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Can Improved Biomass Cookstoves Contribute to REDD+ in Low-Income Countries?

Evidence from a Controlled Cooking Test Trial with Randomized Behavioral Treatments

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Abstract

This paper provides field experiment–based evidence on the potential additional forest carbon sequestration that cleaner and more fuel-efficient cookstoves might generate. The paper focuses on the *Mirt* (meaning "best") cookstove, which is used to bake *injera*, the staple food in Ethiopia. The analysis finds that the technology generates per-meal fuel savings of 22 to 31 percent compared with a traditional *three-stone* stove with little or no increase in cooking time. Because approximately 88 percent of harvests from Ethiopian forests are unsustainable, these findings suggest that the *Mirt* stove, and potentially improved cookstoves more generally, can contribute to reduced forest degradation. These savings may be creditable under the United Nations Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries. Because of the highly specific nature of the *Mirt* stove and the lack of refrigeration in rural Ethiopia, rebound effects are unlikely, but this analysis was unable completely to rule out such leakage. The conclusions are therefore indicative, pending evidence on the frequency of *Mirt* stove use in the field. The effects of six randomized behavioral treatments on fuelwood and cooking time outcomes were also evaluated, but limited effects were found.

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1. Introduction

Nearly half the world's population relies on solid fuels, such as wood and charcoal, for cooking (IEA, 2014). In Sub-Saharan Africa, however, 68 to over 90% of the population relies on biomass solid fuels (Rehfuess, 2006; Smith et al., 2004) and in Ethiopia, which is the focus of this paper, the percentage is over 90% (Beyene et al, 2013). To try to improve energy access, particularly for households currently relying on solid fuels, in 2011 the United Nations launched the Sustainable Energy for All Initiative.

A well-known consequence of this dependence is high levels of household air pollution exposures, especially for women and children (Smith et al., 2004). WHO estimates that 4.3 million people die prematurely every year due to these exposures, which is more than the 3.7 million total premature deaths attributable to ambient air pollution (Martin et al., 2011; WHO, 2014). All but 20,000 of these deaths are in low- and middle-income countries, with 3.6 million premature deaths in the Asia and Western Pacific regions and 580,000 in Africa. Ethiopia is estimated to be one of only four countries worldwide that simultaneously have highest levels of fuelwood consumption per capita, household air pollution disease burden and nonrenewable biomass utilization (Bailis et al, 2015).

This paper evaluates the performance of the *Mirt*[1] improved biomass cooking stove (ICS, see Figures 1 and 2) compared with the traditional cooking technology, which is a *three-stone* stove. The paper makes three contributions to our understanding of the economics of cookstoves. First, to evaluate the performance of the *Mirt* stove compared with the traditional cooking technology, we apply a rigorous evaluation methodology that allows us to estimate the per-meal *Mirt* ICS fuel savings when used by real people in real houses (instead of experimental kitchen conditions) to cook *injera*, which is the main staple bread in Ethiopia. Reducing fuelwood to cook *injera* is important, because it

[1] *Mirt* means best in Amharic language and has been promoted by the German aid agency GIZ since 1998. Our study is part of a larger research project that also includes analysis of *Mirt* stove use.

represents the end-use for a majority of fuelwood consumed in the country (Practical Action Ethiopia; Bizzarri, 2010).

Second, using a satisfaction survey our study examines whether people are likely to actually want to use the *Mirt* ICS and assesses the attributes users prefer. This CCT evidence on per-meal fuelwood savings and inferences regarding satisfaction allow us to shed significant light on the potential for ICS adoption to serve as an input-based REDD+ contract element. Finally, we analyze the determinants of fuelwood savings within this field experiment framework with a special emphasis on 6 randomized monetary incentive, price and networking behavioral treatments.

Concurrently with well-warranted concerns about the heavy reliance on biomass fuels in developing countries, climate change has emerged as an important environmental threat. Evidence published in March 2013 suggests that the earth is now on average hotter than about ¾ of the last 11,000 years (Marcott et al., 2013) and IPCC (2014) assessed with medium confidence that the period 1983-2012 was hotter than the last 1400 years. Based on ice core evidence, IPCC (2014) also estimates that the concentration of greenhouse gases in the atmosphere is now higher than at least the last 800,000 years (known for sure) and the rate of increase in the last century is unprecedented in the last 22,000 years (high confidence). As Martin Weitzman noted in a non-technical review, "An unprecedented and uncontrolled experiment is being performed by subjecting planet Earth to the shock of a geologically instantaneous injection of massive amounts of greenhouse gases." (Weitzman, 2011)

A critical part of the international response to the climate change threat is the UN Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation (REDD+), which is seeks to mobilize finance from the developed countries for developing countries like Ethiopia to fund measurable reductions in deforestation and forest degradation. These reductions represent potentially important climate change contributions, because deforestation and forest degradation account for between 12% and 20% of annual CO_2e emissions. In the 1990s, largely from the developing world, forests released about 5.8 Gt per year, which was more than all forms of transport combined (Saatchi et al., 2011; van der Werf et al., 2009). Bailis et al. (2015) estimate that worldwide emissions from fuelwood are approximately 1 Gt CO_2e per year.

In general, the drivers of deforestation in low income countries like Ethiopia are varied and often have proximate and underlying causes (van Kooten and Bulte, 2000), with land use change considered to be the major one (Angelsen and Brockhaus, 2009). But, there are still debates on the contribution of firewood usage to deforestation. For example, some question whether collecting firewood does not lead to deforestation and forest degradation (Arnold et al. 2006), while others point to it as a key driver, mainly in Africa (Kaimowitz & Angelsen, 1998). The literature also suggests that the causes of forest biomass loss vary by region. Based on an analysis of a wide range of case studies in tropical countries, Geist & Lambin (2002) find fuelwood harvesting to be an especially important cause of deforestation in Africa. Accounting for about 87% of the country's final energy consumption (Gebreegziabher and van Kooten, 2013), fuelwood likely constitutes the most important cause of deforestation in Ethiopia.

Perhaps complicating efforts to reduce deforestation, about 25% of these developing country forests are in some way community controlled (Bluffstone and Robinson, 2013) and in most cases in these forests fuelwood is unsustainably harvested and therefore a source of net CO_2 emissions; this is largely the case in Ethiopia, where an estimated 88% of forest harvests are nonrenewable (UNFCCC, 2012). If forests are indeed such a significant source of greenhouse gas emissions and unsustainably harvested community forests are a large part of world forests, it is difficult to imagine credibly addressing climate change without explicitly addressing the opportunities and challenges associated with bringing community forests into REDD+.

Because monitoring and verification of carbon sequestration can be challenge in such settings, there is an interest in input-based REDD+ compliance measures for which impacts can be reliably estimated. Improved cooking technologies that are appropriate and use less fuelwood is one class of measures. No less compelling, however, is the potential for immediate benefits to households from less indoor air pollution and reduced fuelwood collection time.

Shifting to alternative energy sources is certainly the end goal, but reliance on biomass fuels is likely to continue for the vast majority of people in Sub-Saharan Africa. Commercial energy options, such as natural gas, LPG and electricity, require major public infrastructure investments, supply chain development and purchase of expensive stoves. From the household perspective, these fuels and technologies are extremely expensive and typically unreliable in supply.

ICS technologies that use less biomass have therefore received significant attention as important intermediate technologies (Jeuland and Pattanayak, 2012), most of which use fuelwood, the most important biomass fuel. ICSs have important advantages, because they typically do not involve sophisticated technologies and may require only minor changes in household cooking habits. These important features can make them very attractive if meals can be cooked with less wood, ICSs are adopted and subsequently regularly used by households.

The Federal Government of Ethiopia is promoting the use of ICS as a key part of its REDD+, environmental and health agendas. Though activities are just beginning, the government has declared its intention to distribute 9.4 million stoves within five years. Achieving this goal would imply that roughly half the households in Ethiopia would use improved biomass stoves. Most of these stoves designed to more efficiently cook *injera*.

The *Mirt injera* stove, which is currently being promoted in Ethiopia and is the focus of this paper, has been found to save fuelwood under laboratory conditions (Megen Power Ltd, 2008) and using survey methodologies (Dresen et al., 2014), but its performance in the field using field experimental approaches common in the impact evaluation literature (Duflo et al, 2008) has not yet been fully evaluated. Moreover, while it is believed to be better from a technical perspective in terms of fuel consumption, its strengths and disadvantages from the user standpoint are not well understood; there is, therefore, no guarantee that on the balance households will find them to be "improved." Households therefore take on risk and potentially incur costs when they adopt the *Mirt* stove, costs that could be compensated under REDD+.

Our paper presents results from two rounds of controlled cooking tests (CCTs) with randomized behavioral treatments and presents evidence on user satisfaction. A total of 108 individuals, who are the primary cooks, participated in 4 CCTs, two in May/June 2013 and two in October/November 2013 using both *Mirt* and traditional cooking technologies (a total of 432 tests). These individuals come from Amhara, Oromiya and Southern Nations, Nationalities and Peoples Regional States in Ethiopia. These regions include over 75% of the country's population and a similar share of forest area. Respondents are randomly drawn from a 360 household randomized treatment trial (see Section 3 below for more discussion). The satisfaction survey covered all 360 randomly sampled treatment households and was conducted in October/November 2013 (5-6 months after households received *Mirt* stoves).

The paper is organized as follows: the next section discusses key improved cookstove literature. Section 3 presents the experimental methodology and Section 4 presents results, including evidence from the field that on per-kilogram food cooked and per-meal bases the *Mirt* stove saves fuelwood. The last section concludes and draws implications for REDD+.

2. Key ICS Literature

Policy momentum behind improved biomass cookstoves was very strong through the 1980s as concerns about deforestation and impending shortages of fuelwood built under the heading of the firewood crisis (e.g. Foley and van Buren, 1980). The optimism for improved stoves is reflected in a veritable flood of grey literature reports and guides that promoted improved cookstoves (e.g. Shaye et al, 1984; Borthwick and Howard, 1988). *Ex post* program evaluations were often lacking by modern standards (e.g. Bluffstone, 1989; Wood, 1983; 1987), however, and were often done by organizations actively promoting such technologies.

By the 1990s the urgency of the fuelwood crisis had died down as it became clear that market adjustments could reduce potential crises (Bluffstone, 1995) and criticisms were widespread (Manibog, 1984; Gil, 1987; Jones, 1988). Barnes et al (1993), for example, argue that a key reason for disappointing results was that fuelwood savings had typically been overestimated. More recently, Mobarak et al (2012) argue that improved cookstoves are adopted and used at puzzlingly low rates because users - particularly women - do not perceive indoor air pollution as a significant health hazard. They therefore prioritize other needs over ICS adoption and are not willing to pay much of ICS. They emphasize designing and disseminating ICS with features that are highly valued by users, such as reduced operating costs.

The importance of the almost 3 billion people who cook with wood on a regular basis remains, however, and in recent years improved biomass cookstoves have regained traction as a potential solution to important problems. Of special significance is the Global Alliance for Clean Cookstoves, which was founded in 2010 and seeks to foster adoption of clean cookstoves and fuels by 100 million households by 2020.

Contemporary improved biomass cookstove programs may be different from the past in important respects. Perhaps the most important reason is that the *raison d'être* has largely shifted. In the 1970s – 1990s the focus was on fuelwood shortages, but this has changed to an emphasis on the pollutants emitted by cookstoves (Jeuland et al., forthcoming). Of particular interest are effects of biomass dependence on indoor air quality, greenhouse gas and black carbon emissions (e.g. Smith et al, 2007; Grieshop et al, 2011; Hanna et al, 2012).

Second, additional financing mechanisms are increasingly in play (Lewis and Pattanayak, 2012). About a quarter of stove programs in 2010 indeed received or were planning to receive voluntary carbon market or CDM resources. Improved cookstoves are now also typically sold to users for full or subsidized cost rather than distributed free (Gifford, 2010).

Finally, early evaluation methods have in some cases been replaced by more rigorous approaches, including randomized distributions of improved cookstoves with traditional stove controls. Using a CCT method that is similar to the one used in this paper, Burwen and Levine (2012) evaluate a locally made and designed wood burning cookstove in Ghana. They find that the stoves on average reduce fuelwood to cook a standardized meal by 12%. Using electronic stove use monitors they also find that in general the stoves were used very frequently.

Bensch and Peters (2013) conduct an ex post evaluation of the Jambar charcoal stove promoted by the German bilateral aid agency GIZ in Senegal. They run CCTs in which cooks make typical dishes and evaluate outcomes empirically, which is similar to the approach we use in this paper. Using OLS with and without propensity score matching, they find that the Jambar stove reduces charcoal to cook typical meals by 25% compared with traditional (Malagasy) stoves.

In a free randomized control trial also in Senegal, the same authors find that fuel saving per meal cooked on the Jambar stove compared with a control group is even higher at 48%. They also find a suite of co-benefits associated with the virtually 100%

use of the stoves, including fewer eye infections and less cooking time (Bensch and Peters, 2012).

Thakuri (2009) evaluates a customized improved wood burning stove and vent hood in a sample of 400 Nepali households. Though the data are observational and firewood consumption was based on 24-hour respondent recall, he estimates that improved cookstoves use 42% less wood than traditional stoves. Also based on reported data is Nepal et al. (2010), who use the nationally representative 2003/2004 Nepal Living Standards Survey to estimate the effect of improved stove use on fuelwood consumption. Using OLS, 2SLS and village level fixed effects, they conclude that user-identified ICS do not reduce fuelwood use. Evaluations of other stoves find fuelwood reductions (e.g. Johnson et al, 2009; Smith et al, 2007; Masera et al, 2007), but mass-produced brands are found to use only about 1/3 less than traditional stoves (Adkins et al., 2010).

The *Mirt* stove has been promoted in Ethiopia since 1998 by the German aid agency GIZ. It was originally developed in the early 1990s by the cooking efficiency and new fuels marketing project, under the Ethiopian Energy Study and Research Center (EESRC) in Addis Ababa. Initial laboratory tests of the stove showed up to 35% fuel savings compared to the open fire tripod (Bess and Kenna, 1994). Further refinements yielded increases in savings of 50% compared with the open fire tripod (Gebreegziabher et al., 2012).Moreover, in 2005 GIZ introduced a less massive version in order to reduce input requirements while maintaining the stove’s efficiency.

By 2011 approximately 455,000 stoves had been commercially distributed (GIZ-ECO, 2011) and a project impact study was conducted. The impact study focused on a variety of program aspects, including producers trained, cumulative sales and stove uptake by region (Megen Power, 2008). They also present case study vignettes of producers and users and evaluate fuelwood savings. The method to assess fuelwood savings is similar to the approach of Thakuri (2009), which is reminiscent of earlier evaluations that relied on observational data and user-reported savings with no control group. They find that *Mirt* stoves offer fuelwood savings of 50%.

3. Experimental Methodology

3.1 Sampling and CCT Implementation

The data for our analysis were collected from 36 villages randomly selected from Amhara, Oromiya and Southern Nations, Nationalities and Peoples (SNNP) Regional States. The number of villages from each regional state included in the sample was determined based on the forest cover of each state. These regional states represent about 80% of Ethiopia's population and over 70% of the land area.

Fourteen households from each village were randomly chosen to participate in the study, giving a total of 504 sample households. Of the 14 randomly selected sample households per village, 10 were randomly assigned as treatment households to receive a *Mirt* stove and 4 were identified as controls. Three households from each treatment group in each village were randomly selected to participate in CCTs. After receiving informed consent, the CCTs were conducted for both *Mirt* and traditional three-stone stoves in users' kitchens by household cooks without any direction other than initial orientation (all in-home, some in group as well) from enumerators. Because of the field setting and the use of standard, local fuels and cooking materials, we expect cooks to behave during CCTs as they would under day-to-day real-life conditions.

As cooks are observed during the CCT, it is possible that they might behave differently than when they are not observed. This is the so –called "Hawthorne" effect in which outside interventions change respondent behavior. What is most important for our case, though, is that in each study period the cooking task is performed identically and is equivalently observed when the CCT is done on the *Mirt* and the traditional stoves. As the measured effect is the difference between these two CCTs in the same household, we see no reason that a Hawthorne effect would bias the results

Using this approach, households receiving the *Mirt* stove act as their own controls on the same day when the CCT is conducted on their traditional stove. That is, the counterfactual situation is simulated by making the same person prepare a meal on the traditional stove and the ICS. Such an approach avoids the need to assess differences in performance across households or across time, both of which can introduce confounding factors.

The first round of CCT data was collected in May and June 2013.The second round CCT and the improved stove use satisfaction survey were undertaken during October and November 2013. A total of 25 fieldworkers (5 supervisors and 20 enumerators) hired by the Environmental Economics Policy Forum for Ethiopia (EEPFE) at the Ethiopian Development Research Institute (EDRI), which is one of the most important federal government policy research institutes in Ethiopia, were trained to assemble, set up and use the *Mirt* stove, as well as conduct the CCT. All had prior experience in field survey research and spoke the dominant local languages.[2] Five teams consisting of 1 supervisor and 4 enumerators were deployed, each covering 7 villages, except one that covered 8. A brief questionnaire was prepared and used for the stove use satisfaction survey (see Appendix C). The German international aid agency GIZ, an important stakeholder in household energy and stove dissemination, provided a half-day training on CCT procedures and implementation to the fieldworkers.

We use a standard CCT implementation protocol discussed in Bailis et al., (2007). This protocol was chosen, because it allows us to compare traditional and improved stove fuel consumption and cooking time under field experiment conditions. The details of the measurement protocol are available at http://www.aprovecho.org/lab/pubs/testing. Our adaptation of the protocol for Ethiopian conditions is provided in Appendix A.

The CCT involved purchasing *teff*, which is the essential ingredient for baking *injera*. This was purchased either in flour or grain form. If it was in grain form it had to be ground and the flour provided to participants three days before the CCT so that they could prepare the dough. Participants were provided homogenous and equal quantities of all ingredients, which included eight kilograms of *teff* flour; 4kg for baking on the traditional three-stone stove and 4kg for baking on the *Mirt* stove. These amounts were derived from focus groups conducted prior to beginning the research and are believed to be typical of the *injera* dough cooked by a typical family at one time.

The team also supplied fuelwood for cooking that was similar in type across households. These resources not surprisingly differed across regions, but the CCT protocol adjusts for wood species and moisture content, which was measured using

[2] Ethiopia is a multi-lingual country with over 80 languages. The fieldwork required that the enumerators are able to speak the dominant local/official languages in the study regions, i.e., Amharic and Oromiffa.

moisture meters. Household cooks were identified based on who does most of the cooking in the household and the cooking was done with no input or prompting from enumerators. The CCT was supported by two field assistants to ensure high quality.

3.2 Information Provided to Respondents and Behavioral Treatments

Prior to seeking informed consent, participants were told that they were chosen randomly to receive a stove under the same terms as others in their village and were informed about the terms. They were informed about the purpose of the study and they knew why they were observed during the CCTs. Participants were provided with full information on stove features and they were aware of the expected fuel savings associated with the *Mirt* stove.

These terms (i.e. the behavioral treatments) were randomized at the village level, with sample villages assigned into six treatment groups. Thus, one treatment is randomly assigned to 6 villages, implying that 6 villages received the same treatment. All sample households in one village received the same treatment. Descriptions of the attributes making up the six treatments are provided in Appendix D. There were three aspects to each treatment, with only two levels of each aspect (present or absent) divided equally so one-third of all sites received each treatment aspect. These aspects are: 1) payment for stove use; 2) cost of the stove and 3) networking.

Separately from the CCT, respondents were also informed that if they agreed to participate, their stove use would be monitored using stove use monitors (SUMs) and that enumerators would come back to their houses to download data. As the SUMs results are discussed in detail in Beyene et al. (2015) and are not used in this paper, we very briefly cover this part of the research. Respondents were informed that SUMs would be placed on the stoves by enumerators, the device records the temperature of the stove and respondents were requested not to touch these temperature loggers. If they were moved, respondents were asked to put them back on the same spot using the provided heat resistant tape. Respondents were informed that the SUMs are safe at reasonable temperatures, but they are potentially unsafe if they are put in or very close to fires, because they have flammable components. If SUMs fall in the fire, they were told to remove them immediately and after they are cool replace them on the stove with the heat resistant tape.

In the first treatment aspect sites were randomly chosen to receive a 50 Birr payment if the SUM devices indicated that *Mirt* stoves were used at least twice per week during the first monitoring period. The 50 Birr payment was made after checking the recorded SUM data at the end of the first round (about 6 weeks after installation of the SUM device). This treatment aspect tests the hypothesis that use incentives increase fuelwood savings in a manner similar to Charness and Gneezy (2009).

The second treatment aspect is cost. One-third of the sample paid 25 Birr for their *Mirt* stoves and the remainder received their stoves for free. This is about 13% of the real stove cost. This treatment aspect tests the same type of hypothesis examined by Cohen and Dupas (2010) that those who pay for their stoves get better outcomes.

The final treatment aspect is the network component. Network refers to formally informing households about who else in the site received the stoves and providing group training. One-third of respondents therefore not only received in-home training, but also were brought together with others in their village for a meeting with supervisors. The 10 villagers receiving the network treatment aspect in each of the 12 villages were assembled in a common area in the village. Participants also had the opportunity to ask questions. This treatment aspect tests whether making those who received *Mirt* stoves aware of each other in a formal setting and allowing users to learn from and potentially network with each other increases fuelwood savings.

To test this randomization of our treatments we use wealth variance in forest user groups, existence of forest rules and regulations and percent of biomass change over 5 years. These variables/indicators are at the community level, which is the level of our randomization. Using Kruskal-Wallis tests we find no statistically significant differences in these important indicator variables across our sites. Test results are provided in Appendix E.

3.3 Empirical Methodology

To analyze the fuelwood use per-kilogram food cooked and the per-meal cooking time data we use two-sample t tests, often referred to as a "paired" or "paired difference" test (Zimmerman, 1997). This is a method widely used to examine the effect of interventions. It is a hypothesis testing procedure for answering questions about means when data are drawn from two random samples of independent observations or from the same sample with repeated observations. In our case we have the same households participating in both rounds and each time participating in CCTs for both *Mirt* and traditional stoves. This statistical method is in principle very appropriate, though it is a parametric test and assumes an underlying normal distribution.

We run normality tests for the two outcome variables. Because fuel consumption is non-normally distributed, we augment the two-sample t test with the non-parametric two-sample Wilcoxon rank-sum (Mann-Whitney) test (Wilcoxon, 1945). These results are very similar to those from the paired difference tests and are included in Appendix B. We also analyze the determinants of fuelwood savings using regression analysis. Since we expect that the error terms for households in the same village might not be independent, we cluster standard errors at village level.

The variables related to household and cook characteristics, including age, marital status, education and occupation of cook, and family size, are obtained from a household survey conducted shortly after the *Mirt* stove was made available to respondents. Variables generated from the CCT include specific fuelwood savings, changes in cooking time and environmental factors, such as ambient temperature and wind conditions at the cooking site during the CCT. Both groups of variables are included as controls in the regression. Summary statistics of variables used in the regression are provided in Appendix F.

4. Results

4.1 Stove Performance

To evaluate differences in fuelwood to cook the standard quantities of *injera*, we carry out three two-sample t tests. The first test utilizes the pooled data (i.e. for the two rounds together). The second test is by round and the third is by region.

As shown in Table 1, using the pooled data we find that the *Mirt* stove on average uses 291grams less fuelwood (26%) per kg of food cooked than traditional stoves and this result is statistically significant at much greater than the 1% level. Results are similar when disaggregated by round, but we also detect a potential experience effect, because savings increase across the two rounds. While in the first round we find a mean fuelwood difference of about 227 grams (22%) per kg of food cooked ($p = 0.04$), in round 2 (5-6 months later) we find a mean difference of about 353 grams, which is about a 31% fuel savings ($p = 0.0019$) compared to the traditional stove (see Table 2). In the first round CCT the cooks use the *Mirt* stove without having any prior experience with the stove. We therefore believe the difference in fuel savings across rounds is attributable to repeated use of the *Mirt* stove during the intervening period, which allowed households to become familiar with the new stove and enabled them to use it more effectively.

The two-sample t tests by region show that the mean differences are statistically significant in the case of Amhara and Oromiya regions, but insignificant for SNNP (Table 3). In Amhara and Oromiya the statistically significant fuel savings from the *Mirt* stove are 24% and 26%, respectively ($p = 0.0015$ and $p = 0.01$). Our results therefore suggest that fuel savings can vary by region.[3]

Table 4 presents the two sample paired t test results for cooking time using the pooled data. The CCT mean total cooking time for the *Mirt* stove is greater than for the three-stone tripod stove by 7.13 minutes and this difference is statistically significant at greater than the 1% level ($p = 0.0059$). In the pooled sample, therefore, the *Mirt* stove appears to require more cooking time than the traditional technology.

Breaking the pooled data down by round, however, adds substantial insight. We find that the pooled data mean difference in time is driven largely by the first round data, which has a highly statistically different mean cooking time of 12.38 minutes ($p = 0.0028$). In the second round, after cooks had experience with their *Mirt* stoves, the cooking time was still greater, but a much smaller 2.14 minutes, which was not statistically significant ($p = 0.49$). We believe this difference across time again suggests a learning effect.

[3]As noted in the methods section, cooking time is normally distributed, but the distribution of fuel use is not. We therefore conduct non-parametric two-sample Wilcoxon rank-sum tests. All the tests reveal that means are significantly different from zero. For details see Appendix B.

4.2 Stove Satisfaction

During the satisfaction survey respondents were asked to rank the new stove using a five point Likert scale for each of the attributes listed in Appendix C. In contrast to our CCT, the satisfaction survey is based on reported rather than measured data and we cannot be sure that all respondents answered objectively, accurately and truthfully. The results below are therefore best viewed in broad rather than precise terms. For example, if only 15% of respondents said they liked a particular attribute, we can be confident the attribute is not popular, but after purging biases the popularity may be greater or less than 15%.

With these caveats, as shown in Table 5 we find that virtually 100% rate the *Mirt* stove as good or very good and over 80% of respondents give the *Mirt* stove the most positive ranking possible (very good). The same is found to be true for several attributes, but especially reduction of smoke (85% ranking very good and 14% good) and convenience to use compared with the traditional stove (83% very good and 16% good). No more than 10% of respondents ranked any attribute below good, suggesting that in virtually all respects respondents say they like and prefer the *Mirt* stove.

Respondents were also asked if they would take the new stove if they needed to buy it at the current market price, which is between ETB150 and 200 ($8.00 - $12.00). Perhaps surprisingly, about 90% of sample households said that they would buy it even if they had to pay full price.

Respondents were also asked if they would recommend that their neighbors buy the *Mirt* stove. As shown in Table 6, about 75% said they would advise neighbors to buy the stove at full price. Substantial minorities would also suggest that neighbors take the stove if they were given freely (23%) or subsidized (27%). Only 4% said they would not recommend the *Mirt* stove to neighbors. There appears to be significant discussion of the *Mirt* stoves, because about 90% of respondents said they had given others advice regarding the use of the new stove and 42% had received advice.

To gauge the strength of preferences we asked respondents to rank their top three attributes. As shown in Table 7, reduced fuelwood consumption and less smoke (indoor air pollution) turn out to be the attributes most preferred by households. Among attributes that households ***least*** valued, the top choice by a wide margin (69% of respondents) was reduction in cooking time. This finding is perhaps not surprising given that if anything the *Mirt* stove increases cooking time.

As respondents seem to value less smoke the most, we investigated the intensity and distribution of these respiratory health benefits. As shown in Table 8, we see that over half the sample indicated that respiratory discomfort was less or much less with the *Mirt* compared with the traditional three stone stove. Among those who responded, though, as highlighted in Table 9, women, children and men are the first, second and third most important beneficiaries of reduced smoke.[4]

Most respondents agree that *Mirt* stoves reduce fuelwood collection and cooking time. For example, about three-fourths of households report cooking time savings. This result is puzzling and illustrates the difficulties in using reported data about time use, because measured time on average is more for the *Mirt* stove.

Only 4% of respondents say they did not use the improved stove for *injera* baking, though more than half also used it for cooking unleavened *kita* flatbread. Most households are therefore found to use the *Mirt* stove for its intended purpose. Fuelwood is the main cooking fuel (87%), but another 11% use dung and very few households use other fuels.

About 88% of respondents have a second stove and almost all of these are three stones. Approximately ¾ of those cooking with three stone stoves in addition to their *Mirt* stoves say that they use it for making stews, coffee and breads like *kita*. *Mirt* stoves are primarily designed for *injera* baking, but as shown in Figure 1 in the previous section, the *Mirt* stove offers the opportunity to use waste heat before it exits up the chimney. Around 84% of respondents say they use the chimney side of the stove for cooking activities, such as coffee making, cooking stews and boiling water. Most of the households say they use the *Mirt* stove 1-3 times a week for baking (85%) and in each session the majority (66%) of respondents say they bake 11-20 *injera* or less per session. Another 18% made 21 to 30 *injera* per session; these amounts represent food for two to four meals for a typical family.

[4] About 41% of the sample for some reason did not respond.

4.3 Determinants of Fuelwood Savings

We now present our analysis of fuelwood savings by combining household survey and CCT data. We employ robust pooled OLS, with errors clustered at the village level. We provide regression estimates with and without treatment variables. Results are presented in Table 10, with the dependent variable fuelwood savings (i.e., the difference in fuel consumption between traditional and *Mirt* stoves normalized by 100).

We include both linear and squared weight of final food cooked (i.e. weight of the *injera* baked) to control for possible nonlinear scale effects and results suggest significant diseconomies of scale of the *Mirt* stove. At the mean the first order elasticity of fuelwood savings with regard to food cooked is about -3.94.We also find that older, married cooks who primarily do non-household work enjoy more savings from the *Mirt* stove than others and that cooking under calm wind condition results in more fuelwood savings. We control for cooking time, because slow cooks may use more wood, but find no effect. Regional state also appears to be a significant determinant of fuelwood savings. Households in SNNP save less fuelwood than those in Oromiya and Amhara.

We analyze the effect of the randomized treatments on fuelwood savings by including dummy variables for each treatment, with treatment 5 (no payment, no use incentive paid and no network aspects) as the omitted category. Only treatment 2 has a statistically significant effect (positive), suggesting that providing incentives for using improved stoves along with network building and group training may increase fuelwood savings. That said, that other treatments have no statistically discernable effects suggest that the behavioral treatments are not important for per meal fuelwood savings.

5. Conclusions and Implications for REDD+

This paper analyzes the role that biomass cookstoves designed to be cleaner and more fuel-efficient might play in a REDD+ program through reduced fuelwood use and increased carbon sequestration. We utilize random samples from Ethiopia regional states that include about 80% of the country’s population of over 90 million. We therefore believe our results are representative of and applicable to most of this very important country. In addition to contributing to the academic literature on the fuelwood savings of

ICS, we also assess cooking time, user satisfaction and the effects of randomized contract terms (i.e. behavioral treatments) on outcomes. We believe these aspects are important contributions that move the literature forward.

We draw inferences from two rounds of CCT data and find that while the fuelwood savings are not as much as advertised, they are substantial and statistically significant. Because improved stove use has typically been such a barrier to success of improved cookstove programs, we also use a satisfaction survey to evaluate whether the *Mirt* stove is likely to actually be used.

Our CCT results suggest that *Mirt* cookstoves reduce fuelwood use by 22% to 31% compared to traditional *three-stone* stoves, which is similar to other results in the literature. Using the pooled data, the average 26% reduction implies savings of about 0.3 kg of fuel per kilogram of food cooked. This estimate only considers *injera*, though *Mirt* stove users also use the chimney side of the stove to cook other foods. We do not consider this in our analysis as these secondary benefits are not part of our CCT protocol.

We acknowledge that taking these estimates as the net benefit of using the *Mirt* stove to cook a meal supposes limited leakage in which households do not fully substitute the ICS for the traditional technology. That said, three features of the Mirt stove mitigate leakage. First, the Mirt stove is highly specialized for *injera* baking, which makes it very unlikely that it will be shifted to other uses. As shown in Figures 1 and 2, for example, the cooking area is very large and is not designed for use with small pots. Waste gases can be utilized to cook stews and coffee, but the stove is designed for this to be done in conjunction with *injera* baking.

Second, we find that the Mirt stove is on average used 2-3 times per week, which is a very traditional and extremely typical interval for *injera* baking in areas without refrigeration. It is therefore very likely that on average most if not all *injera* baking (but perhaps not all <u>cooking</u>) is done on the Mirt stove.

Finally, it is very unlikely that any increase in real income due to Mirt stove adoption would be realized as significant increased cooking. Our study areas do not have refrigeration, so households that cook *injera* must eat them within one to three days to avoid possible bacterial infection. It is, of course, possible that as real income increases, households over time are able to add extra coffee or stews (typically eaten with *injera*) to their diets or marginally increase their *injera* consumption. These effects – due to the nature of the cuisine and the *Mirt* technology - are expected to be very limited, however, causing us to not be overly concerned with leakage.

What factors determine fuelwood and time savings? First, over time – possibly as cooks gain experience - they cook meals more quickly and use less wood. Additional analysis is needed to evaluate whether wood savings stabilize at 31% or if they increase further over time, because it could imply that the 26% average savings is too conservative.

Second, our analysis highlights the importance of regional variation. In relatively forest-rich SNNP Regional State during the CCT we detect fewer wood savings, while gains are observed in Amhara and Oromiya. We are only speculating when we mention forest quality as a potential explanation, however, and additional research is needed. Fuelwood savings are also affected by the quantity of food cooked, characteristics of cooks and the cooking environment. Concerning the treatment variables, we find no systematic effect on fuelwood savings. Finally, our satisfaction survey suggests that people like the *Mirt* stoves and want to use them. We find that reduced smoke is a particularly important *Mirt* stove attribute.

What might these findings mean for carbon sequestration and user incentives? In this paper we estimate the fuelwood saved per kilogram of food cooked, which is largely determined by the (fixed) amount of *teff* flour provided, and we do not know the actual amount of *teff* flour used in uncontrolled cooking events. Though based on focus group results we believe the amount of *injera* dough cooked in the CCT to be typical, in reality carbon savings are dependent on the actual quantity of food actual cooked and the cooking frequency; the more food that is typically cooked during each event and the more frequently the *Mirt* stove is used, the larger will be the savings. We therefore view carbon savings results as indicative and suggest necessary extensions.

Typically, half of wood biomass is estimated to be carbon (Pearson et al, 2007; MacDicken, 1997). If we use the UNFCCC (2012) default percentage of nonrenewable biomass of 88%, each year the *Mirt* stove could reduce carbon emissions by about 528,000 tons if 9.4 million units were in service. This amount of carbon is equivalent to about 1.938 million tons of CO_2, which is the metric used in carbon markets. At the May

2015 California auction price of $13.93 per ton,[5] this carbon would be worth about $27 million per year or $3.00 per household. At the voluntary carbon market price of $6.00 per ton these savings would be worth about $11.88 million or less than $1.50 per household per year.

Unless households use the *Mirt* stoves more intensively (e.g. by cooking more than the four kilogram of *teff* flour provided in the CCT), the carbon benefits generated – even if fully compensated at market prices – cannot drive adoption and use if households are motivated purely by financial benefits. Households must therefore also find the stoves to be appropriate for their private needs. In other words, <u>*Mirt* stoves must offer users significant private non-carbon finance benefits if they are to be enticed to use them</u>.

Our results suggest that such additional benefits exist. People seem to like the stove, which likely implies that in the field the stoves are regularly used, and reduced fuelwood consumption and less smoke are the most important services. Most participants even say they would buy the new stove at the full market price and would recommend that their neighbors do the same. There appears to be significant discussion of the *Mirt* stoves, because about 90% of respondents say they gave others advice about the new stove and 42% had received advice. This is also interesting from the perspective of how to implement promotion programs, because it might be enough to teach people and allow others to get recommendations from others.

Respondents note that respiratory discomfort is much less with the *Mirt* stove than the traditional one and they say that women and young children are the prime beneficiaries. The smoke benefit requires more detailed examination, however, particularly as it is not only an inconvenience, but also a major human health hazard. Remaining is to actually measure any reductions in indoor air pollution and draw potential inferences for economic outcomes and human health.

Much better than asking respondents how well they like the *Mirt* stove is to document through measurement that they use them frequently enough that they probably are not cooking *injera* on more than one stove. Such analysis would provide evidence

[5] See http://www.arb.ca.gov/cc/capandtrade/auction/may-2015/summary_results_report.pdf downloaded May 29, 2015.

regarding rebound effects that could reduce fuelwood savings or even increase fuel consumption. This task is left for the future.

If the results of the satisfaction survey are confirmed by measurements of use, the role of REDD+ purchase subsidies and payments could potentially be called into question. Our findings indicate that the cookstoves provide considerable benefits for the users themselves and many say they would buy and recommend the stove even without REDD payments. Additionality and eligibility for REDD+ payments therefore remain open to question.

We know, though, that fuelwood savings depend on human behavior and motivations and if *Mirt* stove wood savings was a purely engineering matter we should observe savings of about 50% as advertised. Instead we find that 40% fuelwood savings compared with the traditional stove is at the 95th percentile and at the 5th percentile there is only 12% fuelwood savings. Behavior therefore seems to be important and we know that external benefits like carbon sequestration are under-provided if uncompensated. Careful thinking about the additionality of improved cookstoves is therefore a high priority.

We have shown that private benefits will be critical to mobilizing *Mirt* stoves for climate change mitigation and it would be very useful to look into time-savings. The satisfaction survey suggests that the *Mirt* stove can generate time-savings and most benefits go to women. Yet such findings should be placed in the context of the household labor budget. Do households really save 1-5 hours per week and what is the nature of those savings? The shadow value of time must also be evaluated in order to better understand whether this benefit is substantial for households.

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Tables

Table 1 Two-sample t test of specific fuel consumption, pooled data

Group	Obs	Mean	Std. Err.	t-value	Ha:[a]	Pr(T > t)
Traditional	211	1104.676	59.68748			
Mirt	212	813.231	50.14642			
Combined	423	958.6091	39.55761			
Difference [b]		291.4453	77.92535	3.74	Difference > 0 t =	0.0001***

[a] Ha alternative hypothesis

[b] Difference = mean(traditional)-mean(mirt)

***, ** indicate significant at 1% and 5% levels, respectively

Table 2 Two-sample t test of specific fuel consumption by period

Group	Obs	Mean	Std. Err.	t-value	Ha:	Pr(T > t)
a) October/ November 2013						
Traditional	107	1134.524	82.09017			
Mirt	109	781.8441	76.1178			
Combined	216	956.5515	57.08871			
Difference		352.6804	111.8807	3.15	Difference > 0	0.0009***
b) May/June 2013						
traditional	104	1073.967	87.08292			
Mirt	103	846.4463	64.75871			
Combined	207	960.7562	54.78199			
Difference		227.5208	108.6765	2.09	Difference > 0	0.0188**

Table 3 Two-sample t test of specific fuel consumption by region

Group	Obs	Mean	Std. Err.	t-value	Ha:	Pr(T > t)
a) Amhara						
Traditional	46	1094.624	57.42028			
Mirt	44	808.6315	65.78928			
Combined	90	954.8053	45.86985			
Difference		285.9923	87.1009	3.28	Difference > 0	0.0007***
b) Oromiya						
Traditional	87	1209.872	91.36722			
Mirt	81	914.3733	64.87075			
Combined	168	1067.399	57.69534			
Difference		295.4983	113.5179	2.60	Difference > 0	0.005***
c) SNNP						
Traditional	56	1220.266	128.057			
Mirt	53	1039.308	90.53872			
Combined	109	1132.277	79.28009			
Difference		180.9582	158.3966	1.14	Difference > 0	0.1279

Table 4 Two-sample t test of total cooking time, pooled data and by period

Group	Obs	Mean	Std. Err.	t–value	Ha:	Pr(T < t)
a) Pooled data						
Traditional	207	60.270	1.582516			
Mirt	211	67.407	2.02901			
Combined	418	63.873	1.299901			
Difference		-7.137	2.579417	-2.7669	Difference < 0	0.003***
b) October/November 2013						
Traditional	106	59.038	2.136868			
Mirt	108	61.176	2.219007			
Combined	214	60.117	1.539044			
Difference		-2.138	3.081977	-0.6938	Difference < 0	0.244
c) May/June 2013						
Traditional	101	61.564	2.347082			
Mirt	103	73.942	3.336078			
Combined	204	67.81373	2.087024			
Difference		-12.3774	4.092944	-3.0241	Difference < 0	0.001***

Table 5
Likert Scale for Stove Attributes

Stove attribute	Ranking (in %) (n=360)				
	Very poor	Poor	Average	Good	Very good
How do you find the new stove?	-	-	0.6	15.8	83.6
How did your family members find the new stove?	-	-	1.1	16.9	81.9
Convenience of new stove compared with the traditional one	-	-	0.8	16.4	82.8
Durability of new stove	0.3	1.9	6.4	33.5	57.8
Reducing in amount of time spent for cooking	-	0.8	5.8	31.4	61.9
Reducing amount of fire wood use	-	0.6	3.1	18.3	78.1
Reduction of smoke	-	-	1.4	13.9	84.7

Table 6
Recommendations for Neighbors Regarding the *Mirt* Stove? (n=360)

	# of households	%
I advise them to buy and use it	269	74.7
the government should buy and distribute to them freely	84	23.3
the neighbors should buy it with subsidy	98	27.2
I do not recommend	14	3.9

Table 7
Top three most preferred attribute(s) of the improved stove

Attributes	Preference		
	Most important	Second most important	Third most important
1 Reduction in smoke(indoor air pollution)	35.0%	48.3%	11.9%
2 Reduction in fuelwood consumption	46.9%	32.2%	15.3%
3 Reduction in time of cooking	3.6%	11.1%	58.3%
4 Reduction in flammability	12.2%	7.8%	10.8%
5 Durability of the stove	-	0.3%	3.3%
6 Increase the quality of injera	0.8%	0.3%	-
7 Convenience of use	1.4%	-	-
Total	100.0%	100.0%	99.7%

Table 8
Changes in respiratory discomfort with *Mirt* stove compared with the traditional stove

	# of responses	%
1 much less	160	44.4
2 less	39	10.8
3 no change	-	-
4 more	4	1.1
5 much more	11	3.1
Total	214	59.4

Table 9
Who in the household benefited most from the reduction in respiratory discomfort?

Household members	Benefited		
	First most	Second most	Third most
1 young children	1.1	56.1	1. 1
2 women	61.9	1.1	0.3
3 men	-	2.2	51.7
Total	63.1	59.4	53.3

Table 10
Results of clustered pooled regression estimation of determinants of fuel savings

Variable	Coef	P> | t |	Coef	P> | t |
Weight of food cooked(gm)	-0.002 (0.001)[a,b]	0.032	-0.002 (0.001)	0.100
Weight of food cooked squared	0.000 (0.000)	0.008	0.000 (0.000)	0.038
Household and cooks characteristics:				
Age of cook (adult equivalent)	-0.157 (0.075)	0.043	-0.161 (0.066)	0.019
Marital status of cook(1=Married, 0=Otherwise)	-4,943 (2.179)	0.030	-5.550 (1.906)	0.006
Cooks education(1=Literate, 0=0therwise)	-0.380 (0.895)	0.674	-0.030 (0.967)	0.975
Cooks main occupation				
Household (1=if household work, 0=otherwise)(Reference)			1.809 (0.834)	0.037
Agriculture (1=if agriculture, 0=otherwise)	-1.099 (0.866)	0.213		
Nonagriculture (1=if wage worker, business, or private sector; 0=otherwise)	-3.566 (1.632)	0.036		
Family size (in adult equivalent)	-0.168 (0.257)	0.517		
Cooking environment:				
Ambient temperature (^{0}C)	0.038 (0.150)	0.802	0.009 (0.165)	0.956
Wind condition(1=Calm, 0=Otherwise)	1.464 (0.718)	0.049	1.077 (0.614)	0.088
Region:				
Oromiya (1= yes, 0=otherwise) (Reference)				
Amhara dummy (1=yes, 0=otherwise)	1.163 (1.118)	0.305	0.218 (1.133)	0.848
SNNP dummay (1=yes, 0=otherwise)	-1.419 (1.229)	0.256	-2.394 (1.059)	0.030

lnChange_t (change in total cooking time)	-0.162 (0.684)	0.184	-0.375 (0.693)	0.592
Treatments:				
Treatment 1 (1=if treatment 1, 0=otherwise)			0.462 (0.966)	0.635
Treatment 2 (1=if treatment 2, 0=otherwise)			3.034 (0.974)	0.004
Treatment 3 (1=if treatment 3, 0=otherwise)			-0.109 (1.154)	0.926
Treatment 4 (1=if treatment 4, 0=otherwise)			-0.223 (1.299)	0.865
Treatment 5 (1=if treatment 5, 0=otherwise) (Reference)				
Treatment 6 (1=if treatment 6, 0=otherwise)			2.755 (1.910)	0.158
Constant	16.985 (5.513)	0.004	15.772 (5.437)	0.006
n	166		166	
F(13, 35)	8.79		11.51	
Prob> F	0.000		0.000	
R-squared	0.203		0.236	
Root MSE	5.306		5.2464	

[a]Robust Std. Err. in parenthesis.
[b]Std. Err. adjusted for 36 clusters

Figures

Figure 1

Mirt Stove with *Injera* Cooking

Source:ethiopiaethos.files.wordpress.com/2010/06/comp5.jpg

Figure 2

Cook pouring *Injera* batter on *Mirt* Stove

Source:energypedia.info/wiki/Baking_with_Improved_Ovens

Appendix A: CCT (Controlled Cooking Test) Protocol for Analyzing Cooking of Injera in Traditional and *Mirt* (BEST) Stoves

Adapted from Protocol Available at http://www.aprovecho.org/lab/pubs/testing (Accessed 10 April 2013)

The controlled cooking test (CCT) is designed to assess the performance of the improved stove relative to traditional stoves. Stoves are compared as they perform a standard cooking task that is close to the actual cooking that people do every day. However, the tests are designed in a way that minimizes the influence of other factors and allows for the test conditions to be reproduced.

Equipment Required

- **Fuel:** For all tests within a given household, if possible the same type of air-dried fuelwood should be used. Use local input to determine the quantity of fuel required to cook a "standard meal" on a traditional stove.
- **Food and water:** Testers should be sure they have sufficient food and water for the tests. Like fuel, the food should be homogenous so that variability in food does not bias the results of the test.
- **Injera pans**: if possible, use standard pans. Record the specifications in the Data and Calculation form. If possible, the same type (size, shape, and material) of pots should be used to test each stove.
- **Scale:** At least 6kg capacity and 1 gram accuracy: (see note in WBT section).
- **Heat resistant pad** to protect scale when weighing hot charcoal.
- **Tape measure**
- **Wood moisture meter**
- **Timer**
- **Thermometer** to record ambient temperature.
- **Small shovel/spatula** to remove charcoal from stove for weighing.
- **Dust pan** for transferring charcoal.
- **Metal tray** to hold charcoal for weighing.
- **Heat resistant gloves**.

CCT testing procedure

1. Choose an appropriate cooking task. In our case, this will be cooking Injera.
    - Decide on the exact amount of food on which to base the test.
    - Ensure that sufficient food is available to conduct the tests.
2. Precisely describe the cooking task in writing in as much detail as possible in a way that both stove users and testers can understand and follow.

- This is important to ensure that the cooking task is performed identically on each stove.
- As the food cooked is the same (injera) in all places, ingredients should be roughly the same. Testers should be sure the amounts of ingredients cooked are the same in all test sites.
- If possible, include an objective measure of when the meal is "done". In other words, it is preferable to define the end of the cooking task by an observable factor rather than a subjective measure like "the injera tastes right."

After sufficient ingredients and fuel have been obtained and the steps of the cooking task are understood, the actual testing can begin.

The cooking itself should be done by a local person who is familiar with both the meal that is being cooked and the operation of the stove to be tested.

As the BEST (*Mirt*) stove is a new design that may be different from traditional cooking practices, training will be required before conducting the actual tests. In the follow-on testing to be conducted in September/October, cooks will have experience with the technology. Testers should not intervene or direct the test once it has begun.

3. Record local conditions on the Data and Calculation form.
4. Weigh the predetermined ingredients and do all of the preparations (e.g. washing, peeling, cutting, etc.) as described in cooking directions discussed in step 2.
5. Start with a pre-weighed bundle of fuel that is roughly double the amount that local people consider necessary to complete the cooking task. Record the weight in the appropriate place on the Data and Calculation form.
6. Starting with a cool stove, allow the cook(s) to light the fire in a way that reflects local practices. Start the timer and record the time on the Data and Calculation form.
7. While the cook performs the cooking task, record any relevant observations and comments that the cook makes (for example, difficulties that they encounter, excessive heat, smoke, instability of the stove or pot, etc.).
8. When the task is finished, record the time in the Data and Calculation form.
9. Remove the food from the stove and weigh all the *injera* baked. Record the weight in grams on the Data and Calculation form.
10. Remove the unburned wood from the fire and extinguish it. Knock the charcoal from the ends of the unburned wood. Weigh the unburned wood from the stove with the remaining wood from the original bundle. Place all of the charcoal in the designated tray and weigh this too. Record both measurements on the Data and Calculation form.
11. The test is now complete

Analysis

Variables

Environmental variables and physical test parameters are measured directly.

The environmental variables may vary slightly from one test to another, but should be nearly constant.

Wind conditions

Air temperature

- The physical test parameters should be constant for all tests.

Physical test parameters:

Variable	Label
Avg. dimensions of wood (centimeters)	--
Wood moisture content (% - wet basis)	m
Empty weight of Pot # 1 (grams)	P1
Empty weight of Pot # 2 (grams)	P2
Weight of container for char (grams)	k
Local boiling point of water (°C)	T_b

Measurements and Calculations

Upon finishing the test, a number of measurements are taken and recorded.

Initial weight of fuelwood (wet basis) (grams)	f_i
Final weight of fuelwood (wet basis) (grams)	f_f
Weight of charcoal with container (grams)	c_c
The weight of each pot with cooked food (grams)	Pj_f (j is an index for the cooking pot ranging from 1–4 depending on the number of pots used for cooking)
Start and finish times of cooking (minutes)	t_i and t_f

These measurements are used to calculate the indicators of stove performance:

Total weight of food cooked (W_f) – this is the final weight of all food cooked. It is simply calculated by subtracting the weight of the empty pots from the pots and food after the cooking task is complete:

$W_f = \sum_{j=1}^{4} (Pj_f - Pj)$ where j is an index for each pot (up to four).

Weight of charcoal remaining (Δc_c) – the mass of charcoal from within the stove, including the char removed from the ends of the unburned fuel that is extinguished just at the end of the cooking task. This is found by simple subtraction:

$\Delta c_C = c_C - k$

Equivalent dry wood consumed (f_d) – This measure accounts for two factors: (1) the wood that must be burned in order to vaporize moisture in the wood and (2) the amount of char remaining unburned after the cooking task is complete. The calculation is done in the following way:

$$f_d = (f_i - f_f) * (1 - (1.2 * m)) - 1.5 * \Delta c_c$$

Specific fuel consumption (SC) – This is the principal indicator of stove performance for the CCT. It tells the quantity of fuel required to cook a given amount of food for the "standard cooking task". It is calculated as a simple ratio of fuel to food:

$$SC = \frac{f_d}{W_f} * 1000$$

Notice this is reported in grams of fuel per *kilogram* food cooked, whereas W_f is reported in *grams*. Thus a factor of 1000 is included in the calculation.

Total cooking time (Δt) – This is also an important indicator of stove performance. Depending on local conditions and individual preferences, stove users may value this indicator more or less than the fuel consumption indicator. This is calculated as a simple clock difference:

$$\Delta t = t_i - t_f$$

Appendix B:
Two-sample Wilcoxon rank-sum (Mann-Whitney) test

Specific fuel consumption

Pooled Data			
type_of	obs	rank sum	expected
Traditional	189	38318	34776
mirt	178	29210	32752
Combined	367	67528	67528
unadjusted variance	1031688		
adjustment for ties	0		
adjusted variance	1031688		
Ho:SC(type_of==Traditional) =SC(type_of==mirt)			
z = 3.487			
Prob> z = 0.0005			

October/November2013 Data			
type_of	obs	rank sum	expected
Traditional	106	12229	11077
mirt	102	9507	10659
Combined	208	21736	21736
unadjusted variance	188309		
adjustment for ties	0		
adjusted variance	188309		
Ho:SC(type_of==Traditional) =SC(type_of==mirt)			
z = 2.655			
Prob> z = 0.0079			

May/June 2013Data			
type_of	obs	rank sum	expected
Traditional	83	7292	6640
mirt	76	5428	6080
Combined	159	12720	12720
unadjusted variance	84106.67		
adjustment for ties	0		
adjusted variance	84106.67		
Ho:SC(type_of==Traditional) =SC(type_of==mirt)			
z = 2.248			
Prob> z = 0.0246			

Specific fuel consumption in Amhara

Amhara Region Data			
type_of	obs	rank sum	expected
Traditional	46	2600	2093
mirt	44	1495	2002
Combined	90	4095	4095
unadjusted variance	15348.67		
adjustment for ties	0		
adjusted variance	15348.67		
Ho:SC(type_of==Traditional) =SC(type_of==mirt)			
z = 4.092			
Prob> |z| = 0.0000			

Oromiya

Oromiya Region Data			
type_of	obs	rank sum	expected
Traditional	87	8142	7351.5
mirt	81	6054	6844.5
Combined	168	14196	14196
unadjusted variance adjustment for ties adjusted variance	99245.25 0 99245.25		
Ho: SC(type_of==Traditional) = SC(type_of==mirt) z = 2.509 Prob> |z| = 0.0121			

SNNP

SNNP Region Data			
type_of	obs	rank sum	expected
Traditional	56	3142	3080
mirt	53	2853	2915
Combined	109	5995	5995
unadjusted variance adjustment for ties adjusted variance	27206.67 0 27206.67		
Ho: SC(type_of==Traditional) = SC(type_of==mirt) z = 0.376 Prob> z = 0.7070			

Appendix C
Questionnaire for Improved Cookstove Use Satisfaction Survey
September 2013, Ethiopia

To the Enumerator: Please circle the alternative chosen by respondents (about the household) if choices are given, otherwise please write the answering the space provided.

1. Household ID number ______________________

	Very good (5)	**Good (4)**	**Average (3)**	**Poor (2)**	**Very poor (1)**
2. How did you find the new stove that was provided to you by the fieldworkers a few months ago?					
3. What did your family members say about the new stove? It is….					
4. How did you find the convenience or ease of use of the new stove compared to the traditional one?					
5. How did you find the durability of stove?					
6. How did you find the new stove in reducingamount of time spent for cooking					
7. How did you find the new stove in reducingamount of fire wood use					
8. How did you find the new stove in terms of reducing the amount of smoke created during cooking					
9. If you were supposed to buy the new stove, would you buy it at the market price?	Very likely	Likely	Difficult to say	Not Likely	Very unlikely

Code (A)

1. Reduction in smoke (indoor air pollution) 2. Reduction in fuelwood consumption___

3. Reduction in time of cooking__ 4. Other (specify)

10. Please rank the top three attribute(s) of the improved stove that you liked?)(code A)

1st)________2nd_____________3rd_________________________

12. What aspect of the stove did you like the least? Code (A)__________

13. With your traditional stove, did you or another member of your household experience respiratory discomfort while cooking?

1) Yes 2) No

13.1 If Yes, briefly explain who in your household was effected and how they were effected

____

____

13.2. If your answer to question 13 is yes, how does respiratory discomfort with the *Mirt* stove compare with the traditional stove?

1) much less 2) less 3) about the same 4) more 5) much more

14. Do you believe using the *Mirt* stove saves you or other household members' time?

1) Yes 2) No

14.1. If your answer to question 13 is yes, please check all that apply

1) Fuelwood collection 2) dung collection 3) cooking 4) clothes washing 5) other

15. Compare the *Mirt* stove to your traditional methods of cooking, ________________

1. How much less time did members in your household spend cooking with the new stove?
   Same, 25% less, 50% less, 75% less; more time
2. How much less firewood did members in your household use with the new stove?
   Same, 25% less, 50% less, 75% less; more firewood
3. How less smoke did the new stove create?
   Same, 25% less, 50% less, 75% less ; more smoke

16. For what type of food did you use the improved stove (multiple answers possible)? _________

Code: 1) injera baking 2) Bread/kita 3) kocho 4) other (specify) ________

17. What was your main cooking fuel using the improved stove______________

Code: 1) dung 2) fuelwood 3) crop residues 4) other (specify) ______

18. Did you use the improved stove for any other purpose other than baking? _________

1) Yes 2) No

19. If yes to Q. 13, for what type of purpose did you use it? Code (b)_ ______________

Code (B) 1. For baking tella kita 2. For roasting grains 3. Other___________

20. Did you use the chimney-side for other cooking activities? ______ 1) Yes 2) No

21. If yes to Q. 20, for what other cooking activities have you used it? ________

Code (C): 1) Coffee boiling 2) sauce cooking 3) other (specify) ____

22. On average how frequently did you use the stove in a period of a week for?

Baking ______________________

Other purposes___________________

23.1. How many injera did you bake at a time (on average)? _______________

24.

What do you recommend to your neighbors regarding the new stove (multiple answers possible)?

I advise them to buy and use it

The government should buy and distribute to them freely
The neighbors should buy it with subsidy
I do not recommend them to use it
Other_______________

25. Do you have anything else to say about the new stove?
____

Appendix D

Description of Attributes Making up Treatments

	Attributes		
Treatment	ETB 25 Payment by Respondent to Receive Stove	ETB 50 Total Incentive for Using the Stove at Least 2 Times Per Week for First 40 Days	Network Building and Group Training
Treatment 1	No	Yes	No
Treatment 2	No	Yes	Yes
Treatment 3	Yes	No	No
Treatment 4	Yes	No	Yes
Treatment 5	No	No	No
Treatment 6	No	No	Yes

Appendix E

Kruskal Wallis Test results for final grouping of sample villages

Ranks

	Group assignment	N	Mean Rank
B1 (# of HHs of Kebele)	1	6	10.00
	2	6	22.00
	3	6	18.33
	4	6	19.00
	5	6	20.00
	6	6	21.67
	Total	36	
B2 (# of HHs in FUG)	1	6	13.33
	2	6	20.83
	3	6	18.33
	4	6	15.75
	5	6	20.75
	6	6	22.00
	Total	36	
B3(Wealth Variance in FUG)	1	6	20.75
	2	6	14.42
	3	6	20.75
	4	6	23.50
	5	6	14.42
	6	6	17.17
	Total	36	
D1(Existence of Forest Rules and Regulations)	1	6	18.50
	2	6	18.50
	3	6	18.50
	4	6	18.50

	5	6	18.50
	6	6	18.50
	Total	36	
K1(% of Forest Biomass Change Over 5 Years)	1	6	21.75
	2	6	24.17
	3	6	20.00
	4	6	17.58
	5	6	15.83
	6	6	11.67
	Total	36	

Test Statistics[a,b]

	B1 (# of HHs of Kebele)	B2 (# of HHs in FUG)	B3(Wealth Variance in FUG)	D1(Existence of Forest Rules and Regulations)	K1(% of Forest Biomass Change Over 5 Years)
Chi-Square	5.246	3.085	6.166	.000	6.243
df	5	5	5	5	5
Asymp. Sig.	.387	.687	.290	1.000	.283

a. Kruskal Wallis Test

b. Grouping Variable: Group assignment

Appendix F

Summary statistics for variables used in pooled regression analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
Fuelwood savings(normalized by 100)	175	2.732	560.341	-7.751	39.718
Weight of food cooked(gm)	180	5323.944	2184.34	0	13800
Weight of food cooked squared	180	3.31*10^7	2.43*10^7	0	1.9*10^8
Household and cooks characteristics:					
Age of cook	181	34.685	9.526	18	68
Marital status of cook(1=Married, 0=Otherwise)	181	0.867	0.340	0	1
Cooks education(1=Literate, 0=otherwise)	181	0.431	0.496	0	1
Cooks main occupation					
Household work (1=if household work, 0=otherwise)	181	0.691	0.463	0	1
Agriculture (1=if agriculture, 0=otherwise)	181	0.237	0.427	0	1
Nonagriculture (1=if wage worker, business, or private sector; 0=otherwise)	181	0.072	0.259	0	1
Family size (in adult equivalent)	181	4.801	1.743	1.84	9.56
Cooking environment:					
Ambient temperature (^{0}C)	178	22.5	3.360	14	30
Wind condition(1=Calm, 0=Otherwise)	181	0.735	0.443	0	1
Region:					
Oromia (1=yes, 0=otherwise)	181	0.464	0.5001	0	1
Amhara (1=yes, 0=otherwise)	181	0.249	0.433	0	1
SNNP (1=yes, 0=otherwise)	181	0.287	0.454	0	1
lnChange_t(change in total cooking time)	174	4.094	0.547	0	5.328
Treatments:					
Treatment 1 (1=if treatment 1, 0=otherwise)	181	0.166	0.373	0	1
Treatment 2 (1=if treatment 2, 0=otherwise)	181	0.146	0.352	0	1
Treatment 3 (1=if treatment 3, 0=otherwise)	181	0.171	0.378	0	1
Treatment 4 (1=if treatment 4, 0=otherwise)	181	0.182	0.387	0	1
Treatment 5 (1=if treatment 5, 0=otherwise)	181	0.182	0.387	0	1
Treatment 6 (1=if treatment 6, 0=otherwise)	181	0.138	0.346	0	1