The Effects of Fuel-Efficient Cookstoves on Fuel Use, Particulate Matter, and Cooking Practices: Results from a Randomized Trial in Rural Uganda

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- **Poverty**
- **Disease**
- **Climate Change**

The Effects of Fuel-Efficient Cookstoves

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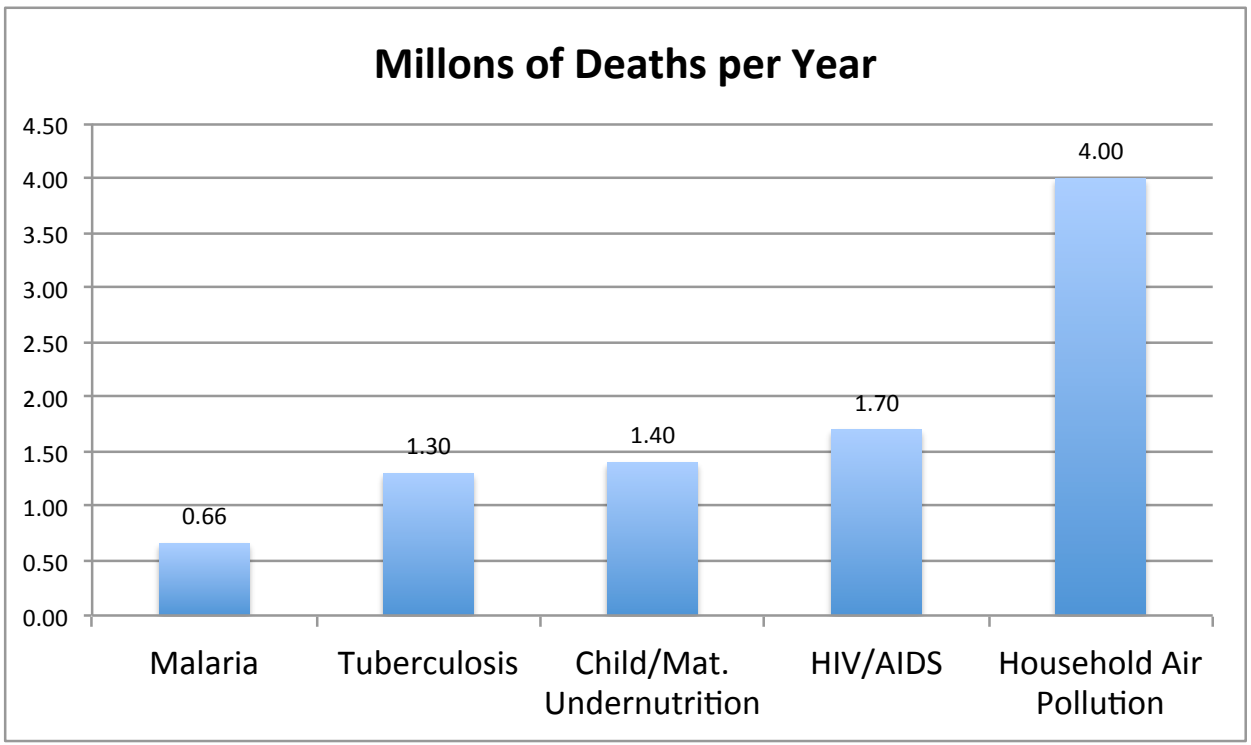

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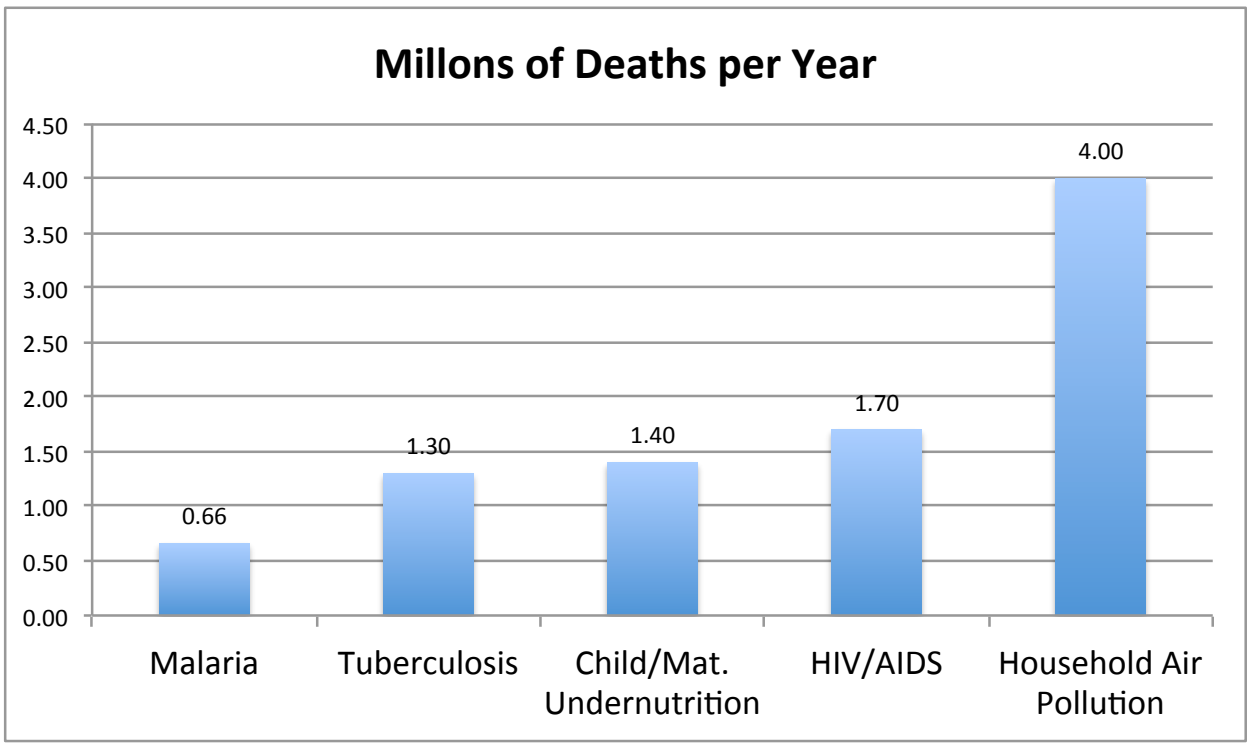

- **Smoke from this cooking contributes to climate change and deforestation (Ramanathan and Carmichael 2008; Bailis *et al.* 2015).**

A possible solution

- **First best solution (look at my kitchen or yours)**:
  - Replace biomass fuels with gas or electricity
  - Unfortunately, most who cook with soils fuels lack affordable consistent supply of gas or electricity (Lewis and Pattanayak 2012; Rehfuess *et al.* 2010)

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- **Second best solution (?)**:
  - Fuel-efficient cookstoves that use the same types of typical solid fuels

A possible solution

Figure: Wood burning stoves: three stone fire versus Envirofit G-3300

(a) Three Stone Fire

(b) Envirofit G-3300

Well, maybe...they look good in the lab

April 27, 2011

ENGINES & ENERGY CONVERSION LAB

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Emissions and Performance Report

The stove listed below has been tested in accordance with the "*Emissions and Performance Test Protocol*", with emissions measurements based on the biomass stove testing protocol developed by Colorado State University (available at www.eecl.colostate.edu). Percent improvements are calculated from three-stone fire performance data collected at Colorado State University.

Stove Manufacturer:	**Envirofit International**
Stove Model:	**G-3300**
Test Dates:	**4/4/2011-4/22/2011**
Average CO emissions (grams):	**18.7**
80% Confidence Interval:	**17.7-19.7**
Percent Improvement:	**65.30%**
Average PM emissions (milligrams):	**995**
80% Confidence Interval:	**944-1046**
Percent Improvement:	**51.20%**
Average Fuel use (grams):	**596.7**
80% Confidence Interval:	**591.6-601.7**
Percent Improvement:	**50.10%**
Average Thermal efficiency:	**32.6**
80% Confidence Interval:	**32.3-32.8**
Percent Improvement:	**105.20%**
High Power (kW):	**3.3**
80% Confidence Interval:	**3.3-3.4**
Low Power (kW):	**1.9**
80% Confidence Interval:	**1.8-1.9**

The above results are certified by the Engines and Energy Conversion Laboratory at Colorado State University. All claims beyond the above data are the responsibility of the manufacturer.

Morgan DeFoort
EECL Co-Director
Technical Lead, Biomass Stoves Testing Program

The Effects of Fuel-Efficient Cookstoves

But mixed results in the field

- **Hanna, Duflo, and Greenstone (2016) find reductions in smoke inhalation in first year, but no changes in smoke inhalation over longer periods in an RCT in India.**
  - Suggest low use results from low valuation (lack of maintenance)

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- **Pillarisetti *et al.* (2014) found that users experimented with a fuel-efficient stove at first, but use declines over time. By one year after introduction, households used traditional stoves for 75% of their cooking in a non-RCT sample of pregnant women in India.**

Our contributions...

- **Typically cookstove studies have given stove away for free or a highly subsidized price. Our sample paid market price.**
  - Debate on appropriateness of subsidies (latrines, mosquito nets, deworming meds, etc.) hinges on how usage of the product varies as price paid varies. Market-price cookstove usage study has not been done.

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  - Could a second fuel-efficient burner substantially reduce stove stacking?

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- **We adjust for observer-induced bias (Hawthorne effect).**

Study design - background

- **Mbarara District, Uganda**
  - Worked with local research organization, CIRCODU, for data collection (in 2012)
  - Almost all households (97%) cooked on three-stone fire in separate cooking huts
  - Agrarian livelihoods, farming matooke, potatoes, millet as well as raising livestock

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  - Visited 26 rural parishes (12 cash-and-carry and 14 free trial plus time payments) this is focus of Levine *et al.* 2018
  - Among stove purchasers in the 14 free trial and time payments parishes, asked for volunteers that met criteria:
    - Use wood as a fuel source
    - Regularly cooked for eight or fewer people
    - Someone usually home
  - In each parish more than 12 agreed to join study, so we randomly selected 12

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  - Then we randomly staggered delivery of Envirofit (identification for RCT)

Study design - RCT

- **Rollout - staggered delivery about 5-6 weeks apart**:
  - Wave 1: only three stone fires
  - Wave 2: half of buyers (early buyers) get one Envirofit
  - Wave 3: other half (late buyers) get one Envirofit
  - Wave 4: all get second Envirofit (as surprise gift)

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  - Quantity (kg) of firewood used daily
  - Levels of household air pollution (PM 2.5)
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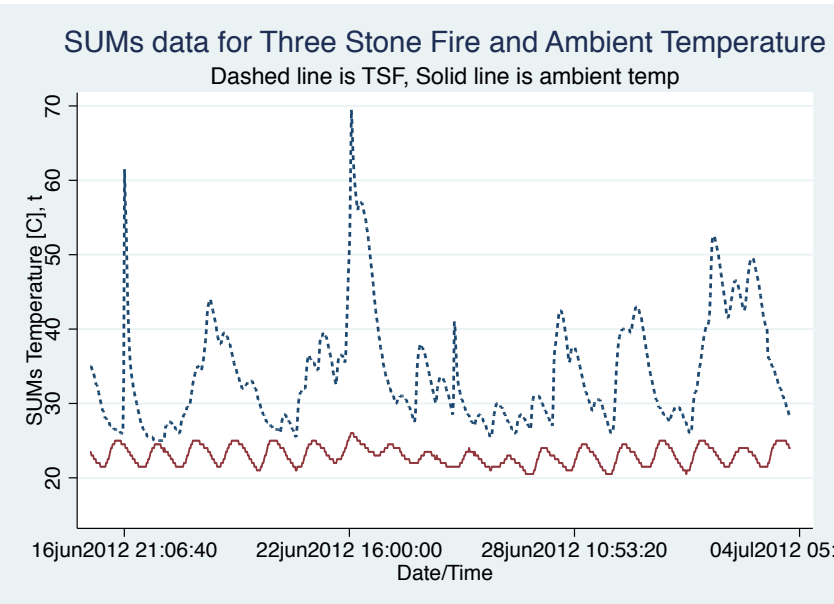
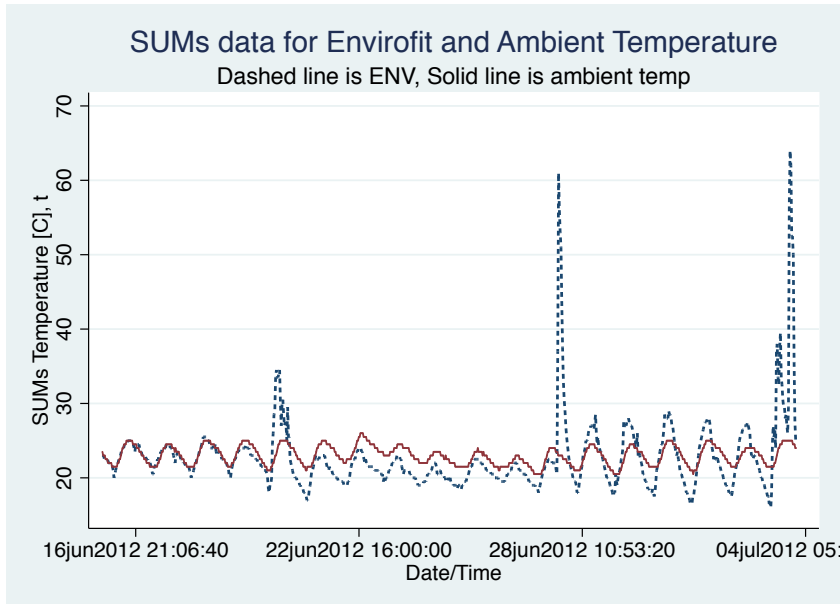
- **Temperature sensors tracking continuously for six months, KPT measures only for the 'week'**
- **Long-term follow up: 3.5 years later we made unannounced visits to all households to examine stove use**

Sample SUMs temperature data

Figure: Example of household level SUMs temperature data in same household at same times



(a) Three Stone Fire



(b) Envirofit

Specification - wood use and PM2.5 (just KPT weeks)

$$Y_{ipt} = \alpha_{ip} + b_0 * T_i + b_1 * Early\_have\_Envirofit_t + b_2 * Both\_have\_Envirofits_t + \beta_1(T_i * Early\_have\_Envirofit_t) + \beta_2(T_i * Both\_have\_Envirofits_t) + \varepsilon_{ipt}$$

- Y_{ipt} is daily wood use or daily PM2.5 concentration for household i in parish p in study wave t
- includes household fixed effects (controls for cooking style or talent of cook, fixed structures of kitchen like windows)
- study wave and treatment dummies
- coefficient of interest is β_1 - the causal effect of owning one Envirofit

Specification - accounting for Hawthorne effects

- **We found participants increased Envirofit use about 2.5 hours per day while decreasing three stone fire use by about 2.5 hours per day in the final KPT (Simons *et al.* 2017)**:
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$$\boldsymbol{\Delta Adj\_Wood_{group}^{wave} = \Delta TSF\_Hours_{group}^{wave} * (\frac{TSF\_Wood}{hour}) + \Delta ENV\_Hours_{group}^{wave} * (\frac{ENV\_Wood}{hour})}$$

  - ΔTSF_Hours and ΔENV_Hours are differences in hours cooked due to observer presence
  - $(\frac{TSF\_Wood}{hour})$ is hourly rate of wood consumption from first KPT (when no Envirofits)
  - $(\frac{ENV\_Wood}{hour})$ is laboratory result (we had not periods of exclusive Envirofit use) so $(\frac{ENV\_Wood}{hour})$ is half the rate of a three stone fire

Balance and summary statistics

- **Study was balanced, out of 20 covariates only one was statistically significantly different (at 10% level) between randomly assigned early buyers and randomly late buyers at baseline**

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- **Study was balanced, out of 20 covariates only one was statistically significantly different (at 10% level) between randomly assigned early buyers and randomly late buyers at baseline**
- **Key baseline statistics (control group) related to stove usage**:
    - Net wood weight used was 9.3 kg/day
    - Average PM2.5 reading was 414.3 μg/m^3
    - Total daily hours cooked on three stone fires was 12.4 hrs/day

Results - effect of Envirofit on daily wood use (kg/day)

VARIABLES	(1) OLS	(2) FE
Treatment	0.72	
	(0.72)	
Early buyers have one Envirofit	-1.86***	-1.73***
	(0.60)	(0.56)
All buyers have two Envirofits	-2.48***	-2.48***
	(0.68)	(0.66)
Treatment x Early buyers have one Envirofit	-0.95	-1.08*
	(0.85)	(0.56)
Treatment x All buyers have two Envirofits	-0.46	-0.55
	(0.88)	(0.59)
Constant	12.40***	
	(0.46)	
Observations	1,116	1,116
R-squared	0.15	0.42
Number of household fixed effects		163

Standard errors clustered at parish-wave level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Results - effect of Envirofit on daily ln(PM2.5)

VARIABLES	(1) OLS	(2) FE
Treatment	-0.02	
	(0.03)	
Early buyers have one Envirofit	0.12**	0.12**
	(0.05)	(0.05)
All buyers have two Envirofits	-0.10**	-0.10*
	(0.04)	(0.05)
Treatment x Early buyers have one Envirofit	-0.13*	-0.12**
	(0.07)	(0.06)
Treatment x All buyers have two Envirofits	-0.02	-0.02
	(0.06)	(0.06)
Constant	6.57***	
	(0.07)	
Observations	1,242	1,242
R-squared	0.87	0.92
Number of household fixed effects		164

Standard errors clustered at parish-wave level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Results - adjusted for Hawthorne effect

- **When we adjust for stove use outside of KPTs (the periods when observers were present), we find**:
  - Most of the reductions disappear
  - Wood use declines 1.7%, instead of 11.6%
  - PM2.5 concentrations decline by 0.3%, instead of 12.0%

Results - long-term use (3.5 years later)

- **Similar to Bensch and Peters (2015) and Hanna, Duflo and Greenstone (2016) we made unannounced return visits 3.5 years later** :
  - At time of visit about 80% of households were home (137 out of 164)
  - At moment of visit, about 48% were actively cooking (66 out of 137)
  - Among those, only 9% were cooking with Envirofits (6 out of 66)

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  - At moment of visit, about 48% were actively cooking (66 out of 137)
  - Among those, only 9% were cooking with Envirofits (6 out of 66)
- **So enumerators asked those not cooking to see their stoves (131 HHs) to inspect for obvious signs of use**
  - 65% had an Envirofit with obvious signs of use
  - 17% had Envirofit stored and clearly not in use
  - 2% had Envirofit in perfect condition (essentially never used)
  - 8% said Envirofit was damaged and disposed of
  - 8% said they had given the stove away

Conclusions

- **Despite our sample that paid market prices for fuel-efficient cookstove, usage rates were not markedly different than in previous studies**:
  - Initial period of higher use, then decline in use (likely implying poor substitutability)
  - Pillarisetti *et al.* (2014) found that traditional stove used about 75% and introduced stove about 25%
  - By end of our study, roughly 67% of cooking on three stone fires and 33% on Envirofits
  - Hanna, Duflo and Greenstone (2016) argued low long term use was due to lack of maintenance by the stove owner
  - In our long term followup we confirm low usage levels, but it was not due to durability or maintenance issues

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- **Do households fully switch when they have a second stove?**
  - No, anecdotally households used the fuel-efficient stove to heat things that cook relatively quickly (boil water for tea), but preferred three-stone fires for low-heat cooking such as simmering common dishes like rice and beans or cooking bananas.

Conclusions...continued

- **We document large Hawthorne effects**:
  - Households cooked about 2.5 hours per day more on the Envirofit and 2.5 hours a day less on three stone fires when observers were present
  - They switch use patterns back when observers left
  - This issues had been mentioned as a concern (but largely ignored) in previous cookstove literature
  - Reductions in wood use (11.6%) and PM2.5 concentrations (12.0%) after the introduction of one Envirofit, but once we adjust for Hawthorne effect this reduction was almost zero

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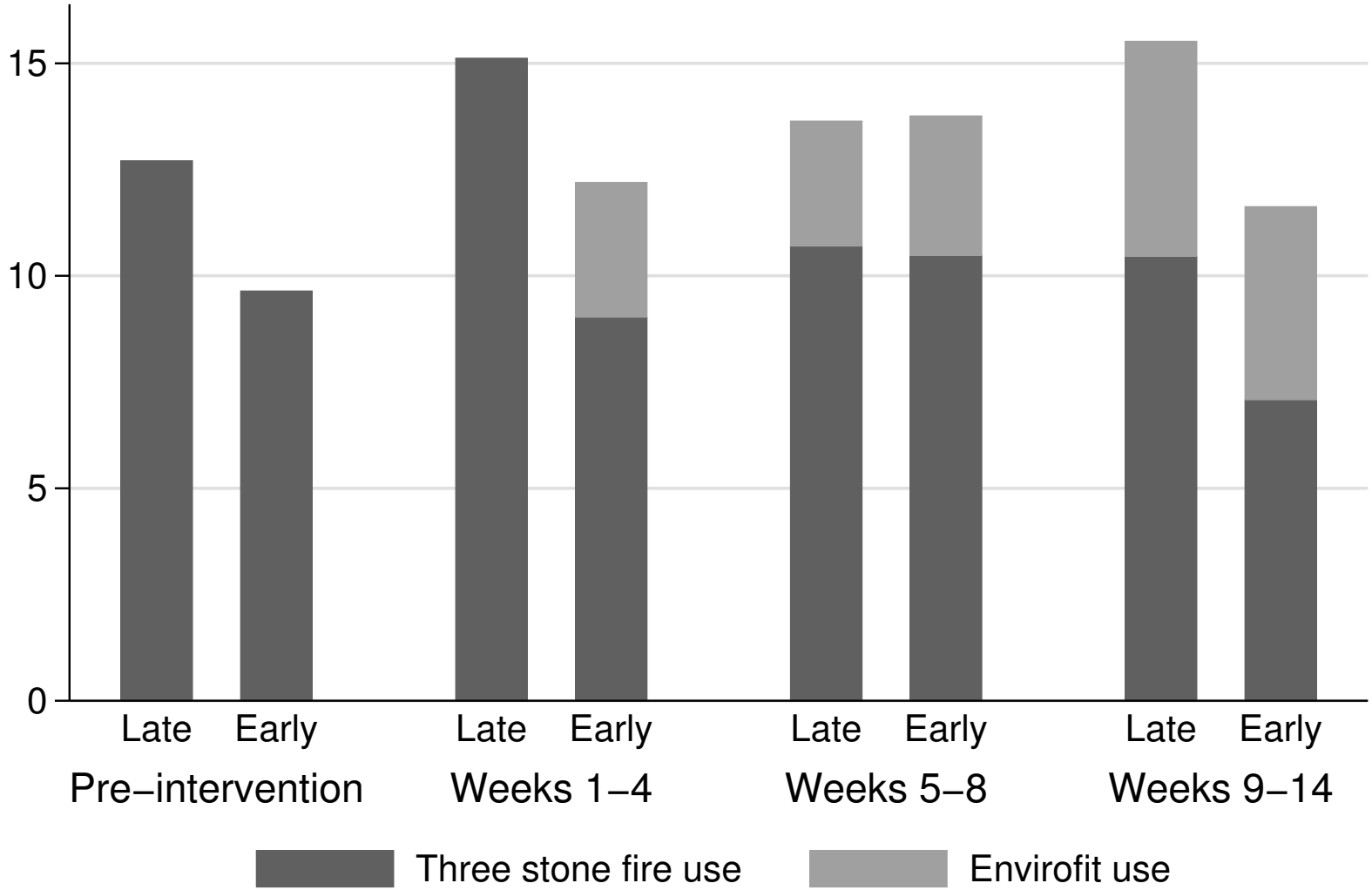
- **Recommend focusing research/policy on transitioning households to gas or electric, coupled with policies to decrease biomass stove use**
  - PM2.5 levels would have needed to fall by 90% from baseline to reach WHO targets (even with no Hawthorne effect, PM2.5 only fell 12.0%)

Whole paper in a graph - average daily stove use (hours/day)



Note: Pre−intervention (4 weeks) no Envirofits; Weeks 1−4 early buyers have one Envirofit; Weeks 5−8 all have one Envirofit; Weeks 9−14 all have two Envirofits.

Thank You