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ABSTRACT *This article uses a field experiment to evaluate effects of monetary treatments on usage intensity of an important improved biomass-burning cookstove promoted in Ethiopia. Understanding whether, how much and why improved stoves are used are important, because use frequency critically determines fuelwood savings and related benefits. We find that distributing stoves free-of-charge is at least as effective for promoting short-run adoption as requiring payments or offering usage incentives. Free distribution is most effective at promoting both high and increasing levels of longer-run regular use. First period incentives do not better promote usage habits compared with the other two treatments.* (JEL O12; O13)

1. Introduction

Humans have cooked their food for several hundred thousand years (e.g., Wrangham et al. 1999), mainly using biomass fuels. About two-fifths of the human population, or 2.8 billion people, rely on solid cooking fuels, including biomass, combusted in their homes rather than gas, liquid fuels or electricity (e.g., Grieshop, Marshall, and Kandlikar 2011; Jeuland, Pattanayak, and Bluffstone 2015). Biomass fuels are widely used in low-income developing countries, such as Ethiopia, which is the focus of this article. They are often self-collected and combusted in simple, flexible stoves, such as the three-stone tripod, which is the traditional technology in much of sub-Saharan Africa. Biomass fuel use is a potential problem because it often contributes to indoor and outdoor air pollution (Smith et al. 2013; Martin et al. 2011; Lim et al. 2012) and forest degradation (Gebreegziabher and van Kooten 2013), which can increase fuelwood collection time (Bluffstone 1995; Amacher et al. 2004;Cooke, Köhlin, and Hyde 2008) and increase climate change (Saatchi et al. 2011; Bond et al. 2013; Bailis et al. 2015).

Several large international initiatives, such as Sustainable Energy for All (www.se4all.org), promote modern energy services to reduce the use of biomass fuels. Fuels such as gas and electricity require major infrastructure investments, supply chain development, and the purchase of often expensive stoves. Biomass fuels will continue to be extensively used, particularly by people in sub-Saharan

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Africa, and the number of people who depend on biomass is expected to decline relatively little by 2030 (International Energy Agency 2017).

Improved cooking stoves (ICSs),[1] which use less biomass, have received significant attention as important intermediate technologies while modern fuel availability and adoption expands (Jeuland and Pattanayak 2012). These technologies, most of which burn fuelwood, have the potential to reduce many of the harmful effects of biomass burning,[2] and may require only minor alterations in cooking habits. Many ICSs were introduced in the 1980s and accepted into people's homes, but cooks often did not regularly use those stoves (e.g., Gil 1987; Barnes et al. 1993). It soon was recognized that ICS adoption has two parts. The first is willingness to try stoves, but the second and more ambitious aspect is regular use, which is the main litmus test of true adoption (Johnson et al. 2009; Beyene et al. 2015; Hanna, Duflo, and Greenstone 2016). For this reason, we focus on adoption measured as regular use.

We use a field experiment to examine short- and longer-run usage intensity of a relatively durable, simple, low-maintenance improved biomass stove called Mirt. This stove is an important part of a federal government of Ethiopia effort to disseminate ICSs to 20 million households by 2030 (Federal Democratic Republic of Ethiopia 2011). It has also been shown to use less wood (Gebreegziabher et al. 2018).

We seek to add to the literature on the effects of monetary incentives on regular and sustained use of new technologies in developing countries. To date, this literature has largely focused on explicitly health-related technologies (see Cohen and Dupas 2010; Ashraf et al. 2010; Chassang, Padro, and Snowberg 2012; Dupas 2014). Recently, however, the effect of monetary incentives has also been examined with regard to ICS (see Pattanayak et al. 2016;; Bensch and Peters 2017; Usmani, Steele, and Jeuland 2017; Levine et al. 2018). Our article provides additional evidence that lessons from this important literature apply to improved biomass cookstoves.

2. Literature

Evidence on actual, field-based use of ICSs in sub-Saharan Africa is important because improved biomass cookstove designs promoted in Africa have often been found to reduce the fuelwood or charcoal needed to cook typical meals by approximately 20% to 35% compared with traditional technologies.[3] A significant portion of this literature either ignores real-world usage (e.g., Gebreegziabher et al. 2018) or uses relatively long-term respondent recall rather than actual measurements (e.g., Dresen et al. 2014; Bensch and Peters 2015; Hanna, Duflo, and Greenstone 2016). As was done by Simons et al. (2017), we avoid self-reporting, which may give results that differ from actual use (Ramanathan et al. 2016) and has been shown to lead to use overestimates by as much as 100% (Beltramo and Levine 2013; Thomas et al. 2013). We directly calculate use frequency with electronic stove use monitors (SUMs), which measure stove surface temperature every 10 minutes for one to two months.

Recent literature includes careful analyses of usage behaviors, many of which focus on benefits and costs from users' perspectives. Although the literature includes evidence of robust usage and significant benefits (e.g., Bensch and Peters 2015), other research suggests limited usage, which has been explained

[1] In this article, ICS means improved biomass cooking stoves. We recognize that other types of technologies, such as electric induction and LPG stoves, are also important improvements.

[2] A particularly interesting development is the potential for improved stoves to reduce greenhouse gas emissions, and carbon finance has been used to fund both private sector and nonprofit pay-for-performance stove programs (Lewis and Pattanayak 2012). For example, the firm DelAgua Health has distributed more than 100,000 EcoZoom stoves in Rwanda (http://www.delagua.org/projects/rwanda). See www.projectsurya.org for an interesting example of a nonprofit project relying on carbon finance.

[3] The potential for fuelwood savings can be undercut in important ways by stove-stacking behaviors, in which ICS and traditional technologies are both used (Beltramo and Levine 2013; Bensch and Peters 2015; Ruiz-Mercado and Masera 2015; Brooks et al. 2016). In some cases, these effects are significant enough to offset efficiency gains (Beltramo and Levine 2013). In other situations, such rebound effects are minor (Brooks et al. 2016).

in terms of limited direct benefits to ICS users (e.g., Hanna, Duflo, and Greenstone 2016) or overemphasis on respiratory health benefits, which may not be highly valued by users (e.g., Pattanayak and Pfaff 2009; Mobarak et al. 2012).

First cost has been found to be important for initial adoption. Price elasticities are likely to be high (e.g., Mobarak et al. 2012) and adoption quite low with full-cost pricing even if stoves cost less than $7.00 (Bensch, Grimm, and Peters 2015). Female-headed households, marginalized groups, and the poor may have especially low willingness to pay (e.g., Jeuland et al. 2015). For this reason, significant subsidies or free distribution are common in large-scale stove programs (e.g., Rosa et al. 2014; Samaddar 2017). Financing has been found to dramatically increase adoption (Beltramo et al. 2015; Levine et al. 2018). First costs are therefore of critical importance to ICS adoption, which is why we emphasize them in this article.

Subsidies, such as free distribution, can create incentives to try technologies, but they may also affect regular usage. Subsidies can reduce screening effects, implying that technologies go to those who do not value them and will not regularly use them (e.g., Ashraf, Berry, and Shapiro 2010; Chassang, Padro, and Snowberg 2012). Free distribution may mute psychological sunk cost effects that could promote use. There is a growing literature on how monetary incentives affect use of goods and services as diverse as mosquito nets (Dupas 2014), exercising at gyms (Charness and Gneezy 2009), water treatment tablets (Ashraf, Berry, and Shapiro 2010), and, more recently, ICSs (Usmani, Steele, and Jeuland 2017). Overall, little evidence seems to exist that psychological sunk costs (i.e., payments in the past) promote use (Ashraf, Berry, and Shapiro 2010; Cohen and Dupas 2010) or that low initial costs reduce long-run values (Bensch and Peters 2017). These findings suggest that subsidized prices may not reduce usage.

Our study adds to the literature, which seeks to continue to bring ICS into the discussion. Using a difference-in-difference empirical specification applied to our field experiment data, we evaluate the effects of three monetary incentive structures on Mirt ICS use. Mirt costs about $12.00 (about the same as the stove analyzed by Hanna, Duflo, and Greenstone [2016]), is made locally of molded concrete, and is one of the most important improved stoves promoted in Ethiopia.[4] This stove is less prone to breakage than others that have been evaluated in the literature (e.g., Hanna, Duflo, and Greenstone 2016), allowing us to focus on the role of monetary incentives in regular and sustained ICS usage.

Mirt is used to make *injera*, the main staple bread consumed in Ethiopia, and in areas without refrigeration is baked at least twice a week (Kindu Trust n.d.). Reducing fuelwood to cook *injera* is important because it may represent the end-use for as much as half of the primary energy consumed in the country (Bizzarri 2010; Tesfay, Kahsay, and Nydal 2104). Mirt has been estimated to use 50% less wood in laboratory tests (Green Climate Fund 2011), 40% to 50% based on surveys (Megen Power 2008; Dresen et al. 2014), and 20% to 30% using field-based controlled cooking tests (Gebreegziabher et al. 2018). Very few rural households use ICSs (Mondal et al. 2018), with most households relying on tripods made of three large stones that waste approximately 90% of the energy input (Alem, Hassan, and Köhlin 2014).

We randomly distribute the Mirt ICS free of charge, at a subsidized cost, and with a reward for regularly using it during the first monitoring period, which was approximately six weeks long. Although subsequent usage varied, under all monetary treatments nobody refused to accept the stove at the terms offered. Sample households on average used the Mirt stove approximately twice a week, which in rural areas is consistent with regular *injera* baking. We find that the rate of complete disuse after approximately one year is low at about 10%, with limited evidence of reduced

[4] Mirt means "best" in Amharic language. The Mirt stove was initially developed by the Ethiopian Energy Study and Research Center (EESRC), has a lifetime of about five years, and has been promoted since 1998. It is a key part of the government's Climate Resistant Green Economy Strategy (Federal Democratic Republic of Ethiopia 2011, 2015). Nongovernmental organizations are also involved, and as of 2016, approximately 50,000 Mirt stoves had been distributed by World Vision alone.

average use frequency over time. During the study period, no stoves were abandoned, and no breakage precluded use.

Consistent with the literature, we do not find evidence of psychological sunk cost effects. In the short run, incentivizing use generates the highest level of regular usage, which is statistically different from requiring payment, but not from the free distribution treatment. We do not find that offering a one-shot regular usage incentive promotes long-run habits, but we do find evidence of high and increasing regular use over time when the stove is provided for free.

3. Field Experiment

To better understand improved biomass stove use decisions and generate testable hypotheses, we modify the one-period analytical model of Jeuland et al. (2015). We focus exclusively on contemporaneous use decisions, because in our field experiment all users accepted the stoves (i.e., took, purchased, or agreed to an incentive arrangement) regardless of the terms offered. The details of the analytical framework are presented in Appendix A. Results from the model suggest the following hypotheses, which are empirically tested in the context of our randomized field experiment:

1. Sunk costs do not affect stove use.
2. Pay-for-use schemes promote higher usage rates compared with the other two monetary treatments during the incentivized period.
3. Pay-for-use schemes do not promote higher usage rates after the incentivized period.

Experimental Design

We test these hypotheses using three monetary treatments: (1) users receive the stove for free; (2) inspired by Cohen and Dupas (2010), users pay 25 birr for the Mirt stove (about 13% of the approximately192 birr cost) paid the same day or at latest the following day,[5] and (3) users pay nothing for their stoves and receive a 50 birr incentive payment if the electronic SUM indicated that Mirt stoves were used at least twice a week during the first approximately six-week monitoring period. We chose twice a week, because it is consistent with regular *injera* cooking. This treatment investigates the longer-run effect of incentivizing use during the first period and follows an experimental approach similar to Charness and Gneezy (2009) and Usmani, Steele, and Jeuland (2017).[6]

We test the hypothesis that sunk costs do not affect usage by comparing regular usage in the study arm, which did not pay anything for the Mirt stove, with those who paid a subsidized price. The level of subsidization provided to those who paid for the stove limits our ability to draw inferences. Second, we evaluate whether our one-shot, pay-for-use scheme spurs higher usage during the incentivized period. We test this hypothesis by testing differences in first-period regular usage of those who received the incentive and the other two treatments. Finally, we examine whether pay-for-use schemes better promote usage habits than the other monetary treatments. We accomplish this goal by testing for differences in regular usage by treatment, in and between the first and last periods, which are approximately one year apart.

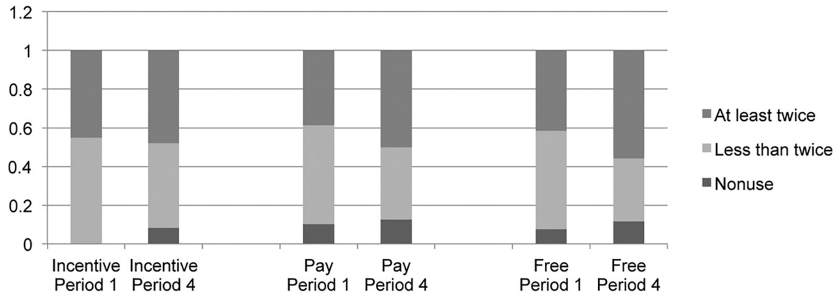
An exclusive focus on the very short-run can lead to erroneous extrapolations about longer-run usage intensity if short-run effects are not persistent, if people need time to become accustomed to interventions to develop habits or both. For this reason, we evaluate effects over an approximately one-year timeframe.[7]

[5] Mirt stoves are made by private producers, so prices vary. The exchange rate in June 2013 when the Mirt stoves were distributed was approximately 19 birr/US$, and the daily unskilled wage rate was approximately 40 birr. This subsidy level is fairly typical if stoves are not provided for free as in Rosa et al. (2014). For example, in Ethiopia, the World Food Programme (n.d.) reports offering an 80% subsidy; Samaddar (2017) provides an 87% subsidy in Udaipur, India; and Bailis (2018) reports an 80% subsidy in their liquefied petroleum gas randomized controlled trial in India.

[6] Half the sample was randomized into village-level groups that received one-time group training. These groups were found to have no effect on usage and are treated as a control in all models, but not analyzed.

[7] See Alcott and Rogers (2014) on electricity use, Hanna, Duflo, and Greenstone (2016) for improved stoves and Frey and Rogers (2014) for an overview.

Figure 1
Stove Usage Intensity by Treatment for Periods 1 and 4



We randomized treatments at the village rather than the household level to assure that everyone in a village received Mirt stoves on the same terms. This approach best reflects implementation at scale, where all individuals in a site receive stoves under the same conditions. If stoves were allocated using different treatments in a village, this would have been perceived as unfair, potentially biasing usage intensity compared with use based purely on stove attributes and treatments. In sum, treatments were randomly assigned by village, and households were randomly selected within each village. Sampling details are discussed in Section 3.

Measuring Use of the Mirt Stove

We monitor all stoves over four intervals lasting one to two months for approximately one year. In contrast to some of the literature (e.g., Hanna, Duflo, and Greenstone 2016), we identify cooking events by electronically measuring surface temperature. For this purpose, we use DS1922T SUMs, which were purchased from Berkeley Air Monitoring Group of Berkeley, California. As shown in Appendix Figure B1, the SUMs are approximately the size of a watch battery. The recording intervals are adjustable, and we recorded temperatures every 10 minutes for up to 60 days. The DS1922T can tolerate temperatures up to 120˚C.

Respondents were shown the SUMs, which were placed on stoves using heat-resistant tape. They were told that the devices record the temperature of the stove and that enumerators would come to their houses to download the data. Field workers informed respondents about necessary safety measures. Although Simons et al. (2017) argue that such sensors can reduce Hawthorne effects compared with other alternatives, we acknowledge the possibility of behavioral responses to the monitors that differ by treatment. For example, those who received payment for use after period 1 may have been somewhat more aware of the monitors than those in other treatments because of the incentive. We believe such effects are limited, however, because respondents were treated equally over a reasonably long timeframe with the very small monitors (1.7 cm in diameter); it is therefore likely that after a short time, users would ignore the device.[8]

We define a cooking event as occurring if the temperature exceeded 40˚C. We chose 40˚C as our cutoff, because in our research sites, which are in highland areas, 35˚C was the maximum ambient temperature measured using thermometers in respondents' homes. We conduct robustness checks with 45˚C and 60˚C cutoff points, which only strengthen our findings.

To measure the frequency of use during a monitoring period, we use signal processing and analysis (O'Haver 1997), which count the number of contiguous 10-minute logging period blocks the stove surface temperature exceeds the critical value; whether it takes a household 45 minutes or 2 hours for a particular *injera* baking event, each event counts as one cooking period. To allow for the pos-

[8]A subset of 108 households participated in three controlled cooking tests that are not part of this study, but are discussed in Gebreegziabher et al. (2018). In our regression models, we control for participation in this activity.

sibility that in some weeks the Mirt stove may be used more often than others, we do not further restrict this measure of usage. It is therefore possible that in a particular week the Mirt stove may not be used at all or could be used several times. The average stove use in a monitoring period is the number of measured cooking events divided by the number of weeks temperature was measured.

Regular cooking of *injera* is easily defined compared with other foods (e.g., coffee, stews, or breads) and is at least twice a week. To exploit this feature of Ethiopian cooking behavior and focus on true adoption rather than irregular use, which is less meaningful, we mainly examine the effect of our treatments on whether households use the Mirt stove at least twice a week. Such an estimation strategy also helps mitigate any outlier effects. As a robustness check, we analyze cooking frequency as a continuous variable and find no major changes (Appendix C).

The traditional cooking technology in most of Ethiopia and all of our study sites is made from three large stones arranged as a tripod, which is difficult to reliably monitor using SUMs, because it can be easily moved. We imperfectly infer rebound effects, but we note that over 90% of households report using three stones in addition to their Mirt stove. This finding is not surprising because Mirt is highly specialized for *injera* baking.[9] Because we are analyzing stove use rather than fuelwood savings, and because any rebound effects apply equally across treatments, rebound effects are of limited relevance. We nevertheless acknowledge that Mirt reduces the cost of cooking in terms of wood use, possibly causing cooks to cook more frequently or to be less attentive while cooking.

Sampling Strategy

The sample villages are randomly selected from a 110 *kebele* random sample selected in 2012 by the Ethiopian Development Research Institute,[10] from which forestry and other community-level data were collected. Information from these study sites was used to test randomization. From the 110 sites, we remove 15 that were included in our pilot survey. We remove 14 villages where three-stone tripods are not used or *injera* is not typically cooked.

From the remaining 81 villages, we select 36 at random using proportionate random sampling stratified by regional state (Amhara, Oromia, and Southern Nations Nationalities and Peoples [SNNP]), with the weight of each state determined by its forest area. Forest area is used because most fuelwood for cooking comes from forests. This measure is also positively correlated with population and land area. Based on this criterion, 20% of the study sites are from Amhara, 50% from Oromia, and 30% from SNNP regional states. The selection of villages in each regional state was done using simple random sampling. All sites have formal or informal forest user groups, none of which have legal status.

We obtained the official roster of households for the 36 village sites from *kebele* administrations, and from each village 14 households were randomly selected. A total of 360 households (10 from each site) was randomly selected to receive the Mirt stove, with 120 households receiving each monetary treatment. Respondents are adults who make substantive decisions and were typically self-identified household heads. If decision-makers were not at home when enumerators arrived, respondents were either called home by others or enumerators came back later. Respondents were told by enumerators that they were chosen randomly to receive a stove under the same terms as others in their village and would be asked to participate in a baseline survey. The questionnaire included information about the household and the respondent, who was expected to have influence regarding the frequency of Mirt stove use.

Enumerators explained the stove features, SUMs, and details of the treatment to each

[9] Stoves made from three large stones are easy to move, and the fire is difficult to contain, potentially dislodging or overheating SUMs. With its approximately 50 cm main burner, the Mirt stove cannot accommodate normal pots, making it virtually impossible to shift to other uses. The Mirt stove can cook with waste gases before they are vented, and more than 80% say they use the second burner for cooking stews and coffee.

[10] *Kebele* translates as "peasant association" and is made up of several villages. It is the smallest jurisdiction in Ethiopia. We have only one randomly selected village per *kebele*, and therefore we use village and *kebele* interchangeably.

respondent. They informed respondents that although stove use was not required to receive a stove, Mirt was expected to reduce fuelwood consumption, and they were encouraged to use them. Respondents were asked for their formal oral consent, and all agreed to participate. There was therefore 100% initial up-take, likely because of the positive reputation of Mirt, which are typically produced and sold by trained private producers. If there had been refusals, the strategy was to choose randomly from remaining households in the village.[11] There was no attrition during the study period, and no respondent was using a Mirt ICS at baseline (i.e., no respondents had the ICS prior to the intervention). All Mirt stoves remained in place during the first year. There was no abandonment and no breakage that precluded use.

The fieldwork was conducted by five supervisors with significant field experience and an average of four enumerators per supervisor in all four periods of the study. Household representatives came to a centralized location, such as a school or *kebele* office, to receive their stoves. Villagers then took the six concrete stove pieces and the clay cooking plate back to their homes (Appendix B). The following day, enumerators installed the stove in either the main home (36%) or a separate kitchen (64%) by mudding together the six concrete pieces. They gave cooks training on how to use the stove, and the SUM device was installed using heat-resistant tape.

Enumerators initiated SUM devices and set them to record surface temperatures every 10 minutes. We monitored Mirt stove use June–August 2013 (period 1), August–October 2013 (period 2), March–May 2014 (period 3), and May–July 2014 (period 4). No respondents sold or transferred their stoves during or between any of the monitoring periods.

4. Results

Descriptive Statistics

To contrast short-run and longer-run use and evaluate sustained use of Mirt, we mainly emphasize results from the first and last periods, which are approximately 12 months apart. There are seasonal variations in usage and comparing two periods a year apart helps control for these variations. We present results that include periods 2 and 3, which show that results do not change and only become more precise when all periods are included.

We check balance across treatments using 11 village-level metrics that are likely to affect villager decisions to regularly use a new fuelwood-saving technology. These variables include average altitude and rainfall, measures of population size, participation in forest user groups, existence of forest regulations and changes in forest biomass over time. Only for existence of forest rules and regulations can we reject at the 5% level that treatments are from the same distribution (Appendix C).[12]

Table 1 presents summary statistics for households participating in the field experiment. All variables come from our household survey and are used as controls in all empirical models; we therefore adjust for systematic differences across households by including these controls.

During each monitoring period, the SUM devices recorded data for 37 to 56 days. The median recording period was 49 days. Appendix C presents information on valid observations by period and treatment. In the first and last periods, a maximum of 360 households (120*3) could have valid observations. Because of SUM failures, we obtain monitoring data from 300 households in the first period and 301 households in the last period. SUM

[11] Sample households on average spend significant time collecting fuelwood for cooking. Typically, one to four household members collect fuelwood an average of three times a week, with each collection trip on average requiring approximately four hours. We acknowledge that around the world, 100% uptake is rare, but in sub-Saharan Africa, complete initial acceptance may be more common than in other regions. Though monetary treatments differed somewhat from those we used, in Senegal, for example, Bensch and Peters (2015) found that the ICS offered was accepted by all households. Rosa et al. (2014) and Thomas et al. (2013) also have universal initial uptake of freely distributed modified rocket stoves in Rwanda.

[12] We reject that five respondent or household-level variables (respondent gender, number of livestock, average number of *injera* baked, use of Mirt stove for purposes other than *injera* baking, and whether pure teff flour is used to make *injera*) come from the same distribution ($p < 0.05$). We adjust for these variables in all models.

Table 1

Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.
Socioeconomic			
Age of respondent in years	359	42.134	13.172
Male	359	0.880	0.325
Education (literate = 1, 0 otherwise)	360	0.383	0.487
Family size in adult equivalent	360	4.888	1.860
Number of livestock in tropical livestock units (TLU)	356	5.077	3.715
Randomly chosen to participate in controlled cooking test = 1, 0 otherwise	360	0.300	0.459
Estimated coefficient of relative risk aversion	355	3.815	1.214
Cooking			
Average number of *injera* baked at a time	359	19.721	10.303
Use the improved stove for purpose other than baking = 1, 0 otherwise	360	0.333	0.472
Uses pure *teff* flour = 1, 0 otherwise	360	0.156	0.363
The stove is installed inside the house = 1, 0 otherwise	358	0.360	0.481
Baseline (i.e., pre-intervention) Mirt stove usage per week	360	0	0

Note: See Vieider et al. (2018) for a discussion of the method used to estimate risk aversion.

Table 2

Mean Frequency of Mirt Stove Use per Week by Period and Treatment

	Pooled Sample	Period 1 (June–August 2013)	Period 2 (August–October 2013)	Period 3 (March–May 2014)	Period 4 (May–July 2014)
50 Birr use incentive (Incentive)	2.27 (392)	1.95 (96)	2.18 (86)	2.69 (107)	2.22 (103)
Paid 25 Birr (Pay)	2.07 (422)	1.56 (101)	1.81 (103)	2.57 (111)	2.29 (107)
Received stove for free (Free)	2.52 (393)	2.08 (103)	2.41 (99)	2.95 (100)	2.69 (91)

Note: 120 households were randomized into each cell. Valid observations are in parentheses.

failures are mainly due to incompletely controlled flames, causing SUM temperature tolerances to be exceeded. To reduce SUM failures, we could have made more frequent visits. We rejected this option because during such visits, field staff may have unconsciously affected stove use behavior.

We investigate SUM failures and find that most households experienced no failures during periods 1 and 4, which are of primary interest, only 3.9% had failures in both periods, and valid observations are very similar in the two periods. We estimate the determinants of SUM failures and find that they show no systematic variation with the variables in Table 1 or treatments in either periods 1 or 4. Households who used their stoves more frequently in period 3 (the highest average usage period) were more likely to have experienced a SUMs failure ($p = 0.04$). Higher usage in other periods did not affect failures (Appendix C).

Stove Usage

Table 2 presents average Mirt stove usage per week across the four periods by treatment. On average in the pooled sample, and for most periods and treatments, Mirt stoves were used approximately twice a week, suggesting that households typically used the Mirt stove with a frequency consistent with standard *injera* cooking patterns (95% confidence interval 2.16, 2.41).

We find that in the pooled sample, Free Treatment resulted in the highest average stove use of 2.52 times a week (95% confidence interval 2.30, 2.75), followed by Incentive Treatment (95% confidence interval 2.02, 2.52).

Regular use on average across treatments is notable and indicates that households generally seem to have adopted the technology.

For all treatments, period 4 average usage is greater than in period 1 and in period 3 average usage is also greater than period 1.[13] This finding of increasing average use over time probably largely reflects learning to use the stove more effectively. As reported in a related paper (Gebreegziabher et al. 2018), which utilizes a sub-sample that participated in controlled cooking tests, average time to cook a standardized batch of *injera* fell substantially over time. In all periods, Free Treatment average usage is highest.

We now discuss the effects of different monetary incentives on Mirt stove use. We first categorize average usage into three groups: (1) at least twice a week, which indicates regular use; (2) used, but less than twice a week; and (3) nonuse over each approximately six-week monitoring period. In Figure 1, we show usage intensity by treatment in periods 1 and 4. Respondents randomized into Incentive Treatment on average were more likely to regularly use their stoves in period 1 than those randomly assigned to other treatments. We do not find that usage clusters at the minimum to receive the incentive, and we do not find that average stove use decreases after the incentive is withdrawn.

Over the one-year timeframe, we observe a slight increase in the proportion of households using the stove more than twice a week (from 42% to 51%) and in the proportion of nonusers (from 6% to 11%). Using a χ^2 test, at the 5% significance level we can neither reject that the distributions are different between periods for each treatment separately nor that the distribution of usage is different between treatments for each period separately.[14]

[13] Period 3 has the highest average use across all treatments. Ambient temperatures are warmest during March to May, which coincides with period 3. Households in our sample, all of which lack refrigeration, may therefore need to cook more often to avoid spoilage.

[14] During the period of analysis, there was no significant damage to stoves. At the end of period 4, all Mirt stoves could be used. As a robustness check, in Appendix C we include results only for households without SUM failures in either periods 1 or 4 and find results that are very similar to those in Figure 1.

Although in period 1 regular usage in the Incentive Treatment was above the other two treatments (45% versus 38%), with no nonusers (versus 9%–11% for the other two treatments), by period 4 11.1% of Incentive Treatment respondents had stopped using their stoves. At 56%, Free Treatment in period 4 had the highest portion of regular users (versus 47% for Pay Treatment and 51% for Incentive Treatment) and lower levels of disadoption than Pay Treatment, but not Incentive Treatment. Compared with the other monetary incentives, Incentive Treatment is found to generate more short-run adoption, but Free Treatment appears to be most consistent with longer-run regular use.

Explaining Regular Use

Table 3 presents results of random effects probit regressions to explain regular use of the Mirt stove in periods 1 and 4 using a difference-in-difference specification. Table 4 has the same models using observations from all four periods, and results are virtually identical, though increased degrees of freedom offer more precise estimates. Random effects account for time-invariant household-level unobservables, and results are virtually the same in our pooled probit models, which are included in Appendix C along with random effects probit results that include all controls; because the controls are not the main focus, they are only briefly discussed.

Regressors include treatments interacted with time periods, as well as the socioeconomic and cooking controls in Table 1. These controls are included because they could influence the frequency of Mirt stove use regardless of treatments, household unobservables, or time trends. We include a dummy for whether villages had group training. We cluster errors at the village level, which is the highest level of aggregation relevant to our treatments (Cameron, Gelbach, and Miller 2011). Free Treatment in period 4 is the omitted category, which means we compare treatments with the longer-run effect of free distribution. Thus, a positive coefficient for a treatment in a specific period means that this treatment in that period is more likely to result in regular use than Free Treatment in period 4.

Table 3

Random Effects Probit Regression of Use of Mirt Stove at Least Twice per Week (Marginal Effects) for Periods 1 and 4

Variable	Model 1 All Households	Model 2 Households with No SUM Failure in Any Period
Incentive period 1	–0.330(0.49)	–0.186 (0.56)
Incentive period 4	–0.153 (0.516)	–0.077 (0.59)
Pay Treatment period 1	–1.040 (0.62)*	–0.725 (062)
Pay Treatment period 4	–0.135 (0.54)	–0.050 (0.55)
Free Treatment period 1	–0.514 (0.25)**	–0.792 (0.23)***
Socioeconomic characteristics	YES	YES
Cooking characteristics	YES	YES
Group training dummy	YES	YES
Wald X^2 (17) (Prob.> X^2)	43.92 (0.00)***	36.66 (0.00)***
Ln(sigma^{2}mu)	0.174 (1.42)	0.032 (0.47)
Number of groups	334	222
Observations	579	444

Note: Free Treatment period 4 is the omitted category. In both models, we control for the variables presented in Table 1. Robust standard errors clustered at *kebele*/village level in 36 clusters.

***, **, * indicate significant at the 1%, 5%, and 10% levels, respectively. In neither model is the group training dummy statistically significant.

We conduct a number of robustness checks, including analysis of households with no SUM failures to be sure that the distribution of SUM failures does not affect our results. These results are presented in column 3 of Tables 3 and 4. In Appendix C, we include ordinary least squares models with numbers of cooking periods, rather than regular use as the independent variable. We also present random effects probit models with cooking events defined as 45˚C and 60˚C. All these robustness checks provide results that are very similar to Tables 3 and 4. We estimate wild bootstrapped (1,000 replications) probit models, using the score bootstrapping algorithm of Kline and Santos (2012) implemented via the STATA boottest postestimation command. This method is suited to estimating standard errors with relatively few clusters (our 36 clusters is above the suggested cutoff). These models give less precise estimates than in Tables 3 and 4.

As shown in Table 3, all treatments show negative, and in some cases significant, coefficients, meaning that they are equally or less likely to promote regular use than Free Treatment in period 4. The significant negative coefficient for Free Treatment period 1 (p = 0.04) is economically significant, indicating that over the one-year timeframe the estimated probability of regular usage under Free Treatment increases by 51% (overall sample) to 79% (subsample with no SUMs failures). This finding suggests that free distribution promotes increasing regular usage over time.[15] The coefficient estimate for Pay Treatment period 1 is also negative, but significant only at the 10% level. Results are similar for the subsample without SUM failures. We acknowledge that lack of statistical precision could be due to our sample size, so insignificant results should not necessarily be interpreted as no effect.

Table 4 presents results for all periods, and we find they are virtually identical to those in Table 3 but with increased precision. In the full sample, coefficient estimates for Free Treatment and Pay Treatment in period 1 are again negative and large in magnitude, but with data from all four periods included, both are significant at the 5% level; households who were randomized into Free Treatment are estimated to have a 59% to 88% greater chance of regular use in period 4 than in period 1. Pay Treatment period 2 has less regular

[15] Actual change in regular usage was from 42% to 56%, which is less than the estimated percentage. The difference is likely due to including socioeconomic and cooking characteristic controls.

Table 4
Random Effects Probit Regression of Use of Mirt Stove at Least Twice per Week (Marginal Effects) for All Four Periods

Variable	Model 1 All Households	Model 2 Households with No SUM Failure in Any Period
Incentive period 1	–0.407 (0.46)	–0.224 (0.55)
Incentive period 2	–0.158 (0.49)	–0.043 (0.58)
Incentive period 3	–0.165 (0.48)	0.074 (0.55)
Incentive period 4	–0.23 (0.50)	–0.110 (0.58)
Pay Treatment period 1	–1.20 (0.51)**	–0.827 (0.56)
Pay Treatment period 2	–0.936 (0.45)**	–0.646 (0.52)
Pay Treatment period 3	–0.161 (0.42)	0.018 (0.49)
Pay Treatment period 4	–0.207 (0.43)	–0.095 (0.50)
Free Treatment period 1	–0.59 (0.27)**	–0.888 (0.22)***
Free Treatment period 2	–0.012 (0.23)	–0.128 (0.28)
Free Treatment period 3	0.281 (0.21)	0.20 (0.28)
Socioeconomic characteristics	YES	YES
Cooking characteristics	YES	YES
Group training dummy	YES	YES
Wald X^2 (26)	85.65 (0.00)***	65.46 (0.00)***
Ln(sigma^{2}mu)	0.504 (.)	0.457 (.)
Number of groups	342	222
Observations	1166	888

Note: Free Treatment period 4 is the omitted category. In both models, we control for the variables presented in Table 1. Robust standard errors are clustered at *kebele*/village level in 36 clusters.
***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. In neither model is the group training dummy statistically significant.

Mirt stove use than Free Treatment period 4. In both models, except for Free Treatment in period 3, estimated coefficients are negative and magnitudes are similar to those in Table 3.

A number of control variables offer insights. In all specifications, the 36% of Mirt stoves installed in main houses rather than in separate indoor kitchens are regularly used about 79% less than the average ($p < 0.001$). This finding suggests that users prefer to cook *injera* on Mirt outside the main home. Larger households, those that cook more *injera* during each baking session and those who cook foods other than *injera* on the stove are more likely to regularly use Mirt stoves; the Mirt stove may therefore offer scale economies.

We compare the effects of treatments on regular usage by period using pairwise likelihood ratio tests of whether estimated parameters in model 1 in Table 4 are equal across treatments within periods (Appendix C). We do not observe sunk cost effects, as usage is statistically the same for Pay and Free Treatment households in all periods, and we acknowledge that we could observe sunk cost effects if the Pay Treatment subsidy were reduced.

The only statistically significant difference within periods is that Incentive Treatment in period 1 has statistically higher usage than Pay Treatment in period 1, which is likely due to the monetary incentive; there are no first-period differences in regular usage compared with Free Treatment.

Finally, there is no evidence that Incentive Treatment incentivizes usage behaviors that are sufficiently persistent to cause it to better promote period 4 regular use than the other two treatments. That it is not less effective than Pay Treatment suggests that such incentives do not crowd out intrinsic motivations based, for example, on performance of the Mirt stove.

We use the results from Table 4 to analyze changes in regular use over time. Both Pay Treatment and Free Treatment on average promote increased regular use over time, which is in line with our descriptive results. Pay Treatment has the biggest increase in regular usage, but the period 1 average usage for Pay Treatment was the lowest by a wide margin and statistically less than Incentive Treatment ($p \approx 0.09$). Period 4 average usage is much higher for Free Treatment (2.69 versus 2.29 times a week or ≈ 20%); in Tables 3 and 4, the estimated period 4 Pay Treatment coefficient is negative but not statistically significant. Test results are provided in Appendix C. These results are robust to 45˚C and 60˚C definitions of cooking events.

Summary, External Validity, and Caveats

A large proportion of the human population in low-income countries, particularly in sub-Saharan Africa, uses biomass fuels for cooking. ICSs, such as the Mirt stove, can contribute to reduced fuelwood use, possibly resulting in positive effects on forests, the climate, and human welfare if stoves are regularly used. This article uses a field experiment to evaluate the effect of monetary treatments on short and longer-run ICS usage intensity. The monetary treatments examined here—Pay, Free, and Incentive—are common to many cookstove programs and closely resemble real-world treatments. They are also salient in the health technology literature, but to date somewhat less so in the ICS literature, a gap this study seeks to help fill.

Our research has four main findings. First, based on measured free-will usage and informed by our analytical model, the Mirt stove appears to deliver net benefits that are sufficient for average cooks to use it regularly (95% confidence interval 2.16, 2.41).

Second, making people pay for the Mirt stove or offering them a usage incentive does not increase use frequency vis-à-vis free distribution in the short-run (Prob > X^2 = 0.96) or after approximately one year (Prob > X^2 = 0.64). These results are in accord with our simple analytical model, as well as the findings of Ashraf et al. (2010), which suggest that sunk costs have no effect on use.

Third, offering first period incentives to use the Mirt stove spurs regular use during the first monitoring period compared with requiring payment (Prob > X^2 = 0.09) but not with offering the stove for free (Prob > X^2 = 0.70). Incentive Treatment average and regular use after approximately one year are less than under Free Treatment, although in neither case statistically significant (Prob > F = 0.55 and Prob > X^2 = 0.65); in the pooled sample and in all periods, Free Treatment average usage is greater than the other two treatments.

Finally, in contrast with Incentive Treatment, which exhibits no detectable regular-use, habit-formation effect (Prob > X^2 = 0.58), Free Treatment (Prob > X^2 = 0.0001) and Pay Treatment (Prob > X^2 = 0.03) promote increasing, economically significant use over time. The Free Treatment longer-run regular usage rate is higher than for Pay Treatment, but the difference is not statistically significant (Prob > X^2 = 0.63).

How externally valid are our findings? Ethiopia is one of many low-income countries with institutional constraints, such as poorly functioning labor, credit, and savings markets, that affect affordability. Our findings on monetary treatments may be externally valid in rural areas of other low-income countries if, as appears to be the case for the Mirt stove, ICSs are appropriate for users. This means that stoves must fulfill cooking needs (e.g., not too inconvenient to use), meet expectations to reduce fuelwood consumption, and be sufficiently durable so they can be regularly used for extended periods. Studies that have noted low usage intensity have typically been identified as lacking one or more of these characteristics.

We can only speculate on the effects of treatment levels other than those we used. Such research would be an obvious extension. In particular, although in our Pay Treatment all potential recipients accepted the stove, screening effects are to be expected at dramatically higher prices.

A combination of appealing features, perhaps including a reasonably user-friendly design, durability during the first year (i.e., there was no breakage that precluded use), and fuelwood savings with no increase in cooking time (Gebreegziabher et al. 2018), appears to have caused the Mirt stove to be regularly used on average. That the Mirt stove cooks such a specialized food should be cause for pause before generalizing findings to contexts where ICS are called on to cook many types of foods. It is also significant that cooks do not typically bake *injera* every day, while even in other sub-Saharan countries main starches are cooked daily. Finally, the Mirt stove is primarily designed to reduce fuelwood consumption. Survey evidence from our sample suggests that many households face significant firewood scarcity. Our results may not transfer well to areas where fuelwood scarcity is less of a factor.

5. Conclusions and Policy Implications

Providing Mirt free of charge is at least as effective as other monetary treatments in terms of encouraging high levels of regular usage and is the most effective treatment to promote high and increasing levels of longer-run use. Those wishing to promote Mirt stoves and other improved biomass cookstoves with similar characteristics may not need to excessively worry that giving stoves away will adversely affect usage. Although free distribution has budgetary consequences, this finding is encouraging, because Mirt and other ICS promoted in sub-Saharan Africa often cost less than $20. Free distribution may therefore be a programmatic possibility, particularly when carbon finance can reduce costs (Levine et al. 2018). Such an approach also offers the advantage that it increases real incomes for often poor households. It also avoids the monitoring associated with usage incentives, which (at least as a one-shot inducement) we find are unnecessary to promote longer-run regular use.

We are now in a period of intensive fuel-efficient biomass stove evaluation in many countries. It is critical to understand what factors drive regular usage, and we strongly suggest that, when possible, stove programs be implemented in conjunction with field experiments. We hope that by better understanding what promotes regular use over the time periods we have investigated, ICS can more effectively fulfill their potential to improve the welfare of those dependent on biomass fuels.

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