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Subsidies, Information, and Energy-Efficient Cookstove Adoption

A Randomized Uncontrolled Trial in Rural Ethiopia

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Mandy Malan, Marten Voors, Jörg Ankel-Peters, Selan J. Seje, Lotte Heuburger, Dawud Seid, and Abiyot Mitiku[1]

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Abstract

Energy-efficient biomass cookstoves (EEBC) are an important technology for the three billion people relying on firewood and charcoal for cooking in the Global South. This paper assesses the price-responsiveness of demand for EEBC and the role of information about health and economic benefits. The pilot program under evaluation randomized different subsidy schemes (40%, 70%, and 100% subsidy) and information treatments across 292 Ethiopian villages. Unlike previous willingness-to-pay studies we examine a take-it-orleave-it approach in an uncontrolled and hence natural setting. We observe that EEBC demand is highly price-sensitive: There is virtually no EEBC uptake in the no-subsidy group, irrespective of which information households received. Yet, uptake increases considerably for households who received a high subsidy (70% or a 100%). Adding information on economic benefits nearly doubles uptake when coupled with such high subsidies. Our results confirm the emerging picture in the literature suggesting that subsidization for EEBC is required to foster widespread adoption.

JEL-Codes: C93, O12, O13, Q41, Q48

Keywords: Household technology adoption; biomass consumption; randomized controlled trial; humanitarian assistance; environmental degradation

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1 Mandy Malan, RWI and Wageningen University NL; Marten Voors, Wageningen University, NL; Jörg Ankel-Peters, RWI; Selam J. Seje and Lotte Heuberger, Netherlands Red Cross, NL; Dawud Seid and Abiyot Mitiku, Ethiopian Red Cross Society, Ethiopia. - **Financial disclosure**: *This research was funded by the 3FM Serious Request Campaign. Additional support was provided by the Ethiopian Red Cross Society and to the Netherlands Red Cross Society.* **Competing interests**: *The authors of this paper from the Netherlands Red Cross and Ethiopian Red Cross Society were involved in the implementation of the project and collection of the data. They declare that they did not in any way influence the data or findings of this study. The data was analysed by researchers from Wageningen University and RWI. These authors declare that they have no competing interests that could appear to influence the findings of this study.* - *We are grateful to Joy de Korte and the staff of Ethiopian Red Cross Society for their efforts in the field and to the Netherlands Red Cross Society for their overall support. In addition, we are grateful for valuable comments and suggestions to Erwin Bulte, Francesco Cecchi, Colin Vance as well as participants of the SETI 2022 workshop.* - *All correspondence to: Jörg Ankel-Peters, RWI, Hohenzollernstr. 1-3, 45128 Essen, Germany, e-mail: joerg.peters@rwi-essen.de*

1. Introduction

Biomass cooking is a considerable cause of environmental degradation, related to deforestation (Jeuland & Pattanayak, 2012) and air pollution (Martin et al., 2011; WHO, 2014b). In Ethiopia, biomass accounts for over 85% of energy demand and has one of the highest per capita fuelwood consumption rates globally (IEA, 2019a). Biomass demand is projected to increase in the coming years, remaining the primary source of energy demand in Ethiopia and Africa as a whole (IEA, 2019b). Firewood and charcoal are extracted unsustainably, making biomass consumption a significant cause of forest degradation and deforestation an hence an important contributor to carbon emissions (Bailis et al., 2015). Energy-efficient biomass cookstoves (EEBC) have been heralded as a potential low-cost solution. EEBC can reduce the burden of fuelwood collection (see (Krishnapriya et al., 2021) and expenses associated with fuel purchases, while also mitigating carbon emissions at low abatement costs of 2 USD to 10 USD (Bensch et al., 2021). Yet, in most African countries, EEBC adoption remains limited.

In this paper, we estimate the impact of lifting financial and information constraints on EEBC uptake in rural Ethiopia. We evaluate a pilot project implemented by the Ethiopian Red Cross Society (ERCS)[1] that provided Ethiopian households with EEBC. ERCS randomized subsidy levels and information treatments across 292 villages, making this study the largest of its kind to our knowledge. We exploit this variation to estimate the price-elasticity of demand and interaction effects with information provision.

ERCS far-sightedly designed a randomized program to enable rigorous ex-post evaluation. An important constraint of this evaluation is that post-intervention data collection could not be administered as intended because of the conflict in Ethiopia (hence the *un*controlled trial). Thus, while ERCS's original evaluation objective was to measure the impact of EEBC on health outcomes, we use the exogenous variation to evaluate the willingness to pay that ERCS embedded in the natural roll-out of the program. Our paper thereby complements the important previous work on the demand responsiveness of cookstoves to price and information variations

[1] With support from The Netherlands Red Cross (NLRC)

that uses the Becker-deGroot-Marschak method or Vickrey auctions (Alem et al., 2023; Bensch & Peters, 2020; Berkouwer & Dean, 2022; Levine et al., 2018). Using a large village sample size (n=292), we observe the willingness to pay in a real market situation with no experimental contact to potential buyers (Berry et al., 2020; Munyehirwe et al., 2022). The setting we study is hence very close to what Levitt & List (2009) call "naturally occurring data", as opposed to "controlled data". Furthermore, the randomization was implemented by a large humanitarian organization with limited interference from researchers – which has been found to co-determine experimental results in other contexts (Usmani et al., 2022). All this, we believe, strengthens the construct validity and external validity of our findings (Esterling et al., 2023; Peters et al., 2018). The downside of this *un*controlled setting is that we lack the detailed information that are usually inherent to randomized controlled trials and field experiments, leaving us with some ambiguities that we cannot fully illuminate (but discuss transparently throughout the paper).

The promoted EEBC is the Mirt stove, specialized for baking *injera*, the main staple food in Ethiopia. Field-based cooking trials in other studies show that the Mirt stove reduces fuelwood consumption by 22% to 31% (Gebreegziabher et al., 2018). Because households in the target region spend, on average, an estimated 15 hours per week on fuelwood collection, the Mirt stove can help save up to 0.40 USD/day, valuing the saved time by the local hourly wage.

In 2019, ERCS organized stove promotion events targeting villagers with children under five to market the Mirt stove. ERCS conducted a randomized trial where villages were assigned different combinations of subsidy and information treatments. The information treatment included a "Health only" group, which received information on the health benefits of the Mirt stove, and the "Health and economic" group, which received information on both health benefits and fuel/time-saving potentials. Hence there is no group that received no information, which is yet also the business-as-usual approach in most EEBC promotion programs. The Mirt stove was then offered at different prices: at the market price of 3 USD, or at subsidized prices with levels of 40%, 70%, or 100%. In addition, in each village, the 30 most vulnerable households received a free stove as part of ERCS' vulnerable household policy. Due to the conflict, survey activities were limited,

resulting in limited data availability. Nevertheless, ERCS managed to record the number of sold Mirt stoves per village after one year, in addition to average uptake rates.

We find that demand for the Mirt stove is very price responsive. Uptake is virtually zero in the 'Health only, no subsidy' group (our reference group). Uptake increases for the 'Health only, 40% subsidy' group to 0.8 stoves per village on average, but this change is not statistically significant. For the 'Health only, 70% and 100% subsidy' groups uptake increases by 2.5 and 5.2 stoves, respectively. Furthermore, in the 'Health and economic' groups, uptake nearly doubles for all subsidy levels.

Our study speaks to the literature on EEBC in three ways. First, we contribute to the nascent literature on price responsiveness and the effectiveness of subsidization (Bensch & Peters, 2020; Mobarak et al., 2012; Munyehirwe et al., 2022a; Pattanayak et al., 2019). Given the scepticism among policy makers vis-á-vis subsidization, our study is an important additional piece of information confirming that subsidization is an effective tool to increase adoption. Second, our findings confirm previous studies, suggesting that depending on the type of information given, information can have substantial effects on uptake when combined with high levels of subsidies (Beltramo et al., 2015; Jeuland et al., 2020; Mobarak et al., 2012). Third, we build on and contribute to the various studies published on the Mirt stove. This literature has focused on different aspects of Mirt adoption, showing reductions of fuelwood consumption and carbon emission (Dresen et al., 2014; Gebreegziabher et al., 2018; Mekonnen et al., 2022), that learning-by-doing reduces cooking time (Bluffstone et al., 2022), that free provision is as effective at promoting short-run adoption as to offering usage incentives, and more effective in the long-run (Bluffstone et al., 2021), and finally documenting positive health impacts (LaFave et al., 2021). To our knowledge, so far there is no study looking at the price-responsiveness of demand for the Mirt stove.

2. Empirical approach

2.1. Background and intervention

Biomass cooking in Ethiopia has substantial negative impacts on health and the environment. Ethiopia is among the top four countries globally with the highest per capita fuelwood demand, non-renewable biomass extraction rates, and household air pollution-related diseases (Bailis et al., 2015). Unsustainable extraction of fuelwood places further strains vulnerable forests, with 3.6% of tree cover loss from 2000 to 2020 (Global Forest Watch, 2021), and fuelwood consumption is responsible for 64% - 79% of carbon emissions in Ethiopia (Bailis et al., 2015). Inefficient biomass stoves impose economic and health burdens on households. Currently, 77% of rural Ethiopian households rely on traditional three-stone stoves and 15% use self-built stoves (Padam et al., 2018). Most rural households (80%) spend significant time collecting fuelwood, predominantly done by women and girls, who consequently face health risks. Household air pollution is estimated to cause 12% of total deaths in Ethiopia (GBD, 2019). The National Government aims to switch 20 million households to EEBC or clean stoves by 2030 (Federal Democratic Republic of Ethiopia, 2011) and several NGOs have subscribed to this agenda.

ERCS, supported by local authorities, implemented an intervention to promote uptake of EEBC in Ethiopia. The intervention took place in 2019 in Ebenat and Simada, two Woreda (or districts) in the Amhara region (see Supplementary Section A for a map).[2] The intervention was conducted in the 292 villages within 10 randomly selected Kebele (or subdistricts). Detailed household data was collected by ERCS in the region on a small sample of households, but these households could not be matched to our study sample. We deem the sampled households to be similar enough to our study sample, so we report some descriptive statistics for a better understanding of the study context (Table 1). The data was collected for 237 randomly selected households with children under five in 17 randomly selected Kebele in Ebenat and Simada. We also report some insights from focus group discussions held in ten villages in the study area.

[2] The project originally aimed to cover the Oromia and Somali region as well, but due to security risks caused by the ongoing civil conflict, all activities by the implementing partner in this area were ceased.

Table 1. Household descriptive statistics in Ebenat and Simada

Variable	N	Mean	SD
Household head age	237	35.975	8.433
Education household head lower than primary (=1)	237	0.532	
Single headed household (=1)	237	0.211	
Number of children under 5	237	1.215	0.487
Cooking outdoors (=1)	237	0.105	
Separate cooking area (=1)	237	0.603	
Cooking in the house (=1)	237	0.291	
Wood for fuel (=1)	237	0.979	
Agricultural residue for fuel (=1)	237	0.759	
Charcoal for fuel (=1)	237	0.072	
Ill child in past two weeks (=1)	237	0.143	
Travel time to health facility >1hour (=1)	237	0.283	
Perceived quality of health facility is poor or fair (=1)	237	0.194	

Note: This data was collected for households in the same region as our intervention, before the start of the intervention. There is some overlap in the villages between this survey and our sample. N is the number of observations, SD is the standard deviation and is provided for continuous variables. Respondents could indicate multiple fuel types. Agricultural residue contains animal dung, agricultural crops, shrubs, grass and straw.

Nearly all households (97.9%) report using firewood for cooking, while agricultural residue was another common fuel type (75.9%). Few households cook outdoors (10.5%), and a significant number of households cooks inside the house (29.1%). Through focus group discussions, women were found to be responsible for cooking and fuelwood collection and typically spend 10 - 20 hours per week on fuelwood collection; only 27% of households purchase wood. Children are often around the women when cooking, exposing them to cooking fumes. Constraints for adopting EEBC is a tight budget. Other factors like intra-household dynamics (men are in control of the budget), limited supply of EEBC, and distance to selling points were also mentioned.

The EEBC introduced in this intervention is the Mirt stove (which translates as ''best" in Amharic). This stove is specialized for *injera* baking, the main staple food in Ethiopia (see the Supplementary Section B for photos) and was developed by the Ethiopian Energy Study and Research Center in the 1990s (Gebreegziabher et al., 2018). The Ethiopian government and various NGOs have supported production and commercialization of the stove and it features prominently in government plans to increase EEBC access. Despite its early introduction, Mirt adoption remains low. In Ethiopia just 4% of rural households use a Mirt stove (Gaia Association, 2014). For this intervention, The Netherlands Red Cross (NLRC) and ERCS followed protocols

and prior experiences by the government and German International Cooperation (GIZ). The stoves were produced by women support groups and available for the price of 3 USD.

The preparation of *injera* accounts for 60% of household fuelwood consumption (Gebreegziabher et al., 2012). The Mirt stove has been found to significantly reduce fuelwood use by 22 to 31% in field tests, whereas lab-tests have shown fuelwood-reductions of up to 50% (Dresen et al., 2014; Gebreegziabher et al., 2018; GIZ, 2011; Mekonnen et al., 2022). Based on a back-of-the-envelope calculation, in our study region, households who rely on wood collection can save the equivalent of 0.4 USD/day (using local wages to value time) and households who buy wood can save 1.5 USD/day when adopting a Mirt stove.[3] The relatively low cost of the Mirt stove thus quickly pays off in theory – a diagnosis similar to other settings where adoption nevertheless stays on a low level (Bensch et al., 2015).

The health impacts of the Mirt stove are uncertain. Although cooking smoke caused 3.2 million pre-mature deaths in 2020 (WHO, 2021), the extent to which household air pollution needs to be curbed and what role cooking technologies play into addressing this health burden remains unclear. Interventions with clean fuels or stoves so far do not provide the proof-of-concept that they improve the health status of users, possibly due to ambient air pollution, fuel stacking, or improper stove usage (Jack et al., 2021; Mortimer et al., 2017; Steenland et al., 2018). There are, in turn, indications that EEBC might lead to exposure reduction due to a shorter cooking duration, more outside cooking (Bensch & Peters, 2015; Langbein et al., 2017; Lenz et al., 2023) or higher awareness of the harmfulness of smoke. For Mirt in particular, LaFave et al. (2021) document positive effects on young children's health – a surprising finding given that La Fave et al. also emphasize that there is no reduction of smoke exposure, and heterogeneity across the sample is noteworthy (see Bluffstone et al., 2019). Nevertheless, based on WHO standards, the Mirt stove

[3] We assume fuel consumption for cooking of 5.3 kg/day, 14.3 hours/week of fuelwood collection, a fuelwood price of 25 ETB/kg (all values from qualitative field visits). The daily wage for casual wage is assumed at 125 ETB/day (from World Food Programme casual labour prices for Ebenat, South-Gondar in 2020), and a workday is assumed to be 8 hours long. Mirt stove fuel wood saving is set at 35%. Last, we assume a linear relationship between fuelwood collection time and the amount of fuelwood collected. We use the 2019 exchange rate of 0.033 USD/ETB.

would not be considered as clean, although no explicit guideline for practitioners exists on which stoves can be expected to be health-improving (WHO, 2014a, 2022). Furthermore, to our knowledge, there is no state-of-the-art test available that provides credible evidence of emissions of Mirt vis-à-vis the baseline scenario[4].

It is against the background of this complex discussion that this project assumed that the Mirt stove can improve users' health outcomes. The study was, in fact, designed to contribute to this ongoing public health debate by measuring direct health impacts of the Mirt stove (on pneumonia, etc.). Unfortunately, due to the ongoing conflict in Ethiopia, implementing an endline survey was not possible.

2.2. Experimental design

We assess the causal effect of two treatments to promote Mirt stove uptake using a randomized 2x4 factorial design (Figure 1). Treatments were randomly assigned to 292 villages through a lottery session blocked at the Kebele-level for geographical balance. In April 2019, parallel promotion events were held in each of the ten Kebele, varying the information on the Mirt stove. All households with a child under five in each village were invited based on randomization. Travel time to the Kebele centre varied, ranging from 20 minutes to 2.5 hours. Both husbands and wives were encouraged to attend. After the meetings, participants received a voucher with subsidy levels of 0%, 40%, 70%, or 100% to purchase the Mirt stove. There is hence no pure control group that received no Mirt offer or information. We estimate the treatment effect of the subsidy and information treatments using the 'Health only, 0% subsidy'-group as a reference group. In addition, the 30 most vulnerable households with under-fives in each Kebele received a free Mirt stove as part of ERCS' vulnerable household policy. These vulnerable households are not

[4] In a memo-style document, GIZ (2011) reports emission reductions in a controlled cooking with a small sample size test but heterogeneity of emissions across the conducted 8 cooking tests for 3 stoves is very large (with average CO emissions ranging from 0.45 ppm to 38 ppm for the same stove). What is more, the testing procedures and methodologies are documented poorly, it remains unclear why results are heterogeneous.

expected to purchase a stove at any non-zero price, making our measure of price sensitivity conservative.

Figure 1. Randomization of villages across 2x4 factorial design

		Subsidy treatment			
		0%	**40%**	**70%**	**100%**
Information treatment	**Health only**	37 villages *reference group*	40 villages	37 villages	37 villages
	Health and economic	33 villages	37 villages	38 villages	38 villages

Note: This figure shows the 2x4 factorial design of this study. Villages were randomly assigned to one of eight treatment groups with varying levels of information and subsidies. The number of villages assigned to each treatment is shown in the table cells. To measure treatment effects, we use the 'Health and economic, 0% subsidy'-villages as a reference group (darker shading).

Based on the randomization, we estimate the following model to assess the effect of subsidy levels and the information treatment on EEBC uptake:

$$Y_{ij} = \beta_0 + \Phi \mathbf{TREAT_i} + \gamma_j + \varepsilon_{ij}$$

Where Y_{ij} refers to the number of stoves sold in village i in Kebele j in the year after the intervention, $\mathbf{TREAT}_i$ is a vector of dummies for each combination of type of information provision and subsidy-level that the village received (i.e., one of seven treatment groups in Figure 2, where the 'Health-only, no subsidy' group is the reference group). γ_j are Kebele-fixed effects. ε_{ij} is a village-specific error term. The estimated intent-to-treat (ITT) on uptake for each information meeting-subsidy level interaction is given by Φ.

The 'Health only'-promotion event included a stove demonstration, comparing the Mirt stove and the three-stone stove. Extension workers then provided information on the potential health benefits related to a reduction in smoke exposure and workload, engaging in discussions about these benefits with participants. At the parallel event, participants received the same information, but now with a focus on time- and monetary savings. Participants did an exercise to calculate potential money saved due to fuel saving (see Supplementary Section C for detailed information on the health and economic benefits conveyed during the meeting). It is worth noting that while also the 'Health only' group received information on the workload, the focus was on the health-related implications, while for the 'Health and economic' group the economic implications where made a lot more salient. Furthermore, by having participants calculate potential savings, the 'Health and economic' treatment included an active learning component. Nevertheless, the overlap in provided information render the interpretation of mechanisms at play difficult.

The vouchers distributed at the end of the event could be used to buy a Mirt stove within one year after the event. After purchasing the stove, the frame-parts of the stove were produced within three months at centralized production sites at the Kebele level. The frame-parts of the stove were then transported to the Kebele administration office, centrally located for all respective villages. Households were contacted about stove dissemination through Health Development Armies[5] and Kebele leaders. In addition, ERCS held biweekly monitoring visits in which households were reminded about stove collection. Upon collection, the household transported the frame-parts of the stove, disassembled into parts, to the house. Installation was done by the household with help of extension officers. Payment for the stove was due upon delivery of the stove and could also be fulfilled in two instalments. In April 2020, a year after the promotion events were organized, ERCS aggregated the number of Mirt stoves per village that had been purchased with a voucher. This number of stoves sold at the village-level is the main outcome of this study. There was no reliable village-level data collected on the number of attending villagers, but we do have an approximation of the total number of villagers that attended the meetings in

[5] Health Development Armies are groups of women-centered community volunteers that aim to improve health outcomes. These groups were launched across Ethiopia in 2011 and work alongside standard health extension workers.

each Woreda. We can thus only approximate the average adoption rate per Woreda. For more details on the randomization, stove promotion meetings, information provided and transport and monitoring, see Supplementary Section C.

Another potential caveat is treatment contamination, since villagers assigned to different subsidy groups attended the same Kebele promotion event; that is, villagers might have sold or swapped vouchers across villages. We deem this unlikely as vouchers could only be handed in at Mirt sales points by the household that received the voucher. Furthermore, ERCS volunteers monitored whether stoves were installed and used by the households themselves on a weekly basis. The produced Mirt stoves could easily be identified by the volunteers due to the ERCS logo on it (see Supplementary Figure B2). ERCS came across two cases where households sold their Mirt stove. ERCS tried to minimize spillovers related to the information treatment by holding the information meetings, to which villagers were randomly assigned, in parallel sessions at different locations. However, since vouchers were valid for a whole year, we cannot fully rule out information spillovers from the economic information treatment groups to the health information group, making the observed information effect a lower bound of the true treatment effect.

3. Results

Table 2 presents the impact of the subsidy and information treatments on stove adoption (see Supplementary Figure D1 for a graphical representation). We find that households in the reference group adopted on average 0.4 stoves. Once subsidies are introduced, uptake increases substantially for the 'Health only'-villages, though only statistically significantly for subsidies of 70% or higher. For the 40% group, Mirt sales increase by 0.8 stoves to 1.2 stoves sold per village on average (not statistically significant). At a subsidy-level of 70%, household uptake increases by 2.5 stoves to almost three stoves sold per village – a sixfold increase. At a subsidy-level of 100%, average stove collection per village rises by 5.2 - a more than twelvefold increase compared to villages that received no subsidy.

Table 2. Effect of subsidy-level and information treatment on stove uptake

	Number of stoves
Health only, 40% subsidy	0.776
	(0.862)
Health only, 70% subsidy	2.518**
	(1.124)
Health only, 100% susbidy	5.156***
	(1.445)
Health and economic, no subsidy	0.613
	(0.816)
Health and economic, 40% subsidy	1.311
	(1.032)
Health and economic, 70% subsidy	4.190***
	(1.336)
Health and economic, 100% susbidy	9.821***
	(3.367)
Mean "Health only, no subsidy" meeting	0.432
Kebele FE	Yes
R^2	0.244
Num. obs.	292

Note: ***p < 0.01; **p < 0.05; *p < 0.1. OLS estimation of the effect of type of meeting x subsidy-level on stove uptake. The coefficients shown are estimated relative to the 'Health only, no subsidy'-reference group. Robust standard errors in parenthesis. Includes Kebele fixed effects.

When looking at villages that also receive information on economic benefits, stove uptake increases even more with increasing subsidies. Again, the effects are only significant for the 70% and 100% subsidy group. For the former, we see uptake increase by 4.19 stoves (to 4.62 stoves in total), much higher than the increase for the 70% group *without* information on economic benefits (2.5 stoves). For the 100% group, we see an increase in uptake of 9.8 stoves, again, much higher than *without* information on economic benefits (5.2 stoves). For pooled versions of our model see Supplementary Section D. As mentioned, the exact number of treated households per village is unknown, though we do have an approximate total number of attendees per Woreda, showing that the adoption rate for Ebinat was around 40% and for Simada around 15%. The observed effects on adoption may be conservative due to ERCS's vulnerable household policy. About 300 households received a free stove, while an average of 1800 households were treated.

Our findings indicate that demand for the Mirt stove is price sensitive. We calculate price elasticity of demand and find a price elasticity of -1.63 going from no subsidy to a 40% subsidy, -1.29 going from a 40% subsidy to a 70% subsidy and a price elasticity of -0.31% going from 70%

to 100%. This implies that demand is elastic at higher prices (lower subsidies) and inelastic at lower prices (higher subsidies). Note again, that the demand elasticity would likely be higher if the 30 most vulnerable households would not have received a stove for free and rather been included in the study. We also find that providing economic information along with health messages more than doubles uptake, but primarily when combined with high subsidies (≥ 70%).

4. Conclusion

Our study adds to the existing literature on subsidies and financing schemes for promoting cookstove adoption. We find that subsidies are a significant driver of adoption, aligning with previous research (Pattanayak et al., 2019; Bensch and Peters, 2020; Berkouwer and Dean, 2022; Jeuland et al., 2023). Additionally, we observe that providing information on economic benefits enhances the impact of subsidies, although this finding may be context and construct-dependent and subject to variations in framing and communication methods (Esterling, Brady, and Schwitzgebel, 2023).

From a policy perspective, our subsidy finding is crucial, particularly considering the uncontrolled nature of the setting in which it was observed. It supports the notion of price-responsive demand for EEBC and clean fuels, consistent with findings in various contexts. Our paper confirms previous policy implications of subsidizing EEBC to facilitate widespread adoption. The fear of long-term market disturbance and non-usage caused by subsidization has been shown to be unsubstantiated in Senegal (Bensch & Peters, 2020), Rwanda (Munyehirwe et al., 2022b) and in Ethiopia for the Mirt (see Bluffstone et al., 2021). A notable constraint for widespread subsidization on a national scale is budgetary limitation. Carbon finance presents an attractive option, due to low abatement costs and substantial co-benefits for people's livelihoods, making the investment into EEBC distribution programs an unparalleled climate mitigation and adaptation policy (see Bensch, Jeuland and Peters 2021).

We echo previous calls for only subsidizing technologies that have demonstrated to meet household needs in terms of usability, cooking habits and fuel savings (Bensch et al., 2021; Hanna

et al., 2016; Jeuland & Pattanayak, 2012; Mobarak et al., 2012). This evaluated project serves as a blueprint on field-testing demand for specific EEBC technologies, with usage-intensity tracking being a valuable addition in future evaluation, which was not feasible in the present case due to the country's conflict.

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Supplementary Information

Demand elasticity of energy-efficient biomass cookstoves – Evidence from a randomized controlled trial in Ethiopia

Table of contents

A. Study context

Figure A1. Map of study area in Ethiopia

B. Details on the Mirt stove

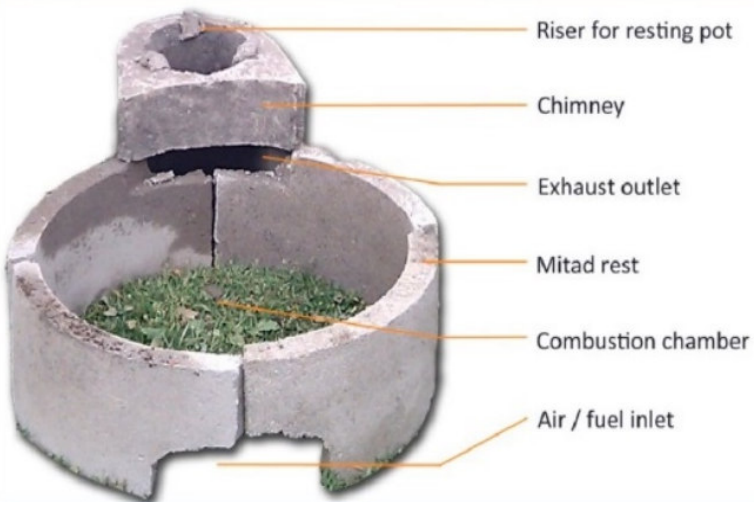

Figure B1. The Mirt stove design. *Source: Forests News (2014).*

Figure B2. The Mirt stove as produced by the Ethiopian Red Cross Society (ERCS). *Source: ERCS.*

C. Details on the intervention

C1. Lottery

The randomization of the treatment took place during a lottery. This lottery took place in a separate event prior to the stove information meetings. Representatives at the Woreda level from the following institutions were invited to the lottery meeting: Health Bureau, Women and Children Affairs Bureau, Ministry of Mines and Energy, WASH, Local Administration and Ministry of Agriculture. In addition, kebele officials (chairperson and manager) as well as Health Extension Workers (HEWs), opinion leaders and the staff members of the involved Ethiopian Red Cross Society (ERCS) branch team were invited for the meeting as well.

At the meeting, the intervention was explained to the local stakeholders. Subsequently, the lottery was conducted. For each Kebele, a separate lottery was held with Kebele representatives and ESRC staff. The lottery was conducted by drawing a ticket for each village. Treatment assignments were noted down by ERCS staff. Then Kebele representatives were given a list of villages with their assigned information treatment A (health only) or B (health and economic benefits). The HEWs and Kebele Administrators were asked to invite the households with children under five from the villages on the list according to their assigned meeting. They were also asked to emphasize the importance of male attendance. The subsidy treatment assignment was not given to the administrators.

C2. Stove information meeting

The two information meetings A and B were held simultaneously in each Kebele at two different locations. At the locations where the meetings took place, music was played, and the traditional stove and Mirt stove were installed while participants were waiting for the meeting to start. Before the meetings started, ERCS made sure that all households were present at the right location, that the groups for meeting A and meeting B did not mix. At both meetings, a drama piece was performed. Because there was only one drama team, the meetings had a slightly different order of activities.

For each of the two meetings, the activities are detailed below:

Meeting A – Health benefits

1. Drama piece on the comparison between three stone stove and Mirt stove. A cooking demonstration was integrated in this drama piece.
2. Discussion on the message of drama piece. What have you learned from it?
3. Introduction of project and stove component by ERCS staff members.
4. The health benefits of the Mirt stove were discussed by ERCS staff members. Also, safety of stove was addressed. See below for the benefits discussed.
5. Presentation of representative of water and energy office on the Mirt stove.
6. Time for comments, testimonies, and questions. HEW repeated lessons learnt.
7. ERCS staff members provided information on the lottery and its outcomes.
8. Issuance of the vouchers.

The following information was disseminated:

General information:

- The Mirt stove is very clean and safe (less burns and fires).
- The Mirt stove reduces smoke up to 50 percent compared to a traditional stove.
- The Mirt stove reduces the negative effect of indoor air pollution on respiratory health and eyes.
- The Mirt stove is very efficient. Reduction of deforestation and workload for women.

Health benefits:

- Eye diseases – e.g., trachoma, cataract.
- ARI – infection chronic lung disease – use local names.
- Severe fatigue (Yelib Dikam – local explanation) – as a result of carbon monoxide and particulate materials.
- 1st degree burn – because of the flame and frequent exposure.
- Stomach upset (GI) due to Poor hygiene and food handling practices.

- Negative effect during pregnancy – could lead to low birth weight, early delivery (premature delivery).
- More time to take care of children under five, have good domestic hygiene practices, have adequate time to feed and breast feed children – this could have a direct and indirect effect on the nutrition status of the child, and child growth.
- Putting more burden on pregnant mothers – during firewood collection, cow dung preparation – (Kebad Sira).
- Back pain and negative effect on posture – due to firewood collection, while working on traditional stove.
- Benefit for men: healthy children, healthy wife/mother, health family.

Meeting B: Health and economic benefits

1. Introduction of project and stove component by ERCS staff members.
2. The health and economic benefits of the Mirt stove were discussed by ERCS staff members. Also, safety of stove has been addressed. See below for the information disseminated.
3. An exercise was conducted to quantify the fuel consumption savings linked to Mirt stove usage. Attendants were asked the following questions: For how much could you sell the result of one fuel collection moment? How often do you collect wood in a week? How much is the cost of one bundle? How many bundles do you use per week? Then this information was used to calculate the fuel consumption savings. So, a reduction in fuel consumption could save you … ETB in one week. This means that after … weeks you have earned back the money that you have invested in the Mirt stove.
4. Presentation of representative of water and energy office on the Mirt stove.
5. Drama piece on the comparison between three stone stove and Mirt stove. A cooking demonstration is integrated in this drama piece.
6. Discussion on message of drama piece. What have you learned from it?
7. Time for comments, testimonies, and questions. HEW repeats lessons learnt.
8. ERCS staff members provided information on the lottery and its outcomes.

9. Issuance of the vouchers.

The following information was disseminated:

General information:

- The Mirt stove is very clean and safe (less burns and fires).
- The Mirt stove reduces smoke up to 50 percent compared to a traditional stove.
- The Mirt stove reduces the negative effect of indoor air pollution on respiratory health and eyes.
- The Mirt stove is very efficient. It can reduce fuel consumption by 30 up to 40 percent (show piles to indicate difference in fuel usage). Reduction of deforestation.
- Other households that have adopted this stove have saved 33 ETB per month or approximately 6 hours of time per week.

Health benefits:

- Eye diseases – e.g., trachoma, cataract.
- ARI – infection chronic lung disease – use local names.
- Severe fatigue (Yelib Dikam – local explanation) – as a result of carbon monoxide and particulate materials.
- 1st degree burn – because of the flame and frequent exposure.
- Stomach upset (GI) due to Poor hygiene and food handling practices.
- Negative effect during pregnancy – could lead to low birth weight, early delivery (premature delivery).
- More time to take care of children under five, have good domestic hygiene practices, have adequate time to feed and breast feed children – this could have a direct and indirect effect on the nutrition status of the child, and child growth.
- Putting more burden on pregnant mothers – during firewood collection, cow dung preparation – (Kebad Sira).
- Back pain and negative effect on posture – due to firewood collection, while working on traditional stove.
- Benefit for men: healthy children, healthy wife/mother, health family.

Economic benefits:

- Saving money for other benefits e.g., health insurance, school fees, payment of Edir, buy more food.

- Less time for fuel collection, have time for farming and other economic activities, take care of animals.
- Less expenditure on medical care.
- Reduce deforestation – reduce negative climate effect – improve productivity from farming.
- Benefit for men: less money spent on purchase of firewood, less money is spent on health problems, use of wood for other activities e.g., fencing, renovating houses, less labour on cutting woods, clean house, healthy children, healthy wife / mother.
- Less time spent on referring sick child to the hospital.
- More time for social activities.

Explanation of the lottery

During the explanation of the lottery, ERCS provided arguments for why the lottery was justified (i.e., budget issues and because of the experience that when something is provided for free it is often not used properly). The process of drawing lottery tickets was explained, and it was emphasised that since different tickets were drawn for different villages, households from one village may pay 100 ETB for the stove, while others pay 60 or 30 ETB and others pay nothing (coinciding with subsidy levels of, 0%, 40%, 60%, and 100% respectively). This was fairly decided by means of the lottery and is simply a matter of chance.

Issuance of vouchers

First, vulnerable HHs from the list prepared by the Kebele administrator and HEWs were asked to come forward to receive their voucher. These households received a 100% subsidy. For these vulnerable households, empty vouchers were filled in with their name, village, kebele, date and stove price (see Figure C1 for a voucher example).

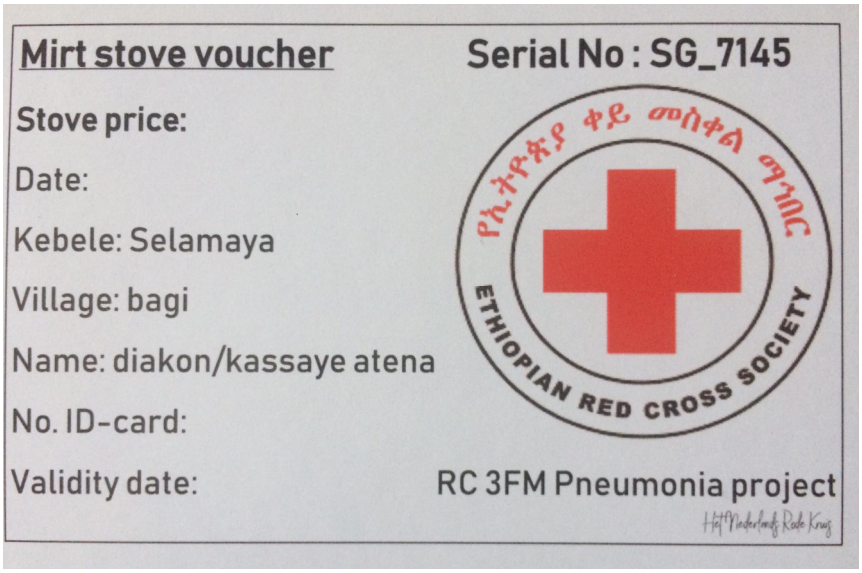

Figure C1. Mirt stove vouchers issued to beneficiaries by ERCS

Subsequently, households from each village were handed their voucher. The attending households with under-fives for which no voucher was prepared were registered using empty vouchers. All beneficiaries who received a voucher were asked to leave their signature or fingerprint behind to confirm receipt of the voucher.

C3. Transportation and installation

To disseminate information on the stove collection, installation, and usage, ERCS collaborated with Health Development Armies, Kebele leaders, and HEWs. Households were also regularly reminded to redeem their voucher and collect their stove through bi-weekly community conversation sessions implemented by ERCS. The stoves could be collected by the household at the Kebele administration point, which is located centrally for all villages within a Kebele. For villages that were far away, ERCS organized transport of the stove. Since the stoves could be disassembled, household members could carry the stove parts to their home. The household members installed the stove with support from HEWs.

C4. Monitoring

ERCS volunteers monitored the installation and use of the stove. Each volunteer is responsible for 15 households and visits these households twice per week. Stoves could easily be identified due to the Red Cross logo. In addition, the branch project officers monitor project activities through random household visits during monthly monitoring visits. Last, ERCS HQ and NLRC team carry out quarterly and bi-annual monitoring visits. In addition, the branch staff jointly with the Woreda Energy Bureau and HEWs, visit some random households monthly.

D. Additional results

Table D1. Effect of subsidy-level on stove uptake

	Number of stoves
40% subsidy	0.763
	(0.702)
70% subsidy	3.078***
	(0.888)
100% subsidy	7.235***
	(1.987)
Mean "No subsidy"-group	0.686
Kebele FE	Yes
R^2	0.229
Num. obs.	292

Note: ***p < 0.01; **p < 0.05; *p < 0.1. OLS estimation of the effect of subsidy-level on stove uptake. The coefficients shown are estimated relative to the 'No subsidy'-reference group. Robust standard errors in parenthesis. Includes Kebele fixed effects.

Table D2. Effect of information treatment on stove uptake

	Number of stoves
Health and economic	1.990*
	(1.119)
Mean "Healh only"-group	2.671
Kebele FE	Yes
R^2	0.161
Num. obs.	292

Note: ***p < 0.01; **p < 0.05; *p < 0.1. OLS estimation of the effect of subsidy-level on stove uptake. The coefficients shown are estimated relative to the 'Health only'-information reference group. Robust standard errors in parenthesis. Includes Kebele fixed effects.

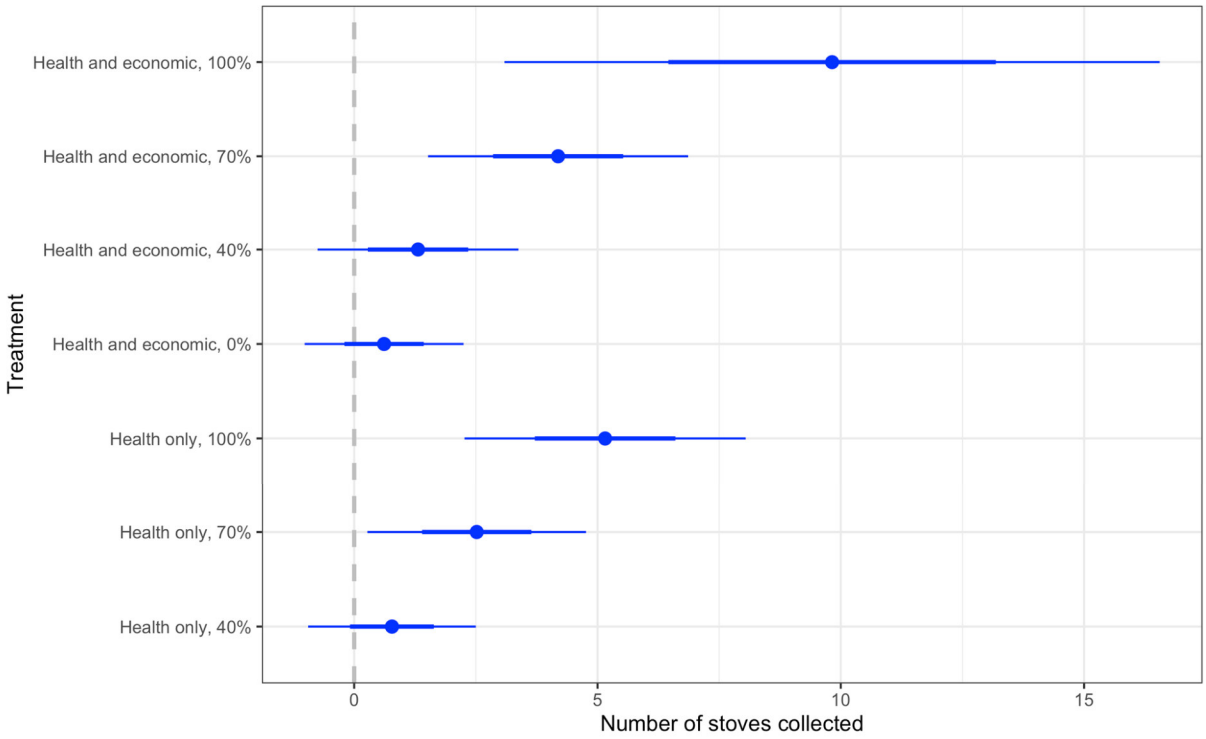

Figure D1. Effect of subsidy level and information type on stove collection.

This figure shows the coefficients and 95% confidence intervals for each meeting type x subsidy level relative to the reference group 'Health only, no subsidy' on stove uptake. Average stove collection for reference group is 0.432 stoves. Estimations include kebele fixed effects and robust standard errors.