**Title:**
The Effect of Solar Ovens on Fuel Use, Emissions, and Health: Results from a Randomized Controlled Trial

**Author:**
Beltramo, Theresa
Levine, David I, UC Berkeley

**Publication Date:**
04-09-2012

**Series:**
CEGA Working Papers

**Publication Info:**
CEGA Working Papers, Center for Effective Global Action, UC Berkeley

**Permalink:**
http://escholarship.org/uc/item/4cq705v3

**Keywords:**
consumer economics, welfare economics, health production, marriage, marital dissolution, family structure, domestic abuse, economics of gender, non-labor discrimination, project analysis, renewable resources and conservation, alternative energy sources, household analysis

**Abstract:**
Emissions from burning biomass fuels cause approximately 2 million premature deaths every year and contribute to deforestation. Due to complex cooking patterns and significant behavior change associated with many clean cookstoves, laboratory results are often far better than those from the field. We ran a phased randomized controlled trial in rural Senegal to test the effects of a solar oven-the Hotpot- on women cook's carbon monoxide inhalation, fuel use, time spent collecting fuel, and usage. We find low usage rates of the Hotpot- 19% after six months, marginal effects on fuel consumption, and no effects on time spent collecting fuel, carbon monoxide exposure, or time spent next to the cook fire. Despite the mismatch of the Hotpot with local cooking practices and large family sizes, the population is well suited for an improved stove intervention as cooks and their accompanying children are exposed to dangerous levels of emissions from the cookfire- 130% of the WHO daily recommended level of CO emissions. A key result from our program is stove designers- both of solar and other improved biomass cookstoves- should reassess product design to produce stoves that are affordable, durable, consistent with current cooking practices (for example, contains two burners) and are large enough to accommodate multigenerational and/or polygamous households with limited incomes and no electricity. Additional key lessons for future research include the importance of researching best practice in marketing strategies to the rural poor, designing a more complete kitchen solution to include optimal kitchen design, and finding solutions to increase the wider households' willingness to pay for a product which primarily benefits

women and children. This evaluation was a policy success because its results halted the proposed nationwide rollout of the solar oven, thus avoiding mass distribution of a stove which cannot reduce Indoor Air Pollution or generate a sizeable decrease in fuel use for the population.

**Copyright Information:**

Series Name: WPS
Paper No.: 003
Issue Date: 4 September 2012

# The Effect of Solar Ovens on Fuel Use, Emissions, and Health: Results from a Randomized Controlled Trial


Theresa Beltramo and David I. Levine


## Working Paper Series

Center for Effective Global Action

University of California

# The Effect of Solar Ovens on Fuel Use, Emissions, and Health: Results from a Randomized Controlled Trial

Theresa Beltramo, Ph.D. and David I. Levine, Ph.D [i].

**Abstract:** Emissions from burning biomass fuels cause approximately 2 million premature deaths every year and contribute to deforestation. Due to complex cooking patterns and significant behavior change associated with many clean cookstoves, laboratory results are often far better than those from the field. We ran a phased randomized controlled trial in rural Senegal to test the effects of a solar oven-the Hotpot- on women cook's carbon monoxide inhalation, fuel use, time spent collecting fuel, and usage. We find low usage rates of the Hotpot- 19% after six months, marginal effects on fuel consumption, and no effects on time spent collecting fuel, carbon monoxide exposure, or time spent next to the cook fire. Despite the mismatch of the Hotpot with local cooking practices and large family sizes, the population is well suited for an improved stove intervention as cooks and their accompanying children are exposed to dangerous levels of emissions from the cookfire- 130% of the WHO daily recommended level of CO emissions. A key result from our program is stove designers- both of solar and other improved biomass cookstoves- should reassess product design to produce stoves that are affordable, durable, consistent with current cooking practices (for example, contains two burners) and are large enough to accommodate multi-generational and/or polygamous households with limited incomes and no electricity. Additional key lessons for future research include the importance of researching best practice in marketing strategies to the rural poor, designing a more complete kitchen solution to include optimal kitchen design, and finding solutions to increase the wider households' willingness to pay for a product which primarily benefits women and children. This evaluation was a policy success because its results halted the proposed nationwide rollout of the solar oven, thus avoiding mass distribution of a stove which cannot reduce Indoor Air Pollution or generate a sizeable decrease in fuel use for the population.

**JEL:** C80; D11; D60; I12; I32; J12; J16; O12; O22; Q20; Q30; Q42; R21;

*Objectives:* Inefficient cookstoves contribute to deforestation and global climate change, require substantial time (usually of women and girls) collecting wood or money for fuel, and lead to just under 2 million deaths a year. We examined the effect of solar ovens on fuel use, time spent collecting wood, carbon monoxide exposure, and respiratory illness symptoms.

*Methods:* We ran a phased randomized controlled trial among women interested in purchasing a solar oven in rural Senegal. Of the envisioned 1000 households, 465 Treatments and 325 Controls took the baseline survey. Households randomly allocated to the control group received their stoves 6 months after treatments.

*Results:* 80% of our respondents typically cook for more people than the capacity of the solar oven and thus even cooks using the solar oven continue using their traditional stove. In the sixth month of owning the stove, treatments used their solar oven 19% of days measured and did not have statistically significantly lower fuel consumption, time spent collecting fuel, or time spent next to the cook fire. However, treatments cooking for 7-12 persons did lower their wood consumption for cooking by 14% ($P < .01$). There is no evidence solar ovens reduced exposure to carbon monoxide or self-reported respiratory symptoms such as coughs and sore throats.

These results contradicted favorable results from a feasibility study conducted by our project partner Solar Household Energy Inc. which concluded the Hotpot is consistent with households' traditional cooking behavior and large enough to cook for the average household size and thus could successfully replace the three-stone fire for the main lunch meal. The results from this RCT show the Hotpot is a poor product choice for the population as a one pot stove cannot replace the three-stone fire for the lunch meal due to complex cooking patterns with multiple stoves, cooks, and burners. A key result from our program is stove designers- both solar and other improved biomass cookstoves- should reassess product design to produce stoves that are affordable, durable, locally appropriate and consistent with current cooking practices- in this case contains two burners, and large enough to accommodate multi-generational and/or polygamous households with limited incomes and no electricity.

This evaluation was a policy success because its results halted the proposed nationwide rollout of the solar oven, thus avoiding mass distribution of a stove which cannot reduce Indoor Air Pollution or generate a sizeable decrease in fuel use.

**Introduction**

Over 3 billion people burn wood and other biomass for cooking (Mehta*, et al.,* 2006; WHO, 2011). Emissions from burning biomass fuels cause approximately 2 million premature deaths every year (WHO, 2011). This is a result of indoor air pollution leading to pneumonia, bronchitis, lung cancer, chronic obstructive pulmonary disease, and a host of other ills (Clark*, et al.,* 2007; Smith-Silvertsen, *et al*., 2004; Diaz, *et al.,* 2007). Particularly vulnerable are children, nearly 50% of pneumonia deaths among children under five are due to particulate matter inhaled from indoor air pollution (WHO, 2011).

Traditional stoves also have high costs of fuel. In rural Africa these costs are primarily the many hours a week women and youth spend gathering fuel each week (Blackden and Wodon, 2006). Hours spent collecting wood- disproportionately by girls- is an opportunity cost of time that may come at the expense of education or other productive activities (Bruce, *et al.,* 2006)

Inefficient cookstoves also contribute to deforestation (United Nations Convention to Combat Desertification, 2010) that contributes to global climate change. By one estimate household energy use in Africa is on track to produce 6.7 billion tons of carbon by 2050 (Bailis, *et al.,* 2005).

Despite generations of efforts designing and disseminating improved biomass cookstoves and the opportunity to potentially positively influence health outcomes for women and children, they have yet to reach most of the world's poor (Goldemberg, *et al.,* 2000). Authors of the few existing rigorous evaluations of the impacts of improved stoves cite the wide agreement in the scientific community that additional rigorous evaluations are needed to accurately evaluate the impacts of improved stoves, particularly on health (Bruce, *et al*., 2006; Smith and Mehta, 2000; Duflo, *et al.,* 2008). Impact studies measuring the effects of improved cookstoves on health have found that reductions of indoor air pollution in the field are often significantly lower than reductions measured in laboratory tests. The heterogeneity of household level characteristics including traditional food preparation, continued use of the old stove, and kitchen design- particularly level of air flow- all influence cookstoves' ability to reduce IAP (Edwards *et al.,* 2007, (Grabow*, et al.,* 2012). Rigorous evaluations, like this one, are key in understanding the real impacts improved cookstoves have on indoor air pollution in the home.

Finally, rigorous evaluations are crucial to understand the key issues present in both the supply and demand side of the adoption of an improved stove and to help craft solutions. The business and policy response should be quite different if the main barrier is poor stove design versus credit constraints versus lack of consumer information.

The importance of clean cookstoves has gained significant attention in the field of public health and international development, culminating in establishment of the over $100 million public-private partnership of the Global Alliance for Clean Cookstoves in September 2010. This paper contributes to the Alliance's goal for 100 million homes to adopt clean and efficient stoves and fuels by 2020 by measuring the impacts of a specific improved cookstoves- a panel solar cooker- on wood use, time spent collecting wood, respiratory health and exposure to carbon monoxide.

This paper also contributes to future cookstoves initiatives by outlining the challenges and corresponding solutions to the inherent difficult task in asking households to switch to a more efficient stove. Challenges identified in our research which should be considered a priori in forthcoming research include complex cooking patterns with multiple stoves and multiple cooks, and finding a stove large enough to accommodate multi-generational and/or polygamous households with limited incomes and no electricity. Willingness to pay for improved stoves can prove to be a significant obstacle in rural settings where women traditionally have less intra-household bargaining power than men, but benefit disproportionately from the reduction in fuel use and indoor air pollution from an improved cookstove (see Miller & Mobarak, 2011). An additional obstacle for poor households is many consumers are skeptical about purchasing an improved cookstove (ICS) when they have traditionally cooked using free three-stone fires. In addition, fundamental to understanding adoption of ICS is addressing the obstacles to technology adoption and behavior change associated with the new cookstove. A variety of explanations have been proposed for low take-up rates of seemingly cost effective technologies in developing countries. Poor households may be liquidity- or credit constrained (Gine et al., 2008; Cohen & Dupas, 2010; Cole et al., 2010; Dupas & Robinson, 2011; Tarozzi et al., 2011), they may not understand adoption benefits (Feder & Slade, 1984; Conley & Udry, 2001; Gine & Yang, 2009), or there could be a lack of local information from a trustworthy source about an unknown technology (Miller & Mobarak, 2011). They may suffer from self-control problems (Banerjee & Mullainathan, 2010; Duflo et al., 2011), the benefits may be external to the household (Kremer & Miguel, 2007), or there may be inefficiently little experimentation in behavior change (Foster & Rosenzweig, 1995; Conley & Udry, 2010; Bryan et al., 2011). These hypotheses are explored in a companion paper Beltramo 2011.

**Methods**

The area we study in the Western Sahel semi-desert Thiès region of Senegal is subject to all of the ill-effects of traditional cookstoves listed above: many hours a week spent gathering fuel, high exposure to indoor air pollution, and poor health.[ii] The balance between collection and purchase of wood fluctuates significantly with the seasons and corresponding relative abundance of wood.

Household fuel use, stove types used for cooking, and kitchen design vary widely between households. At the baseline 88% of households reported burning wood, 50% use farm waste, 8% animal dung, 21% charcoal (mostly for tea), and 74% use gas (mostly to reheat meals and to cook breakfast). During our baseline survey in the dry season (April, 2008) 46% of households report buying wood while 53% households report some member of their households collected wood (Table 3a). The household's choice of stove depends on the meal, season, and size of the household. The choice of the kitchen design varies widely and respondents report cooking in a semi-enclosed kitchen (49%), an enclosed kitchen with no windows (21%); a kitchen with thatch roof but no walls (20%); or outdoors (10%).[iii]

The area is rural and poor and like many developing countries the population is young, with 60% under age 25. Education levels are low: only half of teens 13-18 and 6% of those over 50 report positive years of education. Women in our sample have mean earnings of $1.86/day and for those married their husbands give them another $3.28/day for household expenditures (Table 2). Our respondents live in large, often polygamous, households- an average of 12 persons- and simple math implies a per-person expenditure of 43 cents per day.

With these facts in mind, the NGO Solar Household Energy, Inc. (SHE) approached the local NGO Tostan, active in community development in Senegal, about deploying the HotPot solar oven in Senegal. Tostan was interested in testing the impacts of the solar oven and asked the University of California at Berkeley's Center for Evaluation of Global Action to design a randomized controlled trial in 20 initial villages, with the hope of scaling up the initiative nationally and regionally if the objectives were met.

The HotPot- a panel solar cooker- uses a reflector to direct sunlight to a 5-liter black enameled steel pot that is within a larger tempered glass bowl with a lid. Heating occurs both from sunlight striking the black pot and from the greenhouse effect within the larger glass bowl. Effective cooking requires that the user angle the reflector to the sun, shifting it every hour or so. Under a tropical sun the HotPot can cook rice in under an hour, a chicken in about two hours, and beans in four hours. The Hotpot can cook for an estimated 6 people, however due to traditional cooking practices which require separate, concurrent preparation of rice and the sauce, even a household of six continues to use their three-stone fire to cook the sauce.

In 2007 SHE carried out a pilot study in Méckhé, Senegal, with 20 consumers. They reported finding the Hotpot was sufficient in size to cook for household's families and could cook the main meal of the day (lunch) and the most frequently prepared dish (Ceebu Jen/Yapp, meaning rice served with either fish, chicken, or goat). After reviewing the initial findings of the feasibility study, we decided not to replicate the study, but rather invest the limited development dollars in carrying out more program activities. The mismatch between the feasibility findings and the outcomes of this RCT are likely explained by mis-aligned incentives for SHE, an NGO dedicated to the spread of solar cooking who also designed the Hotpot. In the future when faced with a similar tradeoff, development economists should carefully evaluate the objectivity of project partners, even those with the best intentions like SHE.

Tostan selected 20 villages in the Thiès region in northern Senegal for this RCT. Criteria were that women cooked primarily with wood and villages had been working with Tostan for at least five years and thus completed the three year Community Empowerment Program. SHE trained Tostan staff on using the solar ovens. SHE and Tostan then carried out trainings and marketing demonstrations on how to cook with the Hotpot from January through March 2008 among local focal point women selected to lead the initiative in each of the 20 villages.

Due to shipping constraints of the HotPot only half the target population could receive the solar stoves at one time. Thus, the phased intervention fit well with the program needs.

The program's goal was to distribute 1000 solar ovens, fifty in each of the 20 study villages. Within each village 25 households were randomly selected to receive the solar oven at the time of the baseline survey (April 2008) and up to 25 received the oven when the second shipment arrived (October 2008). We designed the study to have statistical power to detect a 2.5% reduction in kg. of wood per cooking session, a 3.5% reduction in hours spent per week collecting fuel, and a 9.8% reduction of cook's personal exposure to CO while cooking.[iv]

Most villages had fewer than 50 women enrolled at the time of randomization and accordingly our sample has more treatments than controls (a ratio of 1.4 treatments per every control). As a result our minimum detectable effect sizes were 10% larger than initially planned.

Both the baseline and six month follow-up surveys covered demographics, fuel use, time collecting fuel, cooking practices- including those associated with the solar oven, self-reported respiratory symptoms for respondents and their children, and cooking-related symptoms for respondents.[v] For a subset of participating households we also measured personal exposure for cooks to carbon monoxide during the lunch meal. At those households we also collected information on the cooking structure, time spent cooking lunch, and types of fuel.

**Stove Utilization**

Following Ruiz-Mercado *et al.*, 2008, we used ibuttons as our stove usage monitors (SUMs). The ibutton is a computer micro-chip enclosed in a 16mm thick stainless steel case, which we installed on the lid of all solar ovens.[vi]

We programmed the SUMs to take temperature readings every 30 minutes. The SUMs data indicate clear spikes when the solar oven is used. We experimented with different temperature floors to indicate usage, and settled on 110°F (43°C) threshold (Web appendix 1). To ensure this temperature floor is robust and does not yield a false positive for solar stove usage we installed SUMs on unused solar ovens left outdoors and found the Hotpot never reaches this temperature when not in use.

We had SUMs in place during the first month of solar oven ownership (April through May 2008) and during the sixth month of stove ownership (October through November 2008). In addition, we asked self-reported usage rates on the 6 month follow-up survey. We also observed solar oven usage during household visits for the follow-up survey for the subsample where we measured carbon monoxide exposure.

**Primary Impact Measures**

Respondents report the quantity, financial cost, and time cost gathering for the following fuels last week including: wood, charcoal, gas, animal dung, and farm waste. Based on best practice of other impacts papers we conducted a kitchen performance test where respondents were asked to estimate from a large pile of wood the amount of wood they used to cook the lunch meal yesterday. The wood they estimated was then weighed and recorded as kilograms of wood used for the lunch meal. Data collected from the one month follow-up survey indicated most families found the Hotpot was too small to cook the main lunch meal. We adapted our kitchen performance test at the six month follow-up to weigh the wood for all three meals (yesterday), in addition to wood use for the lunch meal (yesterday).

We measured exposure to carbon monoxide with Dräger Color Diffusion Tubes (CO tubes). The CO tubes measure the time-weighted average concentrations of carbon monoxide in parts per million per hour (ppm/hour). We multiplied the reading by a factor supplied by the manufacturer to adjust for local humidity levels and top-coded the 6 month CO data, bringing 5 of our 275 observations down to the 95$^{th}$ percentile (32.19 ppm/hour).

With the help of Tostan's local village point person, we selected a subset of households randomly to receive the CO tube. However, enumerators were instructed to skip households who were cooking only with gas. Unfortunately, we did not retain the count of treatment and control women and compounds that were not given CO tubes because they cooked with gas.

To measure exposure to carbon monoxide while cooking lunch, enumerators attached the CO tube to each cook's attire in the morning in each of our 20 villages (between 8:30-10:00am) and collected them about 5 hours later (2:00-3:30 p.m.) after lunch.

We asked women to self-report if in the last 7 days they had experienced any of the seven respiratory illness symptoms: fever; sore throat; runny or stuffy nose; cough; wheezing or trouble breathing; woke up with chest heaviness at night; and coughed up mucus. At each survey round we also asked them to report on 4 symptoms for each of their children: cough or difficulty breathing; cold and coughed up mucus; runny or stuffy nose; and wheezing. At the follow-up we asked respondents to report all seven respiratory illness symptoms for their husbands. Further, we collected self-reported symptoms associated with traditional cookfires: eye discomfort, headache, irritated throat, and back pain during cooking (as in Diaz, *et al.,* 2007).

**Estimation**

We analyze the impacts $Y_{vi1}$ for woman *i* in village *v* at the sixth month follow-up (time 1) using OLS regressions controlling for a vector of baseline characteristics ($X_{vi0}$) and a vector of village fixed effects $FE_v$:

$$Y_{vi1} = \Sigma_{sj}\, \beta_s\, T_{vsi}\ \ size_{vi1} + \Sigma_k\, \gamma_k\, X_{vik0} + \quad \Sigma_v\, \delta_v\, FE_v + \varepsilon_{vi}$$

where $T_{vsi}$ is a dummy equal to one for treatment homes of size category *s.* Because it is plausible the solar ovens had larger effects for smaller households, we interact the treatment effect with three categories of household $size_{iv1}$: 6 or fewer people, 7-12, and 13 or more.

The baseline household characteristics include: the number of people women report cooking for and its square, wood use at lunch the day prior to the baseline, the amount of money spent weekly on wood, the amount of money spent weekly on gas, the amount of money spent weekly on charcoal, 3 indicators for women's salary category, 3 indicators for the category of the husband's financial contribution to the household, and kilograms of rice. Continuous measures were bottom- and top-coded to the 5$^{th}$ and 95$^{th}$ percentiles to reduce the influence of outliers. To maintain sample size, we include a dummy when observations on a control variable were missing, and impute that value at its mean.

It is possible the number of people a woman cooks for at the follow-up is affected by having a solar oven. Thus, we re-estimate equation 1, but instrument for the number of people a woman cooks for at the follow-up survey (and interactions with treatment) with the number she cooked for at baseline (and interactions with treatment). The first stage is very strong; for example, when we used baseline # cooked yesterday to predict follow-up # cooked for yesterday, the t- statistic was 29 (P < .00001, Web appendix 2).

As a robustness check, we also measured household adult age equivalent by converting children into adult equivalents (as in Atkinson, *et al.,* 1995). We then examine quartiles of adjusted household size and their interactions with treatment. We report these robustness checks only for wood usage, as they had no effect on other specifications.

**Pipeline analysis**

At baseline we surveyed 838 of the envisioned 1000 households in the combined control plus treatment groups (Table 1).

Twelve treatment households (4%) returned their solar ovens, typically due to a financial shock such as a health problem. Tostan redistributed these solar ovens to control homes leading to a small amount of leakage.

Households that dropped out were similar to Treatment and Control households in all respects except with respect to employment, husband's employment, and type of floor of home (Web Appendix 7). A statistically significant difference from the Control group for the women who dropped out of the program was detected in a higher amount of women reporting being employed (100%) in the attrition group, while a lower amount of women reported their husbands were employed- 72%. Further, a lower percentage of women in the attrition group report having cement floor with carpeting (54%), the most typical type of floor. This confirms that those who attrited from the control group would have benefited at least as much from the introduction of the solar oven, if not more.

Contrary to the intended study design, 33% (260) of our participant households lived in a compound with one or more other study participant.[vii] We use this unintended overlap to test whether solar ovens are more effective in compounds with multiple solar ovens (see Web Appendix 5). We discuss the effect of potential leakage (and resulting failure of the Stable Unit Treatment Value Assumption) below.

Of the 790 participants who made up our final sample, 736 weighed wood at the baseline (93%). At the six month follow-up 744 households took the survey (94% of the 790), of which 677 (91% of follow up survey participants) also weighed wood. Of those missing wood weighing, 67% on the baseline survey and 64% on the follow-up are due to the household reports she cooks primarily with gas. The additional missing 18 households at baseline and 24 at the six month follow-up are due to data collection error.

We permitted other women (usually from the same compound) to complete the survey if the enrolled woman was not present. At the follow-up 48% of treatment and 45% of control households had a substitute respondent. This rate was high in part because treatment respondents, who had already received their solar oven, had little incentive to be present in the village to take the follow-up survey. Additionally, the fish smelting season increased absenteeism in two villages located by the sea-side.

**Randomization tests**

To ensure the control and treatment group were correctly randomized we perform statistical T tests on baseline demographic information (Table 2). There are no statistical differences in average age and gender of household members, level of education, Women's daily salary for those employed, husband's level of employment & main occupation, average kg/week of rice and flour consumed, household structure- roof and floor, or the percent of women who indicate their husband is the primary decision maker. There are two statistically significant differences between the Treatment and Control group. Women enrolled in the program in the Control group report being employed 65% of the time while Treatment households report being employed 76% of the time. Contrarily, the second statistical difference is Control households report their husbands give them more money daily to purchase household items ($3.54) while Treatments report ($3.10). Thus, while women in the Control group are under-employed relative to their Treatment counterparts they receive more money than Treatments from their husbands. If we combine average income earned daily by women and money their husband's give them for household expenditure, the overall daily household expenditure is nearly equal- $5.10 for Controls and $5.12 for Treatments and the T test is not statistically significant.

To further test if household characteristics jointly predict treatment we ran a probit regression with the baseline variables listed in Table 2- education, income, household size- and the outcome variables- time spent gathering fuel, kilograms of wood used, self-reported health, and so forth. The results show the same statistical differences as above- woman who report being employed and the daily amount their husband gives them for household expenditures (Web appendix 3) is significant. However, given the total household expenditure is nearly equal and not significant, we conclude these results are consistent with our sample having been correctly randomized.

**Summary statistics**

At baseline, households used an average of 6.8 kg. of wood to cook the lunch meal (Table 3a).

For controls the mean hours household members spent collecting wood for the household was high at baseline (10.6 hours) and more than halved (to 4.9 hours) at the follow-up. In addition to performing about half the household's wood collection, women report spending an average of 5 hours a day cooking, of which about 3 hours are next to the fire (Table 3a). The responsibilities of cooking which fall exclusively on women and girls is likely to contribute to the disproportionate number of women and girls who report no education 68% vs. 62% for men and boys.

At baseline 77% of women reported sometimes or always having their children present when they cook and 31% reported sometimes having their children on their back when they cook.

The average CO exposure for control women is 6.50 PPM/hour at the follow-up.[viii] Multiplying this hourly rate times the 5 hours daily women report cooking implies exposure to approximately 32.5 ppm of CO daily. This is 130% of the recommended 25 ppm limit for an 8-hour exposure recommended by the World Health Organization[ix]. To test if kitchen structure affects personal level exposure of CO for cooks at baseline we regress CO PPM/hour on the four different kitchen designs- enclosed no windows, semi-enclosed with at least one window, open air with thatch roof, and completely open air. At baseline only households which cook in open air have statistically lower CO PPM exposure readings (Web Appendix 6).

Consistent with high smoke exposure, control women at the six-month follow-up reported an average of 2.9 of the four symptoms associated with cooking: eye irritation, headache, throat irritation, and backache (Table 3b).

Control respondents at the six-month follow-up report an average of 3.9 of the seven respiratory illness symptoms we asked about (cough, sore throat, fever, stuffy nose, trouble breathing, chest heaviness and/or coughed up mucus). In contrast, these women reported a third fewer symptoms for their husbands (2.20, which is statistically significant less than their wives, $P < .01$). It is plausible that exposure to the cookfire is responsible for much of the women's higher average number of symptoms, although higher awareness of their own symptoms and exposure to children with many infections may also play a role. Averaging over all children under 5 in the household, control children had a mean of 2.5 of four respiratory symptoms at the baseline (Table 3b).

**Results**

As part of project preparation activities, we designed a feasibility stage to field test surveys and methods. In our test parish, it was quickly apparent that the solar oven was both too small for the majority of households and the stove required significant behavior change, requiring households who traditionally cook using two pans- often frying rice- to transition to cooking with one pot and a method which simmers food instead of frying it. Given the significant behavior change associated with the solar oven and the inability for most households to cook for the main lunch meal for their families with the Hotpot, it seemed clear very early on that the solar oven would not have a large effect in these communities. We communicated this with our project partners, but the solar ovens had already been ordered and were being shipped to Senegal.

We felt it was scientifically important to carry out the randomized trial, as cancelling randomized trials when early results are not promising will lead to a biased set of published results. To address the behavior change inherent in use of the solar oven and to encourage technology adoption we incorporated an intensive training component into the initiative. A local expert trained by SHE travelled to all 20 villages at least three times per village during the six months of data collection to provide both intensive training to the village solar stove focal point person (who then was asked to replicate this training throughout the village) and individual household level trainings for all interested participants who owned a solar oven. Despite these efforts, the effects of the intensive training were limited- solar oven usage increased marginally- from 10% of days at the one month mark to 19% of days at the sixth month mark. Results are discussed more fully in the companion paper Beltramo 2011.

For all our outcome variables- solar oven usage, wood usage, time spent collecting fuel and cooking, carbon monoxide exposure, and self-reported health- we report results for three groupings of household size: 1). 6 persons or less, equivalent to 20% of the population; 2). 7-12 persons equivalent to 46% of the population; 3). 13 persons or more equivalent to 34% of the population. As the solar oven can cook for 6 persons or less, we chose an equivalent household size category to test its effects. To check robustness we ran all of our results without household size groupings as well as a wide variety of household size groupings. Our results remain unchanged despite the grouping specification.

**Solar Oven Usage**

In the sixth month of having the stove, SUMs measured use of the solar oven on 19% of days. The weather that month was sunny enough for the oven to be used almost every day in almost every village.

When we asked about complaints about the solar oven on follow-up surveys, the three most frequent responses were that the size was too small (50% of responses), takes too long to cook (35%), and the reflector is not durable (11%).[ix] The primary complaint, that the solar oven is too small, corresponds with the high number of people our sample cook for; as noted above, at baseline about 90% of respondents reported cooking for more than six people (the capacity of the solar oven).[x] The behavior change barriers to adoption, such as adapting to the time the solar oven takes to cook, are addressed in their own paper (Beltramo, 2011).

At the follow-up survey only 7% of treatments used the solar oven to prepare part or all of the lunch meal yesterday. Respondents reported the most common meal they prepared with the solar oven was dinner (40%), a snack (28%), or separate meals for children or diabetics (13%). The dinner meal is usually smaller than lunch and often porridge, which is well suited to solar cooking. As it is a common practice to pre-cook and then reheat food at meal time, cooking dinner concurrently with lunch did not require behavior change as it was consistent with familiar cooking methods.

Importantly, when we observed cooking during the CO survey at follow-up, every cook who was using the solar oven also had a wood or charcoal fire lit.

The stove usage monitors proved critical in measuring stove usage. Solar oven users at the six month follow-up *report* using their solar oven 38% of days, double the 19% rate recorded by SUMs. When we observed stove usage at the six month follow-up visit, for the 17 of the 20 villages where the weather was sunny, 61% of women were using their solar ovens– or more than 3 times the average usage rate on days they did not anticipate our visit.

**Wood Usage**

Table 4 presents the core regression results on fuel usage. Across many specifications, the point estimates shows a small decline in wood usage only among medium-sized (7-12 people) treatment households.

In the first model we interact treatment with three household size categories. Treatment households of size 7-12 persons showed a statistically significant drop in daily wood use of 1.4 kilograms per day (about 14% of the mean). Households of 6 persons or less or 13 and more do not show any statistically significant change in fuel use.

In column 2 we add baseline control variables such as wood usage and measures of income. The point estimates are almost identical as in column 1.

We instrument for the number of people women report cooking for at the follow-up with the number they report cooking for at baseline (and the various interactions with treatment status). Our results are consistent with the OLS results, including the reduced form (Table 4 column 3).

To check robustness we measured kilograms of wood used four ways: used all day yesterday, used all day yesterday per capita, used preparing yesterday's lunch, and used for yesterday's lunch per capita. We examined compounds with more than one study participant per compound, looking for a treatment effect among compounds with 2 or more solar ovens. In all cases, results were similar to those in Table 4 (Web Appendix 5). When we recode our household size using the adult age equivalent system which gives more weight to adults than children due to differences in consumption of meals, results were similar. Though now the wood savings are statistically significant only for the smallest terciles of households (6 adult equivalents and less, $\beta = -0.45$ kg, SE = 0.20, $P < .05$, Web appendix 4). This is consistent with earlier results as 43% of the smallest adult age equivalent group are households who report cooking for 7-12 persons.

**Time spent collecting fuel and cooking**

The regression results show a small point estimate drop for the treatment effect on the time spent collecting fuels only for households of size 6 persons or less but the coefficient is not statistically significant (Table 5, col. 2).

Treatment status also had no detectable effect on the time women spend next to the cook fire (Table 5, col. 1).

To check robustness, we reran the time spent collecting wood models separately on the women's time and the time of others in her household. Results were unchanged. In addition, we ran the wood collecting models separately on treatment households with 2 or more solar ovens in their compound. Results were unchanged. Finally, we run total household time collecting wood constrained by only those whose wood collected lasts less than 2 weeks and find that treatment interacted with households of size 13 persons or more has a coefficient of 207 minutes per week (that is, over 3 hours/week, $P<.05$). However, we suspect this result is due to sampling error.

**Carbon Monoxide Exposure**

In the follow-up survey 166 treatment households and 109 control households received the CO tube. The mean for the control group is 6.50 while the treatment group is 8.09 ppm/hour. The unexpectedly *higher* CO exposure among treatments is marginally statistically significant at the 10% level.

The regression analysis shows that the marginally significant difference in means is largely due to small household size (Table 5, col. 3). The coefficient on the interaction of treatment times the woman cooks for a household size of 6 persons or less is statistically significant at the 5% level (6.53 CO PPM/hour). Our sample is small (only 20 treatments with CO tubes had household size 6 or under), but the result is not due to outliers. This group has substantially higher median CO readings than the other groups.

Finally, we reran regressions for treatment compounds with two or more stoves and we find no statistically significant effect on CO exposure at the six month follow-up. This is consistent with the findings of lower usage for this group of the solar ovens and insignificant effects on wood use and time spent collecting fuel (Web Appendix 5).

**Self-Reported Health**

In the regression analysis (Table 5, col. 4-6), we analyze women's reports of symptoms for themselves and their children with controls for village, baseline number cooked for, several other baseline characteristics, and the women's reports of their husbands' respiratory symptoms.

For the count of 4 symptoms associated with cooking (eye irritation, headache, sore eyes, and back ache, col. 4) and self-reported respiratory symptoms (cough, etc., col. 5) there is no statistically significant difference between the treatment and control group.

Finally, we repeat the regression predicting the women's reports of under-five children's respiratory symptoms using an average of self-reported respiratory symptoms for all the children within each household (Table 5; col. 6). Children aged 5 and under in households with 13 or more people have 0.30 more symptoms (SE = .13, $P < .01$) if they are in a treatment household than if they are in a similarly large control household. We do not want to make too much of this result, as the 3 household size * treatment indicators are jointly not significant ($P < .19$).

In robustness checks we controlled for whether the women enrolled in the program are part of a polygamous household, and a dummy variable for whether she is employed or not. We removed the endogenous cooking in an enclosed or semi-enclosed hut. We ran the entire set of regression specifications individually for each of the four symptoms associated with cooking and for each of the seven respiratory symptoms. Results were unchanged.

**Limitations**

Our study has several limitations. There was non-random attrition of a few percent of the sample and non-random missing data for a large share. Our data collection was organized around the "household," but in many compounds women rotate cooking duties across meals or days with their co-wives and other compound members.[xi] We did not put stove usage monitors on old stoves. We placed the carbon monoxide tubes only on woman intending to light a fire that day, but did not retain the count of women who were cooking with gas. We rely on self-reported use of wood and time spent collecting wood, both of which have substantial recall error. Finally, the carbon monoxide tubes measured CO exposure during the middle of the day, when most cooks prepare lunch. Thus, we missed any reduction in evening smoke inhalation among women who used the solar oven to pre-cook dinner.

On the one hand, each of these issues limits our confidence in the precise estimates we report. On the other, only the final point might bias our results, while the other concerns primarily reduce our precision. In any case, our basic results are very strong (that is, most outcomes were not affected by the solar ovens), and we do not believe these concerns substantially affect the overall results.

Finally, the methodology could have been improved by an independent feasibility study, installing ibuttons on old stoves, enforcing only one Hotpot per compound, and more comprehensive indoor air pollution measures.

**Discussions**

The results from this randomized controlled trial confirm that the Hotpot solar oven- as it is designed now- is not the right improved stove for our study zone in rural Western Senegal. On average there was no detectable decline in wood usage for treatment homes. At the same time, there was a small decline in wood usage for medium-sized (7-12 people) households in the treatment group, and a similar drop for the relative adult age equivalent group of small size households equivalent to 6 adults or less.

Consistent with low usage of the solar oven and continued usage of traditional stoves, there was no detectable effect of solar ovens on time spent collecting fuel or on time spent next to the cook fire. There is no evidence solar ovens reduce exposure to carbon monoxide or self-reported respiratory symptoms such as coughs and sore throats.

The lessons for solar oven programs are clear. Programs distributing parabolic solar cookers which work poorly in high wind (like the HotPot we studied) must avoid areas with high wind (like two of our villages by the sea). More generally, because switching to slow cooking methods is likely to be a significant shift in cooking behavior, programs should be in areas with very costly or hard-to-gather wood. Most crucially, solar ovens must be large enough relative to household size to replace a cookfire for the main meal of the day.

Despite the mismatch of the Hotpot with local cooking practices and large family sizes, the population is well suited for an improved stove intervention. Cooks and their accompanying children are exposed to dangerous levels of emissions: 130% of the daily recommended level of CO, which is roughly equivalent to 1.5 packs of cigarettes a week. Given this, it is not surprising that at the follow-up control women report an average of four of the 7 respiratory symptoms we asked about (such as coughs and sore throats)—almost twice the rate they report for their husbands.

While women suffer disproportionately from inefficient cookstoves, most report their husband (58%) is the sole decision maker in purchasing large household items. Future stove programs should include in their feasibility stage measures of the level of equality in decision-making of households and women's independent income. Finding solutions to the inequality in intra-household bargaining power is likely to greatly impact adoption and purchase rates of ICS.

SUMs proved critical in measuring objective stove usage. Solar oven users at the six month follow-up report using their solar oven 38%, about double the SUM-measured usage rate of 19%. Evidence of a Hawthorne effect continued when at the six month stove usage visit women used their stove more than 3 times the average actual usage rate measured by SUMs. Given the wide discrepancies between self-reported and observed usage, we conclude that stove usage monitors are critical for future studies to accurately measure usage. Further, future research should install SUMs on both the traditional stove and the ICS in order to accurately measure the shift in usage from the old to the new stove.

Finally, despite low overall stove usage and limited effects on observed outcomes on fuel use, time spent collecting fuel and health, over 30 additional villages expressed interest in receiving the solar oven in their village. In the developing world where resources are extremely limited, enthusiasm for any initiative should not be mistaken for success, and should be thoroughly investigated. The research team observed some households liked the solar oven as a status symbol and others used its hermetically sealed pot to store food.

The future research agenda should prioritize assessing best practice in marketing strategies to the rural poor of ICS, encourage manufacturers of cookstoves to design durable products which require limited behavior change in cooking, assess strategies such as optimal kitchen design or building in more air flow to lower exposure to emissions, and find solutions to increase willingness to pay for improved cookstoves by including additional co-benefits such as the BioLite stove which transforms excess heat from the stove into a cell phone recharger.

Additional randomized controlled trials of impacts on fuel use, time spent collecting wood and particularly health outcomes are needed to ensure the improved stoves can effectively replace traditional stoves and provide stated fuel reduction and health improvements. This evaluation was a success as it halted our NGO partner from following the proposed nation-wide and possible regional West African rollout of the Hotpot, saving many scarce development dollars.

**Acknowledgements**

This research was supported by the National Institute of Health, the Blum Center, Sustainable Product Solutions, Berkeley Institute for the Environment, Berkeley Population Center, Solar Household Energy (SHE), and Tostan. We thank Darwin Curtis, Marie-Ange Binagwaho, and Bridget Huttenlocher at SHE and Molly Melching, Cody Donahue, Dame Gueye and the Community Management Committee organizers at TOSTAN. Lamine Ndiaye, Henry Silverman, Richard Tam, Kenneth Tsang, Miyeon Oh and Cheikh Sidaty Ndiaye, Kine Seck, Magueye Ndiaye, Thierno Diagne, Awa Ndiaye, Wawounde Diop, Maimouna Sow, Ngone Sow, Aminata Bass, Anna Dione, Ibrahima Balde, Babacar Cisse, Yatening Thiang provided excellent research assistance, led by Vanessa Reed in the field. Kirk Smith, Isle Ruiz-Mercado, and the UC Berkeley RESPIRE team guided us on measurement. We appreciate comments from Grant Miller, Mushfiq Mobarak, Rena Hanna, Esther Duflo, Michael Greenstone, Vijay Modi, Alexander Pfaff, Valeria Muller, Darby Jack, Robert Van Buskirk, Jason Burwen, Ashok Gadgil, Dan Kammen, Nils Tomajina, Jimmy Tran, Matt Evans, Evan Haigler, George Scharffenberger, Arianna Legovini, Abdoulaye Sy, Pascaline Dupas, and We thank participants at the World Bank, U.C. Berkeley, ASSA, and Katholieke Universiteit Leuven LICOS. Errors are our own.

---

i. This research was supported by the National Institute of Health, the Blum Center, Sustainable Product Solutions, Berkeley Institute for the Environment, Berkeley Population Center, Solar Household Energy (SHE), and Tostan. This randomized controlled trial passed the University of California Berkeley Office of the Protection of Human Subjects (Review #: 2007-12-50). All errors are our own. Contact information for Dr. David Levine, Eugene E. and Catherine M. Trefethen Professor, Walter A. Haas School of Business, University of California, Berkeley: levine@haas.berkeley.edu and Dr. Theresa Beltramo, Senior Economist, Impact Carbon and Center for European Law & Economics, Stockholm, Sweden: tbeltramo@impactcarbon.org.

ii. Power calculations are based on data collected in similar improved cookstoves programs from colleagues Robert VanBuskirk (2004) in Eritrea and Kilabuko Matsuki Nakai (2007) in Tanzania. From VanBuskirk we took the variance and standard deviation for kilograms of wood used per cooking session and hours per week spent collecting fuel. From Matsuki Nakai who took air pollution samples (PM10, $NO^2$, CO) in 100 kitchens in rural Tanzania in 2007, we derived the variance and standard deviation of CO for cooks.

iii. The sample of type of cooking structure comes from our CO sub-sample at the 6 month follow-up where we visited households' homes and has a total sample size of 281 households, though only 275 CO PPM/hour were successfully recorded.

iv. We document these claims and describe the datasets below. Data from the next two paragraphs are from the baseline survey except data on cooking structures which is from the subsample of our six-month follow-up where we measured carbon monoxide exposure.

v. We also fielded a one-month follow-up, but solar oven usage was so low that first month (9% on average) that we only look for effects using the 6-month follow-up.

vi. The ibutton is sold by Maxim. We appreciate advice from the RESPIRE team on the ibutton SUMs.

vii. 41% (236) of treatments had one or more treatment and/or controls living in the compound and 54% (176) of control households have one or more treatments and/or controls living in the compound. (see web appendix 5)

viii. Measured CO exposure was higher at baseline, but we believe measurement problems biased up those results.

ix. The other common complaints were that it cooked too slowly (35%) and was not durable (11%).

x. An additional barrier was that the solar oven required women simmer, not fry, rice for the most common lunch meal of ceebu jën (Beltramo, 2010).

[xi.] We do not think leakage, where controls used solar ovens of treatments in their compound, were important for our results. First, results were unchanged when we examined only treatments and controls with no other study participants in their compound. Second, the majority of cooking was for nuclear families. Finally, usage rates were low, even including any leakage, so we cannot have missed major benefits of the solar ovens.

**References**

Atkinson, A.B., L. Rainwater and T. M. Smeeding. (1995) Income Distribution in OECD Countries. OECD Social Policy Studies, 18.

Bailis, R., Majid, E., and Kammen, D. (2005) Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. Science, 308(5718), pp. 98-103.

Beltramo, T. (2010) Peer effects and usage of the solar oven- Evidence from rural Senegal. Doctoral dissertation, Ca' Foscari University, Venice, Italy.

Blackden, M. and Wodon Q. (2006) Gender, time use, and poverty in Sub-Saharan Africa. World Bank Working Paper No. 73. Washington D.C.

Bruce, N., Rehfuess, E., Sumi, M., Hutton, G., and Smith, K. (2006) Indoor Air Pollution, in: D.T. Jamison, J.G. Breman, A.R. Musgrove (eds) Disease Control Priorities in Developing Countries, 2nd ed., (New York: Oxford University Press), pp. 591-603.

Clark, M., Paulsen, M., Smith, K., Canuz, E., and Simpson, C. (2007) Urinary Methoxyphenol Biomarkers and Woodsmoke Exposure: Comparisons in Rural Guatemala with Personal CO and Kitchen CO, Levoglucosan and PM2.5. Environmental Science Technology, 41, pp. 3481-3487.

Dherani, M., Pope, D., Mascarenhas, M., Smith, K., Weber, M., and Bruce, N. (2008) Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. Bulletin of the World Health Organization 86, pp. 390–398.

Diaz, E., Smith-Siversten, T., Pope, D., Lie, R., Diaz, A., McCracken, J., Arana, B., Smith, K., and Bruce, N. (2007) Eye discomfort, headache and back pain among Mayan Guatemalan women taking part in a randomized stove intervention trial. J. Epidemiology Community Health, 61, pp.74-79.

Duflo, E., Greenstone, M., and Hanna, R., 2008. Indoor Air Pollution: Health and Economic Well-being. *Sapiens*, 1(1), pp. 1-10.

Edwards, R., Hubbard, A., Khalakdina, A., Pennise, D., Smith, K. 2007. Design considerations for field studies of changes in indoor air pollution due to improved stoves. Energy for Sustainable Development, 11(2), pp. 71-81.

Grabow, K., Still, D., MacCarty, N., Bentson, S. (2012) An affordable, effective method for decreasing indoor air pollution in kitchens. Aprovecho Research Center Working Paper. Cottage Grove, Or.

Goldemberg, J., Reddy, A., Smith, K., and Williams, R. (2000) Rural energy in developing countries, in: Goldemberg, J. (ed.) (2000) World Energy Assessment, Energy and the challenge of sustainability. (New York: UNDP), Ch. 10, pp. 367-384.

Meddleton, E.T., and Morice, A.H. (2000) Breath carbon monoxide as an indication of smoking habit. Chest, 117, pp.758-63.

Mehta, S., Prüss-Üstün, A., and Rehfuess. E. (2006) Assessing household solid fuel use: Multiple implications for the Millennium Development Goals. Environmental Health Perspectives, 114(3), pp. 373-378.

Miller, G., and Mobarak, M.A. (2011) Intra-household externalities and low demand for a new technology: Experimental evidence on improved cookstoves. Yale University Working Paper, New Haven, CT.

Ruiz-Mercado, I., Lam, N., Canuz, E., Davila, G., and Smith. K. (2008) Low-cost temperature loggers as stove use monitors (SUMs). Boiling Point, 55, pp. 16-19.

Smith, K., Samet, J., Romieu, I., and Bruce, N. (2000) Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax: An International Journal of Respiratory Medicine, 55(6), pp. 518-532.

Smith, K. and Mehta, S. (2000) The burden of disease from indoor air pollution in developing countries: comparison of estimates. USAID/WHO Global Consultation on the Health Impact of Indoor Air Pollution and Household Energy in Developing Countries: Setting the Agenda for Action, May 3-4, 2000, Washington, DC.

Smith-Silvertsen, T., Diaz, E., Bruce, N., B.,, Diaz, A., Khalakdina, A., Schei, M., McCracken, J. Arana, B., Klein, R., Thompson, L., and Smith, K. (2004) Reducing indoor air pollution with a randomized Intervention design- A presentation of the stove intervention study in the Guatemalan Highlands. Norsk Epidemiologi, 14(2), pp. 137-143.

United Nations Convention to Combat Desertification. (2010) Assessing the Health Benefits of Air Pollution Reduction for Children. Environmental Health Perspectives, 112(2).

World Health Organization. 2011. Fact Sheet on Indoor Air Pollution # 292. http://www.who.int/mediacentre/factsheets/fs292/en/

| Table 1: Sample Size and General Attendance on Survey Day | | | | | | |
|---|---|---|---|---|---|---|
| | | Randomized treatment | Randomized control | Total intention to treat | Treatment with at least one other treatment in compound | Control with at least one other treatment in compound |
| Number of Households who took Baseline Survey | | 465 | 325 | 790 | 171 | 159 |
| Withdrew from study either at 1 month follow-up or 6 month follow-up | | 12 | 36 | 48 | ... | ... |
| Number Households who took Baseline including those who subsequently withdrew | | 477 | 361 | 838 | 184 | 186 |
| Baseline survey | Original respondent | 430 | 303 | 733 | 158 | 148 |
| | Original respondent absent, but another woman in compound responded for her | 35 | 22 | 57 | 11 | 11 |
| | Total who completed survey | 465 | 325 | 790 | 171 | 159 |
| | Absent at Baseline | 23 | 36 | 59 | 13 | 27 |
| Baseline wood weighing | Yes, woman weighed wood | 421 | 275 | 696 | 170 | 149 |
| | No, cook with gas | 19 | 17 | 36 | 1 | 3 |
| | No, took survey but left before wood weighing | 25 | 33 | 58 | 0 | 7 |
| Baseline CO Tubes | Sub-sample CO tube | 115 | 61 | 176 | 35 | 16 |
| Follow-up survey | Original respondent | 230 | 165 | 395 | 69 | 54 |
| | Original respondent absent but another woman in compound responded for her | 214 | 135 | 349 | 63 | 56 |
| | Absent at follow-up | 21 | 25 | 46 | 39 | 49 |
| | Total who Completed Survey | 444 | 300 | 744 | 132 | 110 |
| Follow-up wood weighing | Yes, woman weighed wood | 406 | 271 | 677 | 128 | 106 |
| | No, cook with gas | 27 | 16 | 43 | 4 | 4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | No, took survey but left before weighing wood | 11 | 13 | 24 | 0 | 0 |
| Follow-up CO Tubes | Sub-sample CO tube | 166 | 109 | 275 | 39 | 38 |

| Table 2: Baseline Summary Statistics from Survey | | | | | | |
|---|---|---|---|---|---|---|
| | Total Sample | | Treatment | | Control | |
| | N | average | n | average | n | average |
| Average age for all household members | 10617 | 23 | 6512 | 23 | 4105 | 23 |
| Female | 5803 | 53% | 3607 | 54% | 2196 | 52% |
| Adults with no education | 7712 | 70% | 4751 | 71% | 2961 | 70% |
| Women enrolled in program with no education | 784 | 74% | 464 | 74% | 318 | 73% |
| Woman respondent is employed | 777 | 71% | 461 | 76% | 316 | 65%** |
| Among women employed their occupation is housework [1] | 197 | 84% | 105 | 84% | 92 | 84% |
| Woman's daily salary (US$)[2] | 419 | $1.86 | 269 | $2.02 | 150 | $1.56 |
| Woman respondent is self employed | 659 | 89% | 399 | 88% | 260 | 91% |
| Husband is employed (only including women who are married) | 727 | 84% | 443 | 83% | 294 | 86% |
| Among husbands' employed whose occupation is driver (includes both a taxi and horse drawn carriage) | 554 | 29% | 325 | 30% | 229 | 27% |
| Husband who are self-employed | 627 | 68% | 376 | 68% | 251 | 67% |
| Amount women report their husband's provide for them to purchase household items daily[2] (US$) | 605 | $3.28 | 362 | $3.10 | 243 | $3.54* |
| Average kg/week of flour the family consumes | 466 | $3.01 | 281 | $3.06 | 185 | $2.95 |
| Average kg/week of rice the family consumes | 770 | $3.08 | 456 | $3.17 | 314 | $2.95 |
| Percentage of household decision indicated as husband | 759 | 58% | 450 | 56% | 309 | 61% |
| Woman's house has tin roof (not straw, cement, slate, or tile) | 772 | 82% | 458 | 81% | 314 | 82% |
| Women's house has floor other than dirt (tile or cement) | 772 | 95% | 458 | 96% | 314 | 94% |
| Women's house has cement floor with carpeting | 705 | 75% | 413 | 78% | 292 | 71% |

1. Many women consider domestic chores such as housework- employment, and thus we note a smaller percentage of women were actually employed outside the home than those who self-identified as employed.

2. This is only for woman (and women's husband's) who reported a salary. The U.S. Treasury Exchange rates is 436 CFA/$1 USD for the second quarter of the year of 2008.

3. T-tests of treatment and control baseline means: * p<0.05, ** p<0.01, *** p<0.001

Table 3a: Summary Statistics for Main Outcome Indicators at Baseline

| | Overall | | Treatment | | Control | | Treat-Control |
|---|---|---|---|---|---|---|---|
| | Mean (s.d) | Obs. N | Mean (s.d.) | Obs. N | Mean (s.d.) | Obs. N | Difference as Percent of control mean (s.e.) |
| Wood used yesterday at lunch (from wood weighing in kg.) | 6.82 | 696 | 6.87 | 421 | 6.73 | 275 | 2% |
| | (2.51) | | (2.45) | | (2.61) | | (0.12) |
| Total Wood used yesterday (from wood weighting in kg.) | ... | ... | ... | ... | ... | ... | ... |
| | ... | ... | ... | ... | ... | ... | ... |
| Minutes per day preparing 3 meals | 295.29 | 790 | 296.97 | 465 | 292.79 | 325 | 1% |
| | (113.28) | | (111.20) | | (116.47) | | (0.86) |
| Minutes per day next to cook fire in preparing 3 meals | 177.41 | 790 | 179.59 | 465 | 174.05 | 325 | 3% |
| | (120.92) | | - (120.91) | | - (121.09) | | (0.83) |
| Minutes / week[1] respondent collects fuel | 322.33 | 790 | 314.88 | 465 | 333.00 | 325 | 1% |
| | (448.37) | | (450.93) | | (445.17) | | (2.19) |
| Minutes / week[1] others in household collect fuel | 298.95 | 790 | 294.50 | 465 | 305.33 | 325 | -4% |
| | (420.05) | | (419.58) | | (421.28) | | (2.20) |
| Minutes / week[1] household members collecting fuel | 621.29 | 790 | 609.38 | 465 | 638.33 | 325 | -3% |
| | (800.69) | | (803.53) | | (797.52) | | (2.79) |
| Days in average collection period | 3.94 | 790 | 3.86 | 465 | 4.06 | 325 | -5% |
| | (5.59) | | (5.20) | | (6.12) | | (0.22) |
| Amount spent buying wood last week for all households who report buying wood (U.S. $)[4] | $3.46 | 361 | $3.41 | 213 | $3.52 | 148 | -3% |
| | (3.35) | | (3.22) | | (3.54) | | (0.20) |
| Carbon monoxide CO PPM/hour for subset of cooks (Control)[2] | 24.60 | 176 | 25.57 | 115 | 22.71 | 61 | 13% |
| | (15.04) | | (16.16) | | (12.60) | | (0.59) |
| Count of 4 problems while cooking (sore eyes, sore back, headache, throat irritated) | 3.12 | 790 | 3.20 | 465 | 3.02 | 325 | 6% |
| | (1.42) | | (1.36) | | (1.51) | | (0.09)* |
| Count of 7 symptoms for self (Symptoms include: fever; sore throat; runny or stuffy nose; cough; wheezing; woke up with chest heaviness; coughed up mucus | 3.30 | 790 | 3.40 | 465 | 3.15 | 325 | 7% |
| | (2.72) | | (2.70) | | (2.73) | | (0.12) |
| Count of 4 symptoms for children (Symptoms: include cough; coughed up mucus; runny or stuffy nose; and wheezing)[3] | 2.57 | 790 | 2.60 | 465 | 2.51 | 325 | 3% |
| | (1.06) | | (1.03) | | (1.09) | | (0.09) |
| Count of 7 symptoms for husband (Symptoms include: fever; sore throat; runny or stuffy nose; cough; wheezing; woke up with chest heaviness; coughed | ... | ... | ... | ... | ... | ... | ... |
| | ... | ... | ... | ... | ... | ... | ... |

| up mucus | | | | | | | |
|---|---|---|---|---|---|---|---|

**Note:** All Data Presented has been top and bottom coded at the 5% level as is common practice to control for outliers unless otherwise noted; [1] Time spent collecting fuel represents both those who do not collect fuel and those who positively report collecting fuel; [2] The Baseline CO ppm Measure has been topcoded for levels over 70 CO ppm and adjusted by the manufacture recommended humidity factor; [3] This is the average of symptoms for all children in the household; [4] The U.S. Treasury Exchange rates is 436 CFA/$1 USD for the second quarter of the year of 2008; ~ p<.10, * p<0.05, ** p<0.01, *** p<0.001

Table 3b: Summary Statistics for Main Outcome Indicators at Six Month Follow-up

| | Overall | | Treatment | | Control | | Treat-Control |
|---|---|---|---|---|---|---|---|
| | Mean (s.d.) | Obs. N | Mean (s.d.) | Obs. N | Mean (s.d.) | Obs. N | Difference as Percent of control mean (s.e.) |
| Wood used yesterday at lunch (from wood weighing in kg.) | 5.56 (2.46) | 677 | 5.44 (2.44) | 406 | 5.73 (2.48) | 271 | -5% (0.12)~ |
| Total Wood used yesterday (from wood weighting in kg.) | 9.99 (4.68) | 677 | 9.85 (4.70) | 406 | 10.19 (4.65) | 271 | -3% (0.17) |
| Minutes per day preparing 3 meals | 246.46 (155.30) | 744 | 246.19 (158.00) | 444 | 244.38 (151.53) | 300 | 1% (0.93) |
| Minutes per day next to cook fire in preparing 3 meals | 164.53 (115.85) | 744 | 163.78 (114.93) | 444 | 165.63 (117.38) | 300 | -1% (0.81) |
| Minutes / week[1] respondent collects fuel | 166.58 (276.94) | 744 | 180.30 (293.79) | 444 | 146.94 (250.02) | 300 | 15% (1.22)* |
| Minutes / week[1] others in household collect fuel | 128.79 (278.26) | 744 | 135.66 (272.94) | 444 | 118.97 (285.94) | 300 | 4% (1.25) |
| Minutes / week[1] household members collecting fuel | 295.37 (498.30) | 744 | 315.96 (527.03) | 444 | 265.91 (453.21) | 300 | 15% (1.64) |
| Days in average collection period | 32.18 (69.42) | 744 | 32.77 (63.70) | 444 | 31.40 (76.50) | 300 | 4% (0.63) |
| Amount spent buying wood last week for all households who report buying wood (U.S. $)[4] | $0.63 ($0.41) | 744 | $0.64 ($0.43) | 444 | $0.62 ($0.38) | 300 | 4% (0.05) |
| Carbon monoxide CO PPM/hour for subset of cooks (Control)[2] | 7.46 (8.83) | 275 | 8.09 (9.60) | 166 | 6.50 (7.43) | 109 | 24% (0.35)~ |
| Count of 4 problems while cooking (sore eyes, sore back, headache, throat irritated) | 2.88 (1.53) | 744 | 2.88 (1.53) | 444 | 2.88 (1.54) | 300 | 0% (0.09) |
| Count of 7 symptoms for self (Symptoms include: fever; sore throat; runny or stuffy nose; cough; wheezing; woke up with chest heaviness; coughed up mucus | 4.00 (2.72) | 744 | 4.05 (2.76) | 444 | 3.93 (2.66) | 300 | 3% -$0.12 |
| Count of 4 symptoms for children | 3.22 | 744 | 3.34 | 444 | 2.98 | 300 | 12% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (Symptoms: include cough; coughed up mucus; runny or stuffy nose; and wheezing)[3] | (1.05) | | (0.96) | | (1.17) | | (0.08)* |
| Count of 7 symptoms for husband (Symptoms include: fever; sore throat; runny or stuffy nose; cough; wheezing; woke up with chest heaviness; coughed up mucus | 2.10 | 744 | 2.02 | 444 | 2.20 | 300 | -8% |
| | (2.70) | | (2.67) | | (2.75) | | (0.12) |

Note : All Data Presented has been top and bottom coded at the 5% level as is common practice to control for outliers unless otherwise noted; [1] Time spent collecting fuel represents both those who do not collect fuel and those who positively report collecting fuel; [2] Topcoded of CO ppm scores over 70 CO ppm; [3] This is the average of symptoms for all children in the household; [4] The U.S. Treasury Exchange rates is 436 CFA/$1 USD for the second quarter of the year of 2008; ~ p<.10, * p<0.05, ** p<0.01, *** p<0.001

| **Table 4: Regressions Results Wood Use** | | | |
|---|---|---|---|
| Coefficient (standard error) | y= Kg. of wood used yesterday, and Model 3 is the reduced form | | |
| | 1 | 2[a] | 3 |
| Cook for 6 persons or less$_1$ *Treatment indicator | 0.31 (0.73) | 0.20 (0.72) | ... |
| Cook for 7-12 persons$_1$ *Treatment indicator | -1.38 (0.48)** | -1.43 (0.48)** | ... |
| Cook for 13 persons or more$_1$ *Treatment Indicator | 0.10 (0.56) | -0.09 (0.54) | ... |
| Cook for 6 persons or less$_1$ | ... | ... | ... |
| Cook for 7-12 persons$_1$ | 1.75 (0.66)** | 1.75 (0.65)** | ... |
| Cook for 13 persons or more$_1$ | 2.43 (0.71)*** | 2.12 (0.73)** | ... |
| Village fixed effects | Yes*** | Yes*** | Yes*** |
| Lunch kg. of wood used$_0$ | ... | 0.29 (0.09)*** | ... |
| Amount of money spent last week on gas$_0$ | ... | 0.01 (0.00)** | ... |
| Cook for 6 persons or less *Treatment indicator [b] | ... | ... | -2.65 (0.91)** |
| Cook for 7-12 persons$_0$ *Treatment indicator | ... | ... | -1.47 (0.55)** |
| Cook for 13 persons or more$_0$ *Treatment Indicator | ... | ... | 0.48 (0.47) |
| Cook for 6 persons or less$_0$ | ... | ... | ... |
| Cook for 7-12 persons$_0$ | ... | ... | 0.16 (0.64) |
| Cook for 13 persons or more$_0$ | ... | ... | 0.06 (0.61) |
| Constant | 12.12 (0.80)*** | 6.29 (1.34)*** | 13.91 (0.71)*** |
| $R^2$ | 0.291 | 0.343 | 0.283 |
| Observations | 659 | 659 | 677 |

Notes: ~ p<.10, * p<0.05, ** p<0.01, *** p<0.001; Dependent variables are compressed to the 5[th] and 95% percentiles and imputed when missing; Sample is those who completed the baseline survey. Subscript 0 is for baseline, 1 is for 6-month follow-up.

[a] Other baseline control variables included in Model 2 but not statistically significant and thus not shown include number of people for who whom women prepared lunch, number of people for whom women prepared lunch centered and squared; amount of money spent last week on wood and charcoal; kg. of flour and rice consumed per capita per week; terciles of low, medium, and high salary for respondent and for her husband.

| **Table 5: Regression Results- Time Spent Collecting Fuel, Personal Exposure to CO, Self-Reported Respiratory Symptoms** | | | | | | |
|---|---|---|---|---|---|---|
| | Coefficient (standard error) | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| | Min. /day by cookfire | Min. / week household gathers fuel [2,4] | Exposure to Carbon Monoxide (ppm/ hour) | Own symptoms associated with cooking (0-4) | Own respiratory symptoms (0-7) | Child respiratory symptoms (0-4)[5] |
| Cook for 6 persons or less *Treatment indicator [b] | 18.26 (19.74) | -77.17 (84.64) | 6.53 (2.64)* | 0.25 (0.27) | 0.15 (0.46) | -0.07 (0.16) |
| Cook for 7-12 persons *Treatment indicator [b] | -16.15 (13.51) | 39.98 (57.93) | 0.33 (1.78) | -0.17 (0.18) | 0.11 (0.32) | 0.07 (0.11) |
| Cook for 13 persons or more *Treatment Indicator [b] | -0.21 (15.48) | 80.85 (66.38) | 0.19 (2.16) | -0.09 (0.21) | 0.23 (0.36) | 0.26 (0.13)* |
| Cook for 6 persons or less [b] | ... | ... | ... | ... | ... | ... |
| Cook for is 7-12 persons [b] | 18.73 (21.97) | -1.70 (93.97) | 0.95 (2.89) | 0.24 (0.30) | 0.33 (0.51) | 0.02 (0.18) |
| Cook for 13 persons or more [b] | 15.81 (35.81) | -40.57 (153. 25) | 3.99 (4.93) | 0.10 (0.48) | -0.19 (0.84) | -0.04 (0.29) |
| Village fixed effects [a] | Yes*** | Yes** | Yes* | Yes*** | Yes*** | Yes*** |
| Lunch kg. of wood used [a] | 0.42 (2.45) | 21.03 (10.49)* | 0.07 (0.32) | -0.01 (0.03) | 0.04 (0.06) | 0.02 (0.01) |
| No. people woman reports cooking for [a] | 0.69 (1.22) | -2.51 (5.24) | -0.07 (0.15) | 0.02 (0.02) | 0.01 (0.03) | 0.02 (0.02) |
| Enclosed or semi-enclosed cooking area (not wall-less roof or open air) [3,b] | -3.54 (10.65) | -66.24 (45.66) | -2.16 (1.36) | 0.16 (0.14) | -0.08 (0.25) | -0.10 (0.09) |
| # of 7 Women Respiratory Symptoms [a] | ... | ... | 0.11 (0.23) | 0.03 (0.02) | -0.02 (0.00) | -0.01 (0.01) |
| # of 4 Respiratory Symptoms by Average Child [a] | ... | ... | -1.08 (0.70) | 0.04 (0.07) | 0.21 (0.12) | 0.07 (0.04) |
| Minutes per day next to cook fire in preparing 3 meals [a] | 0.02 (0.04) | 0.00 (0.16) | 0.01 (0.00) | -0.01 (0.00) | -0.01 (0.00) | 0.00 (0.00) |
| Min/week entire | ... | -0.01 | ... | ... | ... | ... |

| | | | | | | |
|---|---|---|---|---|---|---|
| household collects wood [a] | | (0.03) | | | | |
| # of Husband's Respiratory Symptoms [b] | ... | ... | ... | 0.06 (0.02)** | 0.27 (0.04)*** | 0.01 (0.01) |
| Constant | 188.83*** (40.66) | 184.85 (177.41) | 11.52 (5.46)* | 1.92 (0.59)** | 3.78 (1.01)*** | 0.42 (0.35) |
| $R^2$ | 0.100 | 0.141 | 0.294 | 0.106 | 0.139 | 0.299 |
| Observations | 701 | 704 | 250 | 701 | 701 | 660 |

1 All Regression specifications contain additional baseline control variables not shown in this table and include: Number of people women cook for centered and squared, Amount of money spent on Charcoal, Wood, and gas, dummy variables for women's and her husband's household income, and kilograms of both flour and rice consumed per week by household.

2 Additional Control Variables are the same as in footnote 1 with the addition of Total time spent by all the household collecting fuel. Sample is respondents reporting they or others in household collect fuel.

3 This is from the CO survey

4 A separate regression analysis replacing total household time (minutes/day) spent collecting fuel with only Women's time spent collecting fuel, the results (apart from Village FE's) remain insignificant. And as time spent collecting wood has a high variance due to some of our population collecting wood in stock we top and bottom code the time spent collecting fuel on the sixth month survey and rerun our regressions, but again they remain insignificant.

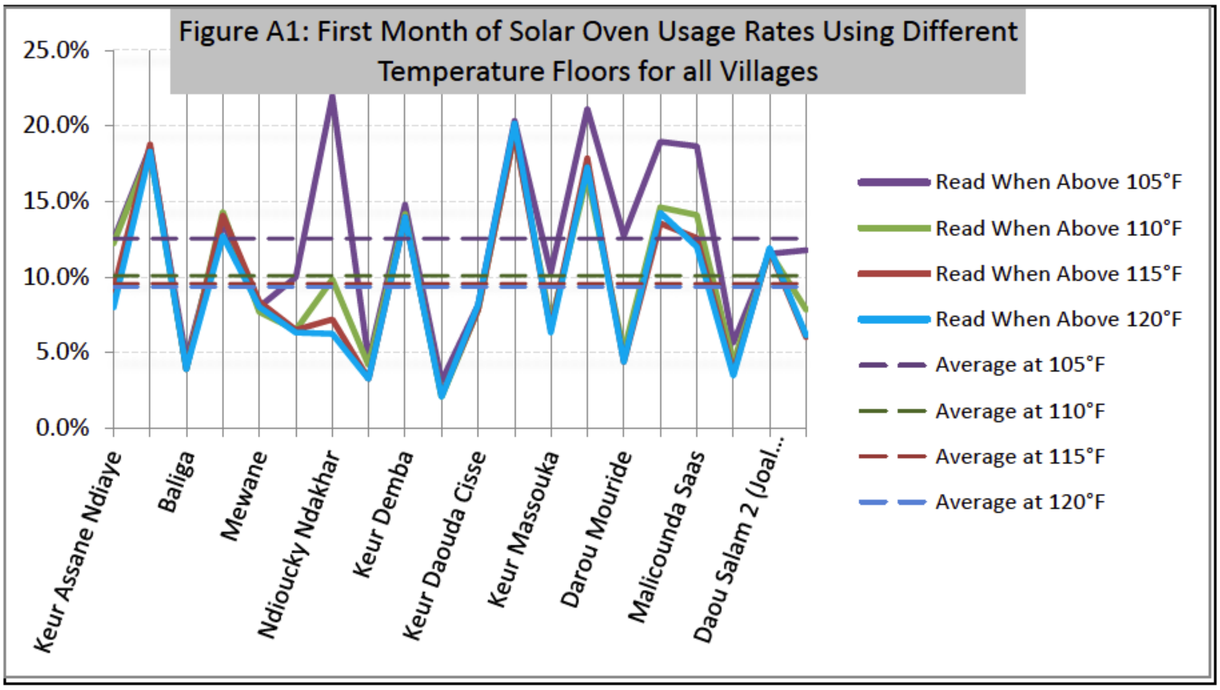
5 Because surveyors did not have a list of women's children at the six month follow-up to prompt women to report for the entire household it is possible that women did not report symptoms of ARI for all children present in the household. Thus, to avoid bias, we averaged all symptoms of all children reported per household to generate an "Average Child per Household" of ARI symptoms for all children 5 and under.

a This explanatory variable comes from the baseline survey

b This explanatory variable comes from the Six Month Follow-up

## Appendices

| Web Appendix 1: Testing for a Temperature Threshold to Indicate Stove Usage | | | | | |
|---|---|---|---|---|---|
| **First Month Usage of Stoves** | | | | | |
| | 105 degrees F and below | 110 degrees F and below | 115 degrees F and below | 120 degrees F and below | N |
| Average Time Period Measured- No. of days (median) | 24 | 24 | 24 | 24 | 457 |
| Average # of Uses (mean) | 2.61 | 2.24 | 2.1 | 2.02 | 457 |
| Daily Usage Rate | 10.9% | 9.9% | 8.8% | 8.4% | 457 |
| Average # of uses without Beach Villages(mean) | 2.58 | 2.2 | 2.05 | 1.97 | 418 |
| Daily Usage Rate without 2 Beach Villages | 10.8% | 9.2% | 8.5% | 8.2% | 418 |
| **6 Month Usage of Stoves** | | | | | |
| Average Time Period Measured-No. of days (median) | 25 | 25 | 25 | 25 | 438 |
| Average # of Uses | 5.11 | 4.76 | 4.74 | 4.77 | 438 |
| Daily Usage Rate | 20.4% | 19.0% | 19.0% | 19.1% | 438 |
| Average # of uses without Beach Villages(mean) | 5.47 | 5.1 | 5.09 | 5.12 | 396 |
| Daily Usage Rate without 2 Beach Villages | 21.9% | 20.4% | 20.4% | 20.5% | 396 |



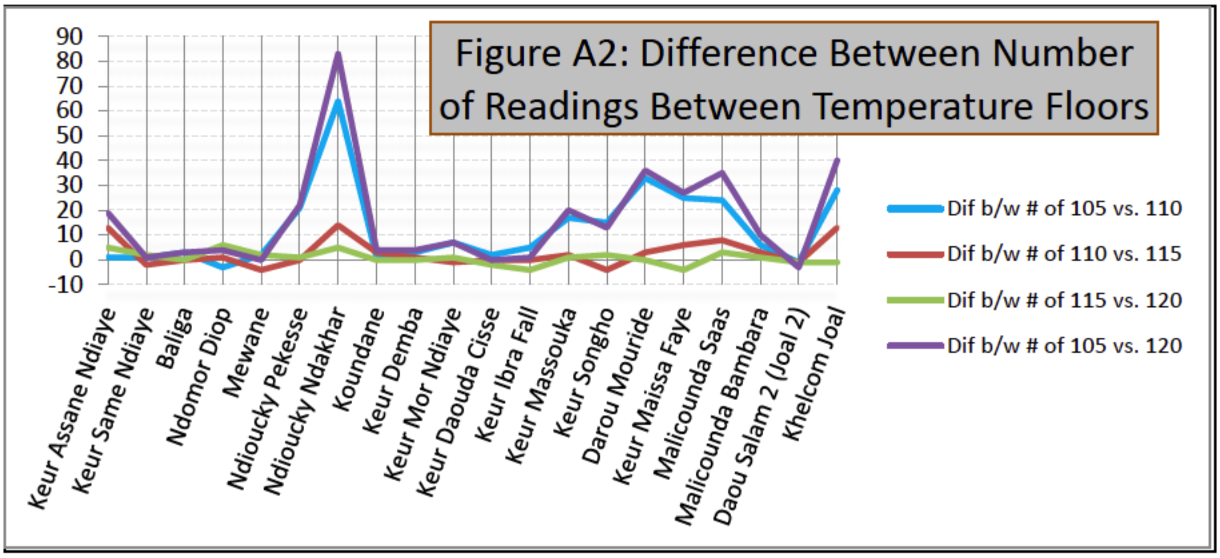


Figure A2: Difference Between Number of Readings Between Temperature Floors

From Figure A1 and A2 we see that the there are many more recorded uses of the solar oven when the temperature floor is 105°F versus any of the other three temperature floor. In particular, following the purple line in Figure A2 which indicates the total difference in readings between 105°F and 120°F, one can see that the difference between 105°F and 110°F (blue) accounts for most of this discrepancy. Given this we reject the105°F cutoff for a temperature floor reading indicating usage of the solar oven and choose 110°F as a cutoff. Results are reassuring that this threshold is robust as 110°F is highly correlated with recorded temperature movements of 115°F and 120°F, and hence more robust overall.

**Web Appendix 2: Regression: Follow-up Kg. of Wood used Yesterday**
**Instrumental Variable for 6 mo. Follow-up hhld size with Baseline hhld size.**

| | Model 1 2nd stage | Model 2 first stage | Model 2, 2nd stage |
|---|---|---|---|
| Outcome: | Kg. of wood used yesterday | No. People Cook for follow-up | Kg. of wood used yesterday |
| | Coefficient (standard error) | | |
| Cook for 6 persons or less for follow-up (instrumented)*Treatment indicator | -5.861 (2.64)* | … | … |
| Cook for 7-12 persons for follow-up (instrumented)*Treatment indicator | -1.60 (1.27) | … | … |
| Cook for 13 persons or more for follow-up (instrumented)*Treatment Indicator | 3.38 (1.23)** | … | … |
| Cook for 6 persons or less for follow-up (baseline group) | … | … | … |
| Cook for 7-12 persons for follow-up (instrumented) | -1.82 (2.88) | … | … |
| Cook for 13 persons or more for follow-up (instrumented) | -2.81 (2.69) | … | … |
| Village fixed effects | Yes*** | Yes*** | Yes*** |

| | | | |
|---|---|---|---|
| Lunch kg. of wood used at baseline | 0.34 (0.09)*** | 0.37 (0.10)*** | 0.43 (0.08)*** |
| Number of People Cook for baseline | | 0.88 (0.03)*** | |
| Number of People Cook for follow-up (instrumented) | … | | 0.06 (0.03)* |
| Constant | 9.19 (2.51)*** | 6.28 (1.39)*** | 6.28 (1.39)*** |
| F or t-statistic (Prob>F) | | 29.3 <0.001 | … |
| $R^2$ | 0.212 | 0.652 | 0.307 |
| Observations | 658 | 605 | 605 |

Notes: * p<0.05, ** p<0.01, *** p<0.001; Independent variables are compressed to the 5th and 95% percentiles and imputed when missing; Data is only for those who have completed the baseline survey.

a Other control variables included in Model but not statistically significant and thus not shown include Baseline amount of money spent last week on wood and charcoal; Baseline kg. of flour and rice consumed per capita per week; terciles of low, medium, and high salary for women and their husbands.

b This explanatory variable comes from the baseline survey. We instrument for # cooked for at the six-month follow-up with the # cooked for at baseline.

Instruments for model 1 included baseline values of cook for 6 or fewer, 7-12 or 13 as main effects and interacted with treatment.

**Web Appendix 3 : Probit Regression to test if Baseline Characteristics Jointly Predict Treatment**

Number of Observations=790
LR chi2(13) = 27.97
Prob > chi2 = 0.01
Log likelihood = -521.12887 Pseudo R2 = 0.03

| treat | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| Dummy woman's husband is self- employed | 0.06 | 0.11 | 0.54 | 0.59 | -0.15 | 0.27 |
| Woman's Salary per week | 0.00 | 0.00 | 1.89 | 0.06 | 0.00 | 0.00 |
| Husband's Salary per week | 0.00 | 0.00 | -2.35 | 0.02 | 0.00 | 0.00 |
| Dummy for woman is employed | 0.27 | 0.10 | 2.62 | 0.01 | 0.07 | 0.48 |
| Kg. per flour hhld consumes per week | 0.52 | 0.48 | 1.07 | 0.28 | -0.43 | 1.46 |
| Kg. rice hhld consumes per week | -0.21 | 0.25 | -0.85 | 0.40 | -0.71 | 0.28 |
| Roof Material Type | -0.01 | 0.02 | -0.34 | 0.73 | -0.05 | 0.04 |
| Household Decision Maker | -0.03 | 0.04 | -0.85 | 0.40 | -0.11 | 0.05 |
| No. of people women cook for | 0.02 | 0.01 | 2.33 | 0.02 | 0.00 | 0.04 |
| Kg. of wood used for the lunch meal | -0.01 | 0.02 | -0.41 | 0.68 | -0.05 | 0.03 |
| Total time preparing meals daily by fire | 0.00 | 0.00 | 0.65 | 0.52 | 0.00 | 0.00 |
| Total time preparing meals | 0.00 | 0.00 | -0.04 | 0.97 | 0.00 | 0.00 |
| Total time household collects wood per day wood lasts | 0.00 | 0.00 | -0.48 | 0.63 | 0.00 | 0.00 |
| Constant | -0.14 | 0.51 | -0.27 | 0.79 | -1.14 | 0.86 |

**Note:** Missing Values for explanatory variables are imputed to the mean

**Web Appendix 4: Regression:**

**Follow-up Kg. of Wood used Yesterday by Adult age equivalents**

| Coefficient (standard error) | y= Kg. of wood used yesterday [a,c] |
|---|---|
| Cook for Small (1.5 to 4.2) adult age equivalents) *Treatment Indicator[b] | -0.45 (0.20)* |
| Cook for Medium (4.4 to 7.3) Adult age equivalent*Treatment Indicator[b] | -0.07 (0.08) |
| Cook for Large (7.4 to 22.5) Adult age equivalent*Treatment Indicator[b] | 0.03 (0.06) |
| Small Adult age equivalent[b] | 0.33 (0.54) |
| Medium Adult age equivalent[b] | 0.18 (0.27) |
| Large Adult age equivalent[b] | 0.01 (0.14) |
| Village fixed effects [b] | Yes*** |
| Lunch kg. of wood used [b] | 0.42 (0.08)*** |
| Constant | 6.25 (2.89)* |
| $R^2$ | 0.307 |
| Observations | 641 |

Notes: ~ p<.10, * p<0.05, ** p<0.01, *** p<0.001; Dependent variables are compressed to the 5th and 95% percentiles and imputed when missing; Data is only for those who have completed the baseline survey. Adult age equivalents are defined as per the Atkinson *et. al*. (1995) index and in our sample Small (1.5-4.2 persons; N=197); Medium (4.4-7.3 persons; N=370); and Large (7.4-22.5 persons; N=203)All of the 157 households in the defined as Small in Adult age equivalents, 43% are households 7-12 HH are now in the "small household" category.

a Other control variables included in Model but not statistically significant and thus not shown include Baseline amount of money spent last week on wood and charcoal; Baseline kg. of flour and rice consumed per capita per week; terciles of low, medium, and high salary for women and their husbands.

b This explanatory variable comes from the baseline survey

c This explanatory variable comes from the Six Month Follow-up

| Web Appendix 5: Regression Results for Compounds with Two or more Study Participants[1] | | | | | | |
|---|---|---|---|---|---|---|
| Coefficient (standard error) | 1 | 2 | 3 | 4 | 5 | 6 |
| | Kilograms of wood used per day | Min. /day by cookfire | Min. / week HH gathers fuel [1] | Exposure to Carbon Monoxide (ppm/ hour) | Own symptoms associated with cooking (0-4) | Own respiratory symptoms (0-7) |
| No. people cook for is 6 persons or less *Treatment indicator 2 or more treatments in compound [a] | -0.04 (1.51) | 32.43 (46.20) | 9.36 (214.24) | 14.44 (6.15)* | 0.56 (0.64) | -1.56 (1.11) |
| No. people cook for is 7-12 persons *Treatment indicator two or more treatments in compound [a] | -1.64 (0.83)* | -41.08 (24.29) | 76.09 (112.65) | -4.53 (3.28) | -0.38 (0.34) | -0.45 (0.59) |
| No. people cook for is 13 persons or more *Treatment Indicator 2 or more treatments in compound a | 1.40 (0.82) | 10.30 (22.98) | -22.02 (106.58) | -1.07 (3.29) | -0.8 (0.32) | 0.42 (0.55) |
| No. people cook for is 6 persons or less [a] | ... | ... | ... | ... | ... | ... |
| No. people cook for is 7-12 persons [a] | 0.80 (1.29) | 29.70 (37.95) | 90.38 (175.98) | 1.28 (4.63) | 0.18 (0.53) | -0.69 (0.91) |
| No. people cook for is 13 persons or more [a] | 2.21 (1.28) | 14.62 (38.34) | 72.31 (177.83) | 0.47 (5.00) | -0.12 (0.53) | -2.06 (0.92)* |
| Village fixed effects [b] | Yes*** | Yes*** | Yes* | Yes* | No | Yes*** |
| Constant | 12.31 (1.29)*** | 208.34 (43.0)*** | 217.30 (199.42) | 11.55 (5.12)* | 3.26 (0.60)*** | 6.81 (1.04)*** |
| $R^2$ | 0.288 | 0.165 | 0.10 | 0.395 | 0.076 | 0.156 |
| Observations | 231 | 238 | 238 | 71 | 238 | 238 |

1 The sample here is all households which are part of a multi-study participant compound and consists of many different combinations of households. The Treatment indicator is an indicator with two treatments in the compound or more. Because the sample size is only for compounds with more than one study participant in the compound we limit the control variables in order to increase the degrees of freedom; a (b): This explanatory variable is from the sixth month follow-up (baseline) survey.

| Web Appendix 6: y= Baseline CO PPM/hour by Kitchen Type<br>Coefficient (standard error) | |
|---|---|
| Dummy Kitchen Type 1: Enclosed with No Windows | 0.08<br>(4.95) |
| Dummy Kitchen Type 2: Semi-enclosed with at Least One Window | … |
| Dummy Kitchen Type 3: Open Air with Thatch Roof | 5.62<br>(4.13) |
| Dummy Kitchen Type 4: Completely Open Air | -10.34<br>(3.07)*** |
| Dummy if Kitchen Type is Missing | 2.66<br>(2.65) |
| Constant | 23.03<br>(2.09)*** |
| $R^2$ | 0.042 |
| Observations | 176 |

Note: The Baseline CO ppm Measure has been topcoded for levels over 70 CO ppm and adjusted by the manufacture recommended humidity factor.

| Web Appendix 7: Baseline Summary Statistics Including Attrition Group | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total Sample | | Treatment | | Control | | Attrition Group | |
| | N | average | n | average | n | average | n | average |
| Average age for all household members | 10617 | 23 | 6512 | 23 | 4105 | 23 | 312 | 23 |
| Female | 5803 | 53% | 3607 | 54% | 2196 | 52% | 166 | 53% |
| Adults with no education | 7712 | 70% | 4751 | 71% | 2961 | 70% | 103 | 70% |
| Women enrolled in program with no education | 784 | 74% | 464 | 74% | 318 | 73% | 27 | 81% |
| Woman respondent is employed | 777 | 71% | 461 | 76% | 316 | 65%** | 27 | 77% |
| Among women employed their occupation is housework[1] | 197 | 84% | 105 | 84% | 92 | 84% | 27 | 84% |
| Woman's daily salary (US$)[2] | 419 | $1.86 | 269 | $2.02 | 150 | $1.56 | 13 | $1.31 |
| Woman respondent is self employed | 659 | 89% | 399 | 88% | 260 | 91% | 26 | 100%* |
| Husband is employed (only including women who are married) | 727 | 84% | 443 | 83% | 294 | 86% | 25 | 72%* |
| Among husbands' employed whose occupation is driver (includes both a taxi and horse drawn carriage) | 554 | 29% | 325 | 30% | 229 | 27% | 25 | 28% |
| Husband who are self-employed | 627 | 68% | 376 | 68% | 251 | 67% | 18 | 72% |
| Amount women report their husband's provide for them to purchase household items daily[2] (US$) | 605 | $3.28 | 362 | $3.10 | 243 | $3.54* | 18 | $3.24 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Average kg/week of flour the family consumes | 466 | $3.01 | 281 | $3.06 | 185 | $2.95 | 15 | $2.71 |
| Average kg/week of rice the family consumes | 770 | $3.08 | 456 | $3.17 | 314 | $2.95 | 27 | $3.44 |
| Percentage of household decision indicated as husband | 759 | 58% | 450 | 56% | 309 | 61% | 27 | 59% |
| Woman's house has tin roof (not straw, cement, slate, or tile) | 772 | 82% | 458 | 81% | 314 | 82% | 27 | 85% |
| Women's house has floor other than dirt (tile or cement) | 772 | 95% | 458 | 96% | 314 | 94% | 24 | 96% |
| Women's house has cement floor with carpeting | 705 | 75% | 413 | 78% | 292 | 71% | 24 | 54%* |

1. Many women consider domestic chores such as housework- employment, and thus we note a smaller percentage of women were actually employed outside the home than those who self-identified as employed.

2. This is only for woman (and women's husband's) who reported a salary. The U.S. Treasury Exchange rates is 436 CFA/$1 USD for the second quarter of the year of 2008.

3. Results from t-tests representing any statistical difference in baseline summary statistics: * p<0.05, ** p<0.01, *** p<0.001

4. The t-test is significantly different only between the attrition group and the control group and not the treatment group.

5. The t-test is statistically significant between the attrition group and that of the treatment group and that of the control group.