	0.3	0.6
Minutes spent cooking per day	702	127.54	59.5	90.0	120.0	150.0
... of which indoor	702	111.80	61.3	70.0	109.0	150.0
Owns Jikokoa	702	0.52				
Owns traditional wood or charcoal jiko	702	0.57				
Owns LPG stove	702	0.59				
Owns electric stove	702	0.01				
Mostly uses modern stove	702	0.53				

Jikokoa ownership is persistent

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

- Randomly assigned price
- Randomly assigned credit treatment
- Interaction

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

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	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*

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Carbon Monoxide (CO)

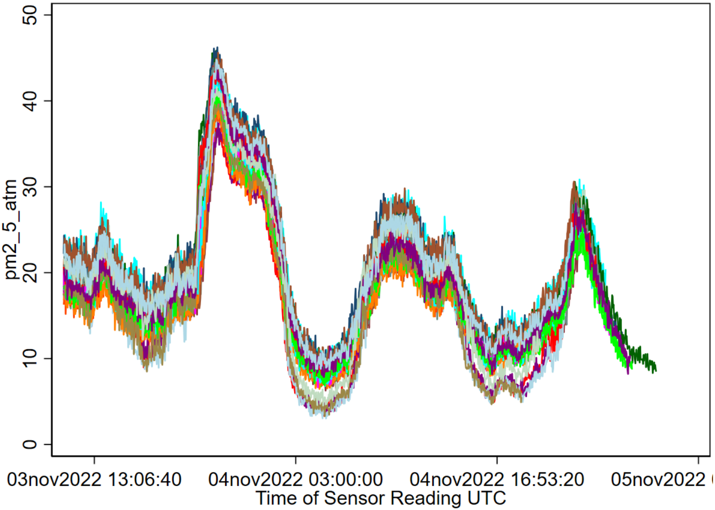
- Lascar Electronics device
- One reading every minute
- Calibrated every 2 months

1. Air pollution measurements

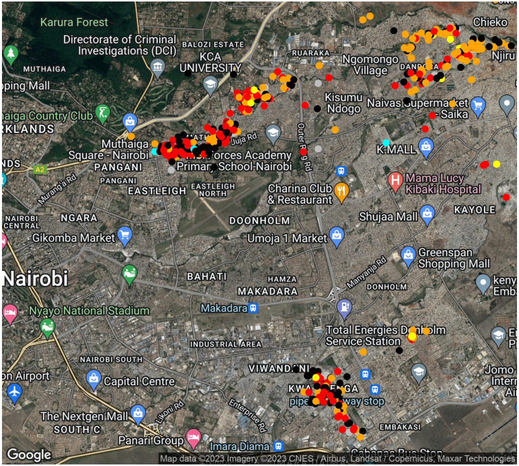
- Methodology and design developed by Berkeley Air Johnson et al 2021
- Best practices Chillrud et al 2021; Burrowes 2019; Gordon et al 2014; Gould et al 2022
- Each backpack contains 2 devices and a battery
- Dropped off during visit 1, picked up ∼48 hours later

Co-located PM2.5 readings for 30 devices

- We include device fixed effects where relevant



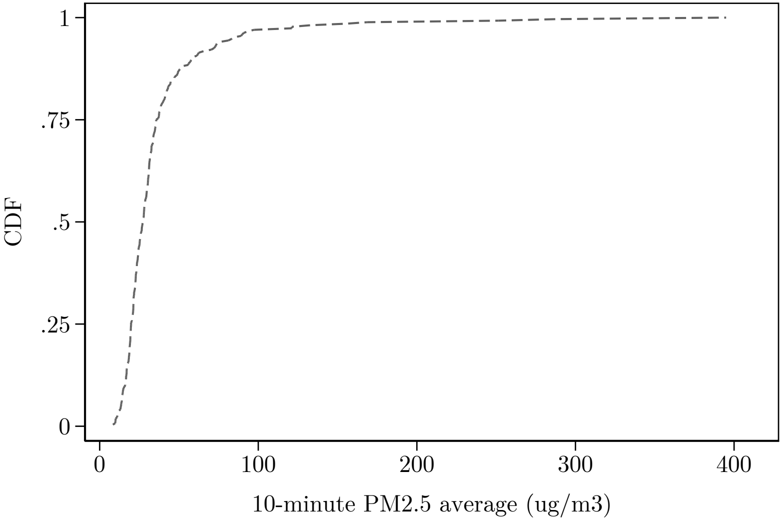
Average PM2.5 concentrations far exceed WHO guidelines



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

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

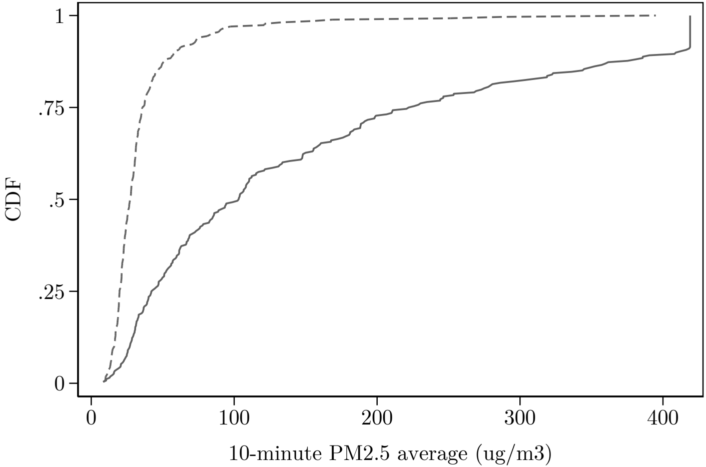
Each respondent's median 10-minute PM2.5:



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

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

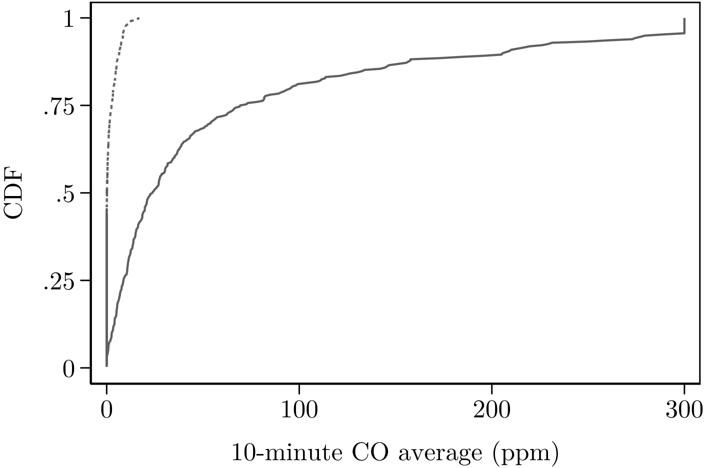
(99th percentile is approx. 15 minutes per day)



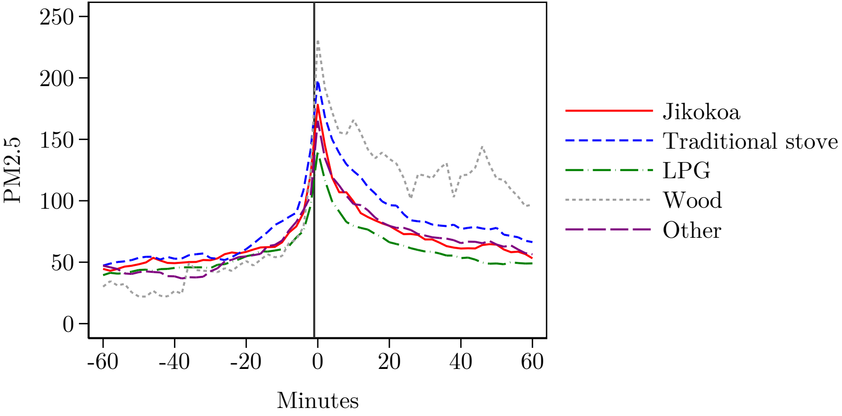
$100 \mu g/m^3$ = AQI 174
$200 \mu g/m^3$ = AQI 250

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)



Stoves have different diffusion patterns:



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

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3. **Child anthropometrics**
   - Weight
   - Height
   - Arm circumference

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    - 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.

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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.

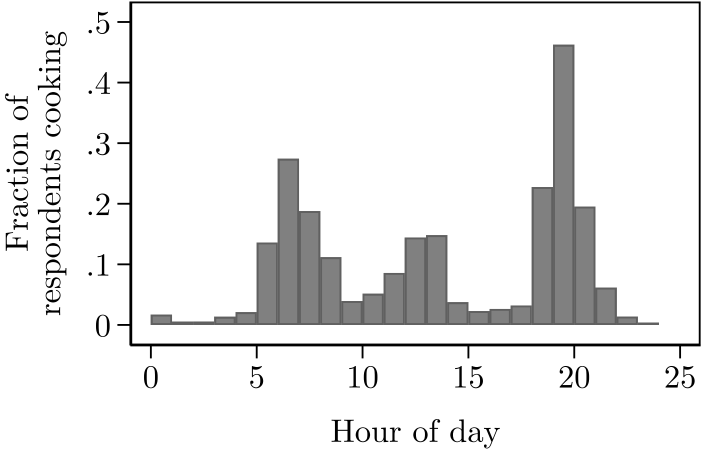
Child outcomes: ask parents about any symptoms or diagnoses in children under 10

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

Breakfast, lunch, dinner:



Adoption does not affect cooking behavior

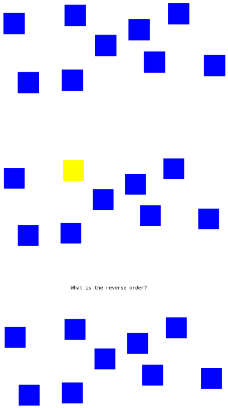
	Minutes per day	Cooking (=1)		Cooking indoors (=1)	
	(1)	(2)	(3)	(4)	(5)
Own Jikokoa	4.131	0.013	0.014	-0.026	-0.065
	(9.025)	(0.010)	(0.010)	(0.047)	(0.061)
Control Mean	137.013	0.101	0.101	0.889	0.872
HOD FE	N/A	N/A	Yes	N/A	Yes
Weak IV F-Stat	51	51	69	46	47
Observations	697	697	31887	649	3068

5. Cognition

Working memory

Ability to store and manipulate information in your mind

Reverse Corsi Blocks:

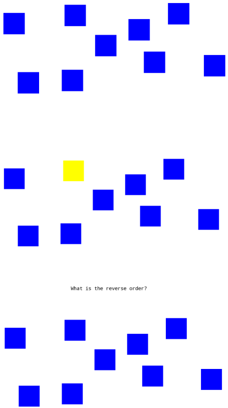


5. Cognition

Working memory

Ability to store and manipulate information in your mind

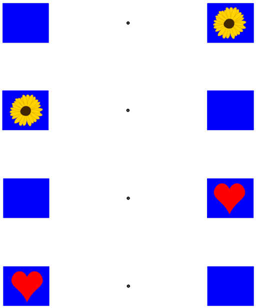
Reverse Corsi Blocks:



Inhibitory control

Ability to resist tempting impulses

Hearts and Flowers:



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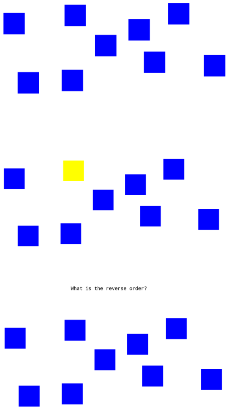

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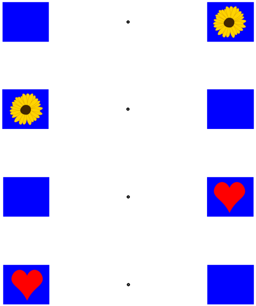
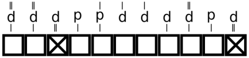


Attention

Ability to ignore distractions

d2 task:



Today

Background

Study design

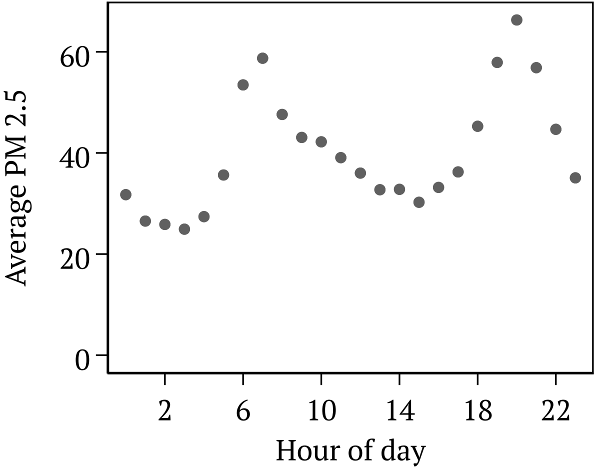
Data & descriptive statistics

Pollution impacts

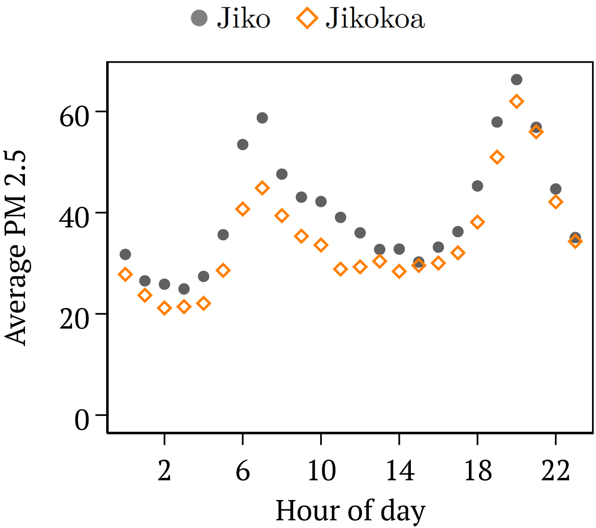
Health impacts

Impacts on poverty & climate

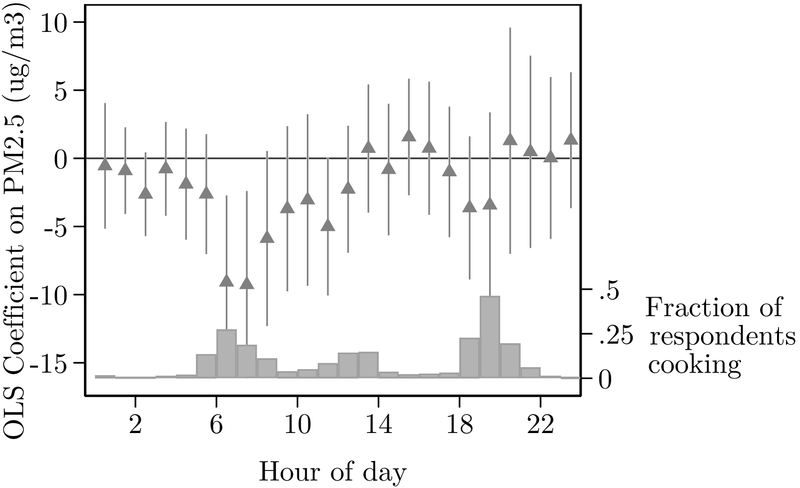
Jikokoa adoption and hourly average PM2.5 exposure



Jikokoa adoption and hourly average PM2.5 exposure

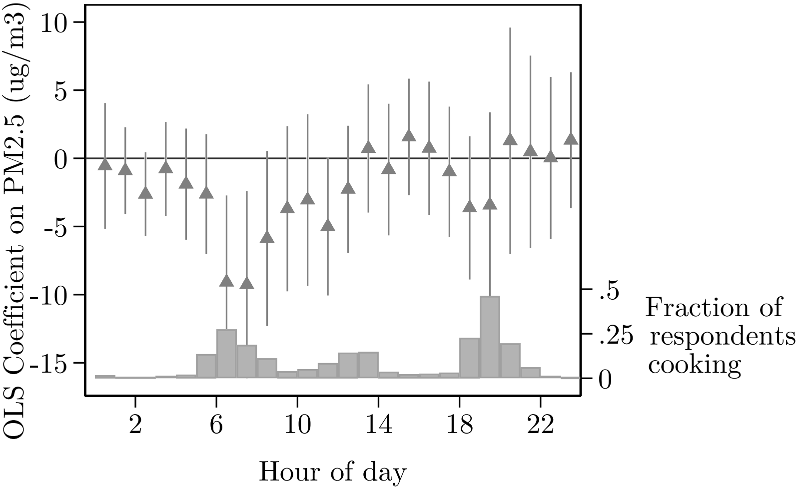


PM2.5 decreases during cooking times:



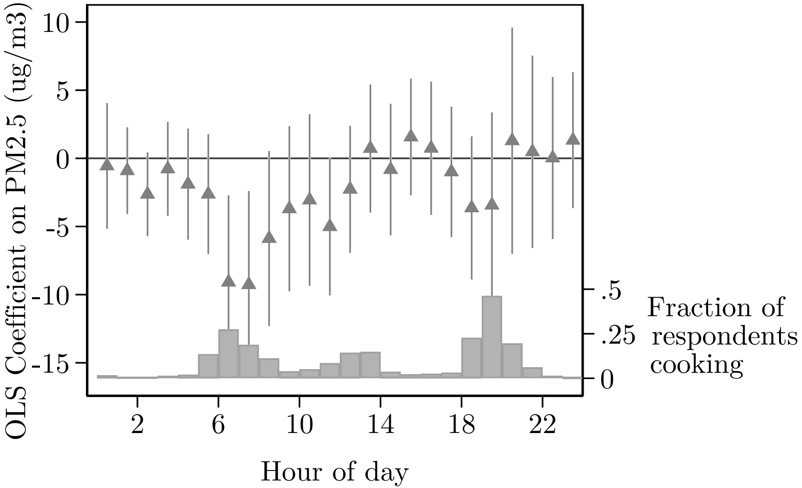
PM2.5 decreases during cooking times:

- Differential morning and evening traffic patterns?



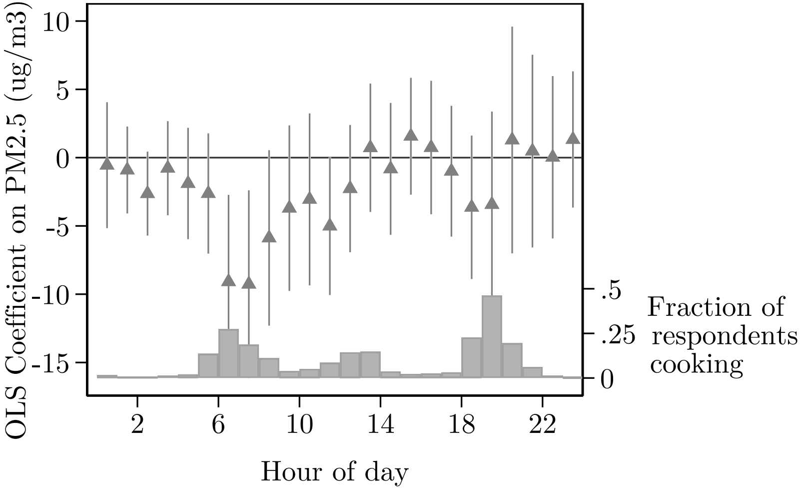
PM2.5 decreases during cooking times:

- Differential morning and evening ventilation?



PM2.5 decreases during cooking times:

- Planetary Boundary Layer Height? 1,500–1,700 meters at 8am, 60-200 meters at 8pm



Respondent-level pollution metrics

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 $125\mu g/m^3$

Panel A) All hours

	Median	Mean	Max Hour	99th
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Adoption reduces peak emissions by $52 \mu g / m^3$ (42%)

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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
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Weak IV F-Statistic	48	48	48	48
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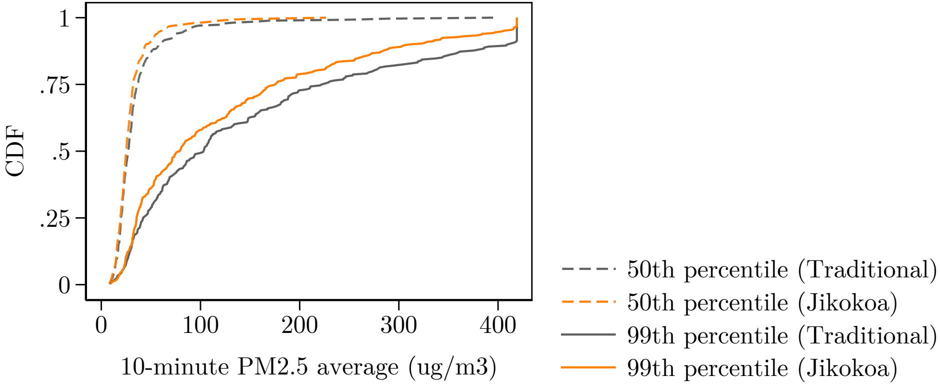
Impact on 50th and 99th percentiles



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%)

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- 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

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- Impacts persist for 3.5+ years
- Still, respondents cook only 9% of the day (2 hours): no detectable impact on average pollution

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- 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

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- 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 health expenditures

	Control Mean	Treatment Effect	N
Non-hospital health expenditures (USD)	4.34	0.80	702
	[7.64]	(1.07)	
Hospital visits in past 30 days	0.33	-0.01	702
	[0.57]	(0.09)	
Hospital visit expenditures (USD)	3.39	1.03	702
	[11.17]	(1.48)	

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.

Summarizing health impacts:

- No detectable impact on clinical health outcomes (blood pressure, blood oxygen)
- No impact on diagnoses by healthcare professionals
- No impact on cognitive function
- A 0.24SD reduction in self-reported respiratory symptoms (sore throat, headache, cough, fatigue)

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

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Pollution impacts

Health impacts

Impacts on poverty & climate

Socio-economic impacts of Jikokoa adoption

	Control Mean	Treatment Effect (2022 Ownership)	Treatment Effect (2019 Ownership)	N
Charcoal expenditures past 7 days (USD)	3.84	-1.50***	-1.12***	702
	[3.16]	(0.47)	(0.35)	
Earnings past 2 weeks (USD)	32.53	4.73	3.45	563
	[35.41]	(7.83)	(5.38)	
Total savings (USD)	53.64	-8.63	-7.07	701
	[86.62]	(19.88)	(14.67)	
Has formal bank account (=1)	0.13	0.11	0.08	702
	[0.34]	(0.07)	(0.05)	
Minutes cooking per day	136.72	3.49	2.60	702
	[57.76]	(8.32)	(6.15)	
People in network who adopted Jikokoa	0.78	1.13***	0.84***	702
	[2.04]	(0.40)	(0.29)	

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

Socio-economic impacts of Jikokoa adoption

	Control Mean	Treatment Effect	N
Has formal bank account (=1)	0.13	0.11	702
	[0.34]	(0.07)	
Total savings (USD)	53.64	-8.63	701
	[86.62]	(19.88)	
... in mobile banking (USD)	5.85	-0.22	702
	[12.29]	(2.05)	
... in SACCO payout (USD)	40.25	-15.30	701
	[64.75]	(13.97)	
... in formal banking (USD)	7.63	6.81	702
	[34.99]	(8.69)	
People in network who adopted Jikokoa	0.78	1.13***	702
	[2.04]	(0.40)	
... neighbors	0.28	0.56***	702
	[0.82]	(0.16)	
... family members	0.20	0.21	702
	[0.69]	(0.13)	
... friends	0.20	0.22*	702
	[0.69]	(0.13)	
... other people	0.10	0.14	702
	[0.45]	(0.10)	

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

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- **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!

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