

Credit, Attention, and Externalities in the Adoption of Energy Efficient Technologies by Low-Income Households[†]

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We study an energy efficient charcoal cookstove in an experiment with 1,000 households in Nairobi. We estimate a 39 percent reduction in charcoal spending, which matches engineering estimates, generating a 295 percent annual return. Despite fuel savings of \$237 over the stove's two-year lifespan—and \$295 in emissions reductions—households are only willing to pay \$12. Drawing attention to energy savings does not increase demand. However, a loan more than doubles willingness to pay: credit constraints prevent adoption of privately optimal technologies. Energy efficient technologies could drive sustainable development by slowing greenhouse emissions while saving households money. (JEL D12, D91, G51, O12, O13, O32, Q54)

Energy efficient technologies are projected to play a crucial role in lowering greenhouse gas emissions. In low-income countries, energy efficiency could also help reduce poverty by generating private cost savings for households. This creates a unique opportunity to reduce emissions at negative cost. We quantify significant underadoption of such an energy efficient technology, and assess barriers to widespread adoption. We evaluate two factors that we hypothesize are most likely to be causing underadoption. First, credit constraints, which are prevalent in low-income settings, may prevent households from adopting even privately optimal technologies

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without subsidies or other policy intervention. Second, households may be inattentive to cost savings.

In a randomized experiment with 1,000 households in Nairobi, Kenya we examine how households decide whether to adopt a more efficient version of their primary energy-consuming durable: a charcoal stove. The efficient stoves, sold under the name Jikokoa, are essentially identical to traditional stoves, but improved insulation reduces the charcoal needed to obtain the same cooking temperature. We measure willingness to pay (WTP) using a Becker, Degroot, and Marschak (1964) (BDM) mechanism to study the impact of attention and credit on demand for the energy efficient stove, and then use the random price in the BDM mechanism as an instrument for adoption to estimate the private and social impacts of stove adoption.

We estimate that adoption causes an immediate and persistent 39 percent reduction in charcoal consumption, measured both by a recurring SMS survey of charcoal expenditures and the weight of charcoal ash generated by the household. This reduction yields private financial fuel savings of US\$237 over the two-year lifetime of the stove—about two months of income for the average respondent. Given the US\$40 price of the stove, this constitutes a 295 percent annual return. Households also spend one hour less cooking each day due to reduced startup time, and self-report a 0.5 standard deviation improvement in health.¹ The reduction in charcoal consumption also reduces annual emissions by 3.5 tons of carbon dioxide equivalent (CO_{2e}) per household, valued at US\$147 when applying a social cost of carbon of US\$42 (US EPA 2016).

In spite of these large benefits, average household WTP is only US\$12—well below the US\$40 market price. In high-income contexts, inattention to fuel savings has been found to be an important moderator of energy efficiency adoption.² Energy is a larger portion of the household budget in this context (22 percent in our sample), so households may attend to these savings more carefully and make optimal trade-offs.³ On the other hand, the cognitive stress of being poor can impair households' decision-making capabilities.⁴ To measure the impact of inattention, we randomize subjects to a multifaceted attention treatment designed to bring as much attention as possible to the savings. Subjects in this treatment arm receive SMSs every three days asking about their charcoal spending in the month leading up to the BDM mechanism. Immediately before stating their WTP, they complete an accounting exercise estimating their yearly savings and what they could spend it on. They then receive five minutes to contemplate the savings as the surveyor enters the savings into the tablet, and the tablet then reminds them of their answers to the accounting exercise during the WTP elicitation. In contrast, participants in the attention control group receive only a standard Jikokoa flyer. This intensive intervention does not impact WTP, suggesting individuals are already attentive to the savings potential or that their inattention can be rectified with standard marketing materials.

¹We discuss additional attributes, such as food taste and durability, in Section IA. To the extent that these provide additional benefits, our estimate of underadoption is an underestimate.

²See for example Allcott and Taubinsky (2015); Allcott and Wozny (2014); Gillingham, Houde, and van Benthem (2021); Jessoe and Rapson (2014); and De Groote and Verboven (2019).

³Shah, Shafir, and Mullainathan (2015); Fehr, Fink, and Jack (forthcoming); Goldin and Homonoff (2013), Dupas (2009) show that attention may be higher in these contexts.

⁴See for example Haushofer and Fehr (2014); Schilbach, Schofield, and Mullainathan (2016); Kremer, Rao, and Schilbach (2019); Duflo, Kremer, and Robinson (2011); Kremer et al. (2013); and Liu (2013).

If the private financial benefits are large, and households attend to them, why is WTP only US\$12? We consider whether this is due to credit constraints. This has been documented with the adoption of other technologies (Banerjee, Karlan, and Zinman 2015; de Mel, McKenzie, and Woodruff 2008; Pitt and Khandker 1998), but less so in the context of energy efficiency adoption (Stern, Stiglitz, and Taylor 2021; Allcott and Greenstone 2012). We offer a random subset of subjects a three-month loan at an interest rate of 1.16 percent per month to finance adoption.⁵ To ensure subjects are not simply short of cash on hand on the day of the experiment, all subjects are notified of the purchasing opportunity one month in advance, and those in the credit control are given an additional 12 hours after the WTP elicitation to make the payment for the stove. The loan doubles WTP, from US\$12 to US\$25. Importantly, this fully closes the gap between savings and WTP during the loan period: average WTP equals the amount of savings they will accrue during the three-month period over which the loan relaxes credit constraints. Since the loan only allows intertemporal substitution within the three-month period, WTP continues to fall far short of the discounted stream of savings over the lifetime of the stove.

Finally, we consider whether this large response to credit is purely rational intertemporal substitution. Credit moves costs to the future and typically disperses one large payment across many periods, which may make a purchase more attractive for an agent who fails to attend to future costs or over attends to concentrated costs (Gabaix and Laibson 2017; Kőszegi and Szeidl 2013; Dertwinkel-Kalt et al. 2021). To study inattention, we subrandomize the attention treatment group to attend to either gross savings or net savings. Those in the net savings group are reminded of their future loan payments during the WTP elicitation. This reminder reduces the effect of credit by US\$4, an economically and statistically significant difference: shifting costs to the future where they are not attended to appears to contribute to the large impact of credit. To study the importance of concentration bias, we subrandomize the credit treatment into either weekly or monthly deadlines. We find no difference across these two arms.

This paper is the first to both experimentally quantify underadoption of a technology with uniformly high financial returns and experimentally estimate the roles of credit constraints and attention in preventing its adoption. We combine the randomized treatments with high-frequency household charcoal expenditure data—corroborated with on-the-ground charcoal usage measures—to document large financial returns to investment for nearly every individual in our sample within months. Comparing these financial returns with elicited WTP demonstrates that WTP is inefficiently low, and by randomly assigning loans and an attention intervention we can identify the source of this inefficiency. Each of these elements we believe is a contribution to the literature and has actionable policy implications.

These contributions build on an extensive development economics literature documenting the low adoption of seemingly beneficial technologies—sometimes referred to as the *Euler equation puzzle* (Kremer, Rao, and Schilbach 2019)—in for example agriculture, health, and firms (Magruder 2018; Kremer and Glennerster 2011; Dupas 2014; Atkin et al. 2017; de Mel, McKenzie, and Woodruff 2008; Kremer et al. 2013).

⁵This corresponds to 14 percent per year, which was the interest rate cap set by the Central Bank of Kenya in 2018.

In the energy efficiency literature, Fowlie, Greenstone, and Wolfram (2018); Allcott and Greenstone (2017); and Davis, Martinez, and Taboada (2020) all find *negative* private rates of return, and we are not aware of any causal estimates of how credit constraints affect energy efficiency adoption (Ankney 2021; Stern, Stiglitz, and Taylor 2021).

The low adoption of improved cooking technologies specifically has been the subject of significant debate (World Bank Group 2020b). Traditional cookstoves can have large negative health impacts (Gordon et al. 2014; Lee et al. 2020). While demand for improved stoves often remains low due to poor stove performance in the field (Hanna, Duflo, and Greenstone 2016; Mobarak et al. 2012; Beltramo et al. 2019; Pattanayak et al. 2019), some research has found that improved stoves have important benefits in some contexts and that access to financing can increase adoption (Beltramo et al. 2015; Levine et al. 2018; Bensch and Peters 2015; Bensch, Grimm, and Peters 2015).

Our results have important and immediate policy recommendations. WTP is already low relative to the private benefits, so a carbon tax is unlikely to increase adoption among these households. In fact, it may be regressive by increasing energy costs among the credit constrained, who tend to be poor. Given the lack of response to an attention intervention, attempts to make potential savings more salient—beyond those already included in marketing strategies—may also be ineffective. Instead, policymakers wanting to increase energy efficiency adoption in these contexts should focus on increasing affordability through subsidies. For policymakers concerned solely with carbon emissions abatement, the Jikokoa abates CO₂ at US\$6 per ton, which is significantly below most technologies available today (Gillingham and Stock 2018). Factoring in the financial savings, the stove reduces emissions at negative cost. Similar to Jayachandran et al. (2017) and Rom, Günther, and Pomeranz (2019), this suggests that low-income countries hold untapped opportunities for relatively efficient carbon emissions abatement that simultaneously provide anti-poverty benefits. In our setting, this simultaneously generates significant private benefits for the poor. Each US\$1 of subsidy would generate US\$19 in total welfare gains.

I. Background: Household Energy Use in Kenya

Traditional charcoal cookstoves produce indoor air pollution that causes millions of deaths each year, and contribute to growing deforestation and climate change (WHO 2017; Pattanayak et al. 2019; Bailis et al. 2015), but more than four billion people still do not have access to modern cooking methods (ESMAP 2020). By 2030, half of Africa's population is expected to be living in cities, where more than 80 percent of households rely on charcoal for daily cooking and heating needs (FAO 2017).⁶

The share of household income spent on energy costs tends to be largest among the poor. This *energy burden* comprises 3.5 percent of income for the median American household, and exceeds 7 percent for the poorest Americans (Drehobl and

⁶Online Appendix E provides detail on global and local charcoal consumption.

Ross 2016). The share in low-income countries is often higher: the energy burden for the median household in our study sample is 22 percent.

Household adoption of energy efficient appliances has the potential to reduce these expenditures meaningfully—but adoption remains low. The International Energy Agency (IEA 2018) estimates that cost-effective energy efficiency opportunities available today to households globally have the potential to save US\$201 billion in avoided fuel expenditures and US\$365 billion in transport costs per year by 2040.

According to the Kenya National Bureau of Statistics (2019), 67 percent of the 12 million households in Kenya rely on biomass (wood and charcoal) as their primary cooking fuel. For participants in our study, the household's primary energy-using durable is a traditional charcoal stove, a Kenyan ceramic *jiko*, which they use for daily cooking. According to Kenya's Ministry of Energy (2019), around 42 percent of Kenyan households use a charcoal *jiko* at home, with the primary alternatives being woodstoves (in rural areas) and liquefied petroleum gas and kerosene stoves (in urban areas).

A. *The Energy Efficient Jikokoa Cookstove*

We study the Jikokoa, a charcoal stove produced by Burn Manufacturing (“Burn”). Burn began producing stoves in Nairobi in 2014 and has now sold more than a million energy efficient cookstoves. As of 2019 they were selling more cookstoves annually in East Africa than any other company: internal retail audit data indicate their sales comprise 80–90 percent of the improved cookstove market. Figure 1 displays a Kenyan ceramic *jiko* as well as the energy efficient Jikokoa stove we study.

Adoption so far has been primarily among Kenyans with higher socioeconomic status. Sixty-six percent of the Kenyan population lives below the Kenyan poverty line of US\$3.20 per person per day (World Bank Group 2018), while only 12 percent of existing Jikokoa adopters do.⁷

The Jikokoa was available for US\$40 in stores and supermarkets across Nairobi at the start of our study. In theory, this could be a concern for eliciting truthful WTP above US\$40; however, fewer than one percent of respondents in the control group had a WTP of US\$40 or higher.

More than 98 percent of respondents had heard of the stove at baseline, primarily via television (64 percent), via a friend, neighbor, or family member (39 percent), on the radio (21 percent), or in a billboard, newspaper, or bus advertisement (11 percent). All respondents received a pamphlet (Appendix Figure A1) containing the information about the Jikokoa that is widely advertised on billboards and television and is accessible to literate and illiterate respondents.

The primary difference between the Jikokoa and the *jiko* is that the Jikokoa's main charcoal combustion chamber is constructed using improved insulation material and designed for optimized fuel-air mixing. It is made of a metal alloy that better withstands heat, and a layer of ceramic wool insulates the chamber to cut heat loss. Parts are made to strict specifications, and components fit tightly to minimize air leakage. These features were designed and tested by laboratories in Nairobi and

⁷Online Appendix F discusses the demographics of the Kenyan population, existing owners, and our study sample.



FIGURE 1. TRADITIONAL *JIKO* (“STOVE”) AND ENERGY EFFICIENT STOVE

Notes: On the left is the traditional *jiko*. On the right is the energy efficient stove. The two stoves use the same type of charcoal and the same process for cooking food, hence the energy efficient stove requires essentially no learning to adopt. After usage, the user disposes of the ash using the tray at the bottom. The central chamber of the energy efficient stove is constructed using insulating materials, creating a higher charcoal-to-heat conversion rate. Engineers *ex ante* predict that the energy efficient stove uses only half the charcoal to reach and maintain the same cooking energy as the traditional *jiko*.

Berkeley, which estimated that they double the charcoal-to-heat conversion rate. Only half the charcoal should therefore be required to reach and maintain the same cooking energy as the *jiko*.

Adoption of the energy efficient stove does not require any behavioral adaptation or learning. The cooking processes are identical, and most adopters continue cooking the same types and quantities of food as before.⁸ Both stoves use the same type of charcoal, so users can continue to purchase charcoal from their preferred charcoal vendors. When asked an open-ended question about the Jikokoa’s best features, 87 percent of respondents state financial savings, 53 percent state reduced smoke, and 22 percent state time savings (online Appendix Figure C1).

Other differences may also affect adoption. If subjects perceive these attributes as additional benefits, these would bias us towards underestimating underadoption. In the pilot, we asked 153 subjects why they had not adopted the Jikokoa as an open-ended question. Answers overwhelmingly had to do with affordability. Zero subjects said their food would taste worse, zero subjects said that it was not healthy, zero said they worried it would break, four said they were not sure how to use it, and zero mentioned the stove’s appearance. This open-ended question was excluded from the main study for the sake of time, but we did ask about taste and durability directly. All but three of the 1,018 subjects believe the food will taste the same or better. The median respondent in our sample (correctly) believes that the Jikokoa has an expected lifespan of three years and typically needs to buy a new traditional *jiko* each year. We therefore define underadoption of the stove conservatively as purely the financial gap between costs and benefits, conservatively defining the lifetime of the stove as the two-year period covered by the warranty.

⁸ Respondents report improvements in food quality, but this is primarily enabled by savings from the stove.

B. Credit in Nairobi

Loans are common in this context. Eighty-six percent of respondents borrowed at least once last year.⁹ Yet, most respondents face significant credit constraints. More than one-third of respondents had sought out a loan in the past year and been refused, and more than half of respondents said they would borrow more if the cost of borrowing was lower. People who had not taken a loan in the past year did not do so largely because they were worried about their ability to pay back the loan.

Kenya's largest mobile lender M-Shwari charges a 7.5 percent "loan facilitation fee" and requires repayment within one month.¹⁰ The company tracks past M-PESA usage and borrowing behavior to place quantity constraints on individual borrowing. In practice, this means that almost a quarter of our sample would not be able to take out a loan today, even if they wanted to. The median amount available for short-term borrowing was US\$10; less than a quarter of the sample was able to borrow the full cost of the stove if they wanted to. In addition, the loans mentioned above are generally used for emergency situations: a respondent may wish to keep their credit available for emergencies and not use it to fund technology adoption, as this would leave them vulnerable to unanticipated shocks (Suri, Bharadwaj, and Jack 2021).

II. Conceptual Framework

To fix ideas, consider an agent deciding whether to adopt an energy efficient appliance that costs p and reduces future energy costs by ψ_t for T periods which the agent discounts using function $D(t)$. Suppose the agent has access to a loan, l , in exchange for future payments, r_t , and that the agent makes these intertemporal substitution choices optimally. The agent's WTP is then p^* such that

$$(1) \quad \underbrace{u(c_0) - u(c_0 - p^* + l)}_{\text{Cost of adoption today}} = \sum_{t=1}^T D(t) \left[\underbrace{u(c_t + \psi_t - r_t) - u(c_t)}_{\text{Future benefits of adoption}} \right]$$

Using this framework, we consider how credit constraints and inattention may operate in lower income contexts. Previous research in the context of other technologies has shown that credit constraints can prevent households from being willing to pay even the privately optimal price. An agent who is credit constrained can borrow at most $l^{cc} < l$ with payments $r_t^{cc} < r_t$. This decreases their WTP for obvious reasons. If credit constraints bind, offering access to a loan should increase WTP.

Agents may also not attend to all of the future savings, instead perceiving the savings as $\theta \psi_t$ where $\theta < 1$. This decreases their WTP for obvious reasons. In this case, an intervention may be able to increase attention and subsequently increase WTP. How well this will work in lower income settings depends both on how attentive agents are to the savings and whether agents are credit constrained. If agents are more attentive to the potential savings at baseline because energy is a larger fraction

⁹Online Appendix E provides more detail.

¹⁰M-Shwari loans that are not repaid within one month are automatically reregistered as a new loan, with an additional 7.5 percent fee charged on the outstanding balance. If a borrower does not repay a loan within 120 days, they are reported to a local credit bureau (Suri, Bharadwaj, and Jack 2021).

of their budget, the intervention will be less effective. Conversely, if they are less attentive due to the many demands poverty places on their attention, the intervention may be more effective. If they are credit constrained, increasing the perceived private benefits alone will be less effective because credit constraints can prevent the adoption of privately optimal technologies.

III. Experimental Design

We enrolled 1,018 respondents who live in the Dandora, Kayole, Mathare, and Mukuru informal settlement areas around Nairobi, Kenya (map in Appendix Figure A2). These are among the lowest-income areas of Nairobi, and have not been targeted by sales teams of the cookstove company. Field officers walked around these areas and enrolled a convenience sample by visiting the homes of potential respondents, until the required number of respondents had been enrolled. To qualify for study participation, respondents had to use a traditional charcoal *jiko* as their primary cooking technology and spend at least US\$3 per week on charcoal, though most households that use a charcoal stove as their primary cooking technology buy at least US\$0.50 of charcoal per day.

Table 1 presents summary statistics of socioeconomic variables. The median household earns a daily income of US\$5 and spends US\$0.70 (14 percent) on charcoal per day. Sixty-four percent of participants purchase charcoal at least once per day. Households buy a new *jiko* around once per year, for between US\$2 and US\$5. Within each household, field officers enrolled the primary stove user, 95 percent of whom were women, largely reflecting Kenyan societal norms around household tasks.¹¹

The following sections describe the timeline, randomized treatments, and measurement methodologies. A target sample size for each treatment was calculated using statistical power calculations and registered in the preanalysis plan. To account for possible attrition between recruitment and treatment, we recruited 110 percent of the total target. Thus, the final sample sizes closely mirror those listed in the plan but do not match exactly.

A. Experimental Timeline

The survey design centers around three in-person visits 25–30 days apart referred to as *visit 1*, *visit 2*, and *visit 3* (*baseline*, *midline*, and *endline*, respectively).¹² One year later a *long-term endline* survey is administered over the phone.¹³ Participants complete three more activities: (i) a recurring SMS survey about their charcoal expenditures every three days, implemented during the main study and after the long-term endline, (ii) collection of ash in a bucket to measure charcoal usage, and (iii) loan payments by respondents who purchased the stove using credit. Figure 2 presents a timeline.

¹¹ Online Appendix F provides more detail on sample representativeness.

¹² Logistical constraints caused some deviation: 88 percent of visit 2 surveys were conducted between 23–33 days of that respondent's visit 1, and 91 percent of visit 3 surveys were conducted between 23–33 days of their visit 2; 90 percent of long-term endline surveys were conducted between 12.2 and 13.1 months of visit 2.

¹³ The long-term endline was intended to be in person, but this was changed to remote due to COVID-19 restrictions.

TABLE 1—SUMMARY STATISTICS

	Mean	St. dev.	25th	50th	75th
Household size	4.73	2.08	3	4	6
Age	37.24	11.83	29	35	44
Female respondent	0.95	0.21	1	1	1
Completed primary education	0.70	0.46	0	1	1
Completed secondary education	0.26	0.44	0	0	1
Respondent income (USD per week)	24.26	25.25	11	21	35
Household income (USD per week)	47.79	39.25	21	35	60
Energy spending (USD per week)	8.60	3.89	6	8	10
Charcoal spending (USD per week)	5.65	2.93	4	5	7
Savings (USD)	74.83	129.45	1	30	82
Current cookstove price (USD)	3.46	1.93	3	3	4

Notes: Summary statistics of key socioeconomic characteristics for all 1,018 study participants. “Savings” includes savings in bank account, mobile money account, or informal group savings.

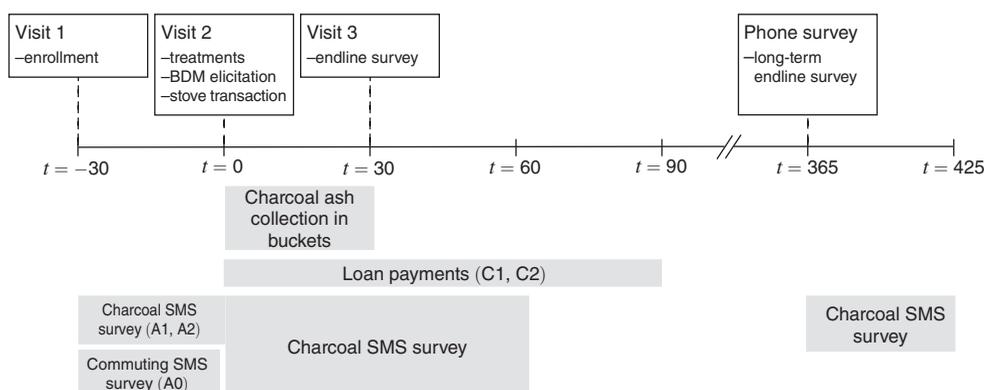


FIGURE 2. TIMELINE

Notes: Timeline of the four main study components: (i) three in-person visits, timed one month after each other, and a one-year endline phone survey; (ii) a recurring SMS survey about charcoal spending (a control group received placebo SMSs about an unrelated topic—their commuting time—for the first month); (iii) ash collection in buckets for one month, to measure charcoal consumption; (iv) loan payments (for respondents who purchased the stove and used a loan to do so).

During visit 1, the field officer completes an enrollment survey and gives the respondent a pamphlet about the stove (Appendix Figure A1). The graphics displayed on the pamphlet are also shown on the box the stove is sold in, and are widely advertised on billboards and television. To relax short-term liquidity constraints, the field officer tells the respondent that a colleague will return one month later, and that if they would like to buy the stove then, they should have sufficient cash on hand. While the respondent's price is not disclosed during visit 1, respondents are told that they “may receive a small discount.” After visit 1, each respondent is randomly assigned a subsidized price for the stove, and is randomly assigned into one of three credit groups and one of three attention groups (described in Section IIIB). Respondents in the treated attention groups then start receiving SMSs about their charcoal spending (described in Section IIID). To prevent contact

imbalance, respondents in the attention control group receive placebo SMSs before switching to charcoal SMSs after visit 2.

During visit 2, a field officer implements the credit and/or attention treatments for this respondent and the BDM mechanism (Section IIIC). They also give all participants a bucket to collect the charcoal ash generated by stove usage between visits 2 and 3. If the respondent wins the stove, they receive the stove during visit 2. Winners in the credit control group must pay their price during visit 2. Winners in the credit treatment groups begin making loan payments after visit 2.

During visit 3, a field officer implements the endline survey and weighs the ash collection bucket. One year later, a field officer conducts a similar endline survey over the phone.

B. Credit and Attention: Experimental Treatment Arms

We implement a three-by-three experimental design, cross-randomizing two credit treatments with two attention treatments (Figure 3). Treatment is stratified by baseline charcoal spending.

Loan payments include an interest rate of 1.16 percent per month, which was the interest rate cap set by the Central Bank of Kenya at the time of our study.¹⁴ Respondents who miss their payments are asked to return the stove.¹⁵ Regardless of credit treatment assignment, every respondent who purchased the stove received it during visit 2.

Credit Control Group (C0): Payment is due at visit 2.

Weekly Deadlines (C1): Payment is due at 12 weekly deadlines, starting one week from visit 2. Payments may be made more frequently or earlier, as long as the cumulative minimum is met by each weekly deadline.

Monthly Deadlines (C2): Payment is due at three four-weekly deadlines, starting four weeks from visit 2. Payments may be made more frequently or earlier, as long as the cumulative minimum is met by each monthly deadline. For example, they could pay in weekly installments. Respondents were told they would have the option to commit to weekly deadlines (C1) after the WTP elicitation.

Monthly deadlines should be strictly preferred: transaction costs are lower, and respondents can choose to make monthly payments, make payments more frequently than monthly, or even commit to weekly payments if they believe this will facilitate repayment (Field and Pande 2008). However, an individual exhibiting concentration bias will disproportionately pay attention to the larger monthly payments. Lower WTP among the monthly deadline group would suggest respondents disproportionately

¹⁴ Most commercial banks during this period also charged supplemental fees that were not regulated by the cap.

¹⁵ Respondents received SMSs reminding them of their upcoming payment deadlines. If a respondent missed a deadline, they were initially sent three reminders over a six day period. If they had not paid within one week, a field officer would visit them to reclaim the stove. Section VC provides detail on repayment.

		Credit control	Credit treatment	
			Weekly deadlines	Monthly deadlines
Attention control		96	98	98
Attention treatment	Energy savings	96	97	96
	Energy savings – costs	145	146	146

FIGURE 3. EXPERIMENTAL TREATMENT ARMS

Notes: We enroll 1,018 respondents and randomly assign them to one of three credit treatments and one of three attention treatments. Respondents in the credit control group must pay for the stove during visit 2 and receive the stove that day. Respondents in the credit treatment group still receive the stove during visit 2 but pay for it over three months. Respondents in the attention control group receive basic information about the stove. Respondents in the attention treatment group are prompted to report charcoal spending every three days in the month before WTP is elicited, to forecast 12 months of savings and spend time thinking about how they could use the savings. Respondents in the treatment to costs group also think through costs associated with adoption. Treatment assignment is stratified by baseline charcoal spending.

attend to costs when these are concentrated in a few large payments (Kőszegi and Szeidl 2013; Dertwinkel-Kalt et al. 2021).

While the conceptual framework does not consider the cost of credit or the cost of default, the credit intervention implicitly addresses three channels through which individuals may face credit constraints. It addresses quantity constraints by not constraining the size of the loan. By charging an interest rate that excludes the fees charged by mobile lenders, it reduces the cost of borrowing. Finally, agents face limited penalties under default: if someone defaults on their loan, a field officer collects the stove, and the participant faces no additional repercussions.¹⁶

We cross-randomize the three credit arms with three arms designed to evaluate attention:

Attention Control Group (A0): Participants are informed that the stove manufacturer says that the stove reduces charcoal consumption by 50 percent with a pamphlet created with images from Burn's marketing materials (Appendix Figure A1). They are informed of the Kenyan shilling equivalent of these savings, based on the respondent's stated average weekly charcoal spending. Field officers carry a calculator that they are allowed to use.

Attention to Energy Savings (A1): Participants receive everything that A0 receives. In the month between visits 1 and 2, respondents are then asked about their

¹⁶Around 13 percent of respondents who adopted the stove using credit had paid less than 10 percent of the required amount by the end of the payment period: for 56 respondents, we do not have any record of them paying any amount. In six cases, the field officer retrieved the stove. In all other cases, field officers were unable to track down the respondent. The research team does not have authority to implement any penalties or legal repercussions. Section VC discusses repayment and default in more detail.

charcoal spending every three days via SMS.¹⁷ During visit 2, prior to the BDM elicitation, the respondent completes an attention sheet (Appendix Figure A3),¹⁸ writing down the amount of money they think they would save each week for the next year if they owned an energy efficient stove. This can be expected to be around 50 percent of their expected spending each week. Since savings are proportional to spending, the respondent might expect larger savings during weeks when they expect to cook more, for example during religious holidays, or when a temporary migrant returns home. The respondent then calculates the expected savings for each of the 12 months, writes down how they would use these savings for each month, and calculates the total amount saved after a year. Respondents are then given a waiting period of five minutes to think about these savings while the enumerator enters them into a tablet.¹⁹ The savings are then shown on the tablet during the BDM elicitation.²⁰

Attention to Energy Savings Minus Costs (A2): Participants receive everything that A1 receives. In addition, during the BDM elicitation, alongside the savings they are informed of the cost of adoption during each period. The cost per period is presented in line with the respondent's credit treatment assignment. The net benefit (cost minus savings) for each period is also calculated and presented to the respondent.

The difference between A0 and {A1,A2} tests whether respondents are inattentive to savings beyond what can be rectified by standard marketing and would thus potentially benefit from interventions that increase attention. The difference between A1 and A2 tests whether attention to benefits only may overstate demand. Finally, the interaction between the attention and credit groups tests whether credit makes adoption more attractive not just by enabling intertemporal substitution but by moving costs into the future where agents may attend to them less.

One may be concerned that the attention treatment addresses math ability or provides awareness of the technology rather than addressing attention alone. To alleviate this concern, respondents complete a short math test consisting of eight questions taken from Kenya's Certificate of Primary Education and Certificate of Secondary Education standardized exams. This allows us to rule out heterogeneity in the attention treatment by math ability. Only ten people had *not* heard of the Jikokoa stove at baseline, so we are unable to test whether the attention treatment works more effectively for respondents that were not aware of the technology at baseline.

One may also be concerned that participating in the experiment, even in the A0 condition, is itself an attention treatment, and that we may thus find no impact of

¹⁷ Respondents in the attention control group received placebo SMSs between visits 1 and 2. The timing and incentives were identical, but respondents were asked about their *matatu* (bus) travel instead of their charcoal expenditures. Starting at visit 2, these respondents received the regular charcoal SMS survey.

¹⁸ Forty-seven percent of respondents filled in the sheet entirely independently; 31 percent of respondents wrote in most of the sheet independently, but required some guidance by the field officer; 22 percent of respondents were illiterate and the field officer completed their sheet on their behalf.

¹⁹ Recent work has shown that a waiting period, defined as a delay between information about a prospective choice and the choice itself, can lead to more forward-looking choices. For example, Brownback, Imas, and Kuhn (2019) find that a waiting period causes a 28 percent increase in healthy food purchases.

²⁰ Online Appendix Figure C2 provides examples of what is shown on the screen for three hypothetical respondents.

attention because participation brings respondents to full attention. While this is possible, the attention drawn to the product in the A0 condition mirrors that done by Burn's typical marketing efforts (such as handing out fliers, bus-side and billboard media, demonstrations by distributors, and reaching out to rotating savings groups). This suggests that such inattention is unlikely to persist in the market. Treatments A1 and A2 examine whether attention failures not addressed by traditional marketing strategies may lead to inefficiently low demand. To the extent that this remains a concern, WTP among the control group provides an upper bound on the effect of participating in the experiment on WTP.

C. BDM Mechanism

We implement the mechanism defined in BDM (1964), building on the implementations developed in Berry, Fischer, and Guiteras (2020) and Dean (2020). Between visits 1 and 2, each respondent is randomly allocated a hidden price that is printed and sealed inside an envelope with the respondent's name on it. The prices range from US\$0.01 to US\$29.99. Neither the respondent nor the field officer know the price inside the envelope or the distribution of prices. Appendix Figure A4 displays the distribution of BDM prices across participants.

To eliminate the need for contingent reasoning and to provide concreteness, rather than asking for the respondent's maximum WTP in an open-ended fashion, the field officer conducts a binary search over the range of US\$0 to US\$40, first asking "If the price of the Jikokoa is 2,000 Ksh [US\$20.00] would you want to buy it?," then proceeding to a higher or lower price based on the respondent's answer. After arriving at a final WTP, the envelope is opened and the respondent buys the stove for the price in the envelope if and only if it is less than or equal to their WTP.²¹

The BDM mechanism serves two purposes. First, since the price is fixed ex ante, the mechanism is incentive compatible: it is in the respondent's best interest to state their true WTP. Second, because the hidden prices are randomly assigned, adoption is random conditional on WTP. Randomized stove adoption allows us to estimate the causal impact of adoption on charcoal spending.

Prior to the BDM each respondent completes two practice exercises, one for a bottle of lotion and one for a bar of soap. Each respondent is allocated a random price for the lotion and a random price for the soap. Respondents are randomly assigned whether they would be offered the lotion using take it or leave it ("TIOLI") and the bar of soap using BDM, or vice versa. These two practice take-up decisions serve two purposes. First, participants learn how the BDM mechanism works relative to the TIOLI they are used to in stores and experience the binding nature of the BDM. Second, comparing the demand curves elicited through the TIOLI and BDM mechanisms provides a test of comprehension. Their similarity for both goods suggests respondents understand the BDM mechanism and that the elicited WTP values reflect realistic decisions (Appendix Figure A5).²²

²¹ Online Appendix F provides more detail.

²² While one might be concerned these practice purchase opportunities would reduce liquidity, the average price paid for these goods was US\$0.68—substantially less than the cost of the stove.

D. *Measuring Charcoal Use*

We use three measures of charcoal use. The primary outcome is a recurring SMS survey. Every three days the respondent receives an SMS asking how much money they spent on charcoal in the past three days.²³ The SMS survey was administered for three months after visit 1 (two months after visit 2 for the attention control group), and again for one month after the one year endline survey. Second, we ask respondents to recall their recent charcoal expenditures during the visit 3 endline survey and the one-year endline survey. Finally, to generate ground-truth comparisons of these self-reported measures and address concerns about experimenter demand, respondents collect the ash generated by stove usage between visits 2 and 3. Normally, when a respondent is done cooking a meal, they dispose of the charcoal ash in the trash. Instead, during visit 2, each respondent is given an empty 20 liter bucket and asked to dispose of the used ash in the bucket. During visit 3, field officers weigh the bucket using a handheld weighing scale.

E. *Heterogeneity Measures: Time Inconsistency and Risk*

We measure time-inconsistency through an effort task allocation exercise (online Appendix Figure C14) closely following Augenblick, Niederle, and Sprenger (2015). Unfortunately, subjects appear to have not fully understood the interest rates as the number of tasks allocated to visit 2 are relatively constant across interest rates with several violations of monotonicity.²⁴ Thus we treat these heterogeneity results as suggestive and focus on the simplest choice where respondents trade off tasks one-for-one across visits and classify respondents who choose to postpone additional tasks during visit 2 relative to their decisions in visit 1 as exhibiting time inconsistency using a binary indicator. Using this methodology, 57 percent of respondents are classified as exhibiting time inconsistency.²⁵

To measure risk preferences, at the end of visit 1 each respondent is offered US\$4 for their time, and offered to invest any amount $x \in [0, 4]$, which pays three times or zero with 50 percent probability each.²⁶ Respondents who choose to invest $x < 2$ (68 percent) are classified as exhibiting risk aversion.

²³To increase response rates, respondents receive US\$0.20 for every SMS they correctly respond to and a bonus of US\$2 for every ten SMSs that they correctly respond to. An SMS is correct if it identifies charcoal spending in the past three days. Incorrect messages include those that refer to quantities (e.g., “1 kg” or “2 tins”); irrelevant messages (e.g., comments about the weather); amounts below US\$0.10 (these are assumed to be typographical errors); or any SMS beyond one per day (only the last correct SMS of the day qualifies).

²⁴An alternative possibility is that subjects were responding to temporary shocks to the cost of effort. We believe this is less likely than confusion because with relatively smoothly distributed costs, we should still see responsiveness to the interest rate. However we cannot rule out this possibility, and it remains another reason to only treat these results as suggestive.

²⁵As is common in these allocations, some subjects also increase their allocation of tasks at visit 2. This is also technically time inconsistent behavior, but for the sake of simplifying exposition, we do not refer to it as such.

²⁶This follows Gneezy and Potters (1997) and Charness, Gneezy, and Imas (2013). Respondents blindly pick one of two pieces of paper from a small bag. If the paper says “Win,” they receive three times what they invested. If the paper says “Lose,” they lose what they invested. Respondents always retain the uninvested amount $(4 - x)$.

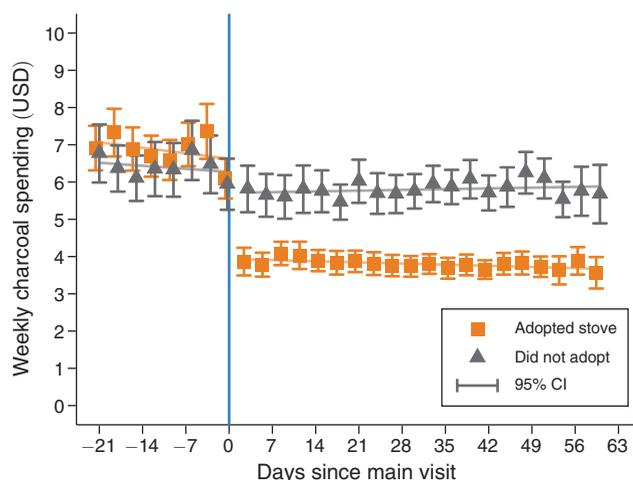


FIGURE 4. ENERGY EFFICIENT STOVES REDUCE ENERGY SPENDING

Notes: Weekly charcoal spending by adopters and nonadopters of the energy efficient stove before and after the main visit (visit 2). Charcoal spending is elicited through a recurring three-day SMS survey. Adoption of the stove causes charcoal expenditures to drop by US\$2.28 per week (39 percent relative to the control group). The causal estimates presented in online Appendix Figure C3 are similar.

IV. Results: Private and Social Impacts of Adoption

Out of the 955 respondents who completed visit 2, 570 (60 percent) adopted the stove, paying an average price of US\$15. In this section, we estimate the welfare effects of adoption. Since WTP cannot be interpreted as the total welfare gain when agents are credit constrained (we discuss this more in Section VID), we compute private and social benefits for the most plausible channels.

The public and private benefits from two years of ownership, discounting weekly with an annualized δ of 0.9, total US\$700. This exceeds the retail cost of US\$40. These discounted benefits consist of US\$214 in financial savings (Section IVA), US\$265 in avoided greenhouse gas emissions (Section IVB), and US\$221 in time savings (Section IVC). We discuss health and other nonfinancial benefits that we do not estimate in Section IVD.

These impacts persist at least one year after adoption (Section IVE) and we cannot rule out that they are homogeneous across agents (Section IVF). Sections IVG and IVH rule out several welfare-reducing attributes and energy rebound effects. Finally, Section IVI documents low and balanced attrition. In a balance test of baseline socioeconomic characteristics, none of the joint F -tests are significant (online Appendix Table D1).

A. Charcoal Spending and Usage

Figure 4 presents charcoal spending before and after the main visit, for adopters and nonadopters of the energy efficient stove, as elicited using the SMS survey. Weekly spending decreases sharply immediately after adoption.

To estimate the causal effect of stove adoption on charcoal spending, we employ an instrumental variables approach using the randomly assigned BDM price as an

TABLE 2—CAUSAL IMPACT OF STOVE ADOPTION ON WEEKLY CHARCOAL SPENDING

	OLS	First stage	IV estimate (one-month endline)			IV estimate (one-year endline)	
	USD (1)	Bought stove (2)	USD (3)	IHS(USD) (4)	IHS(kg) (5)	USD (6)	IHS(USD) (7)
BDM Price (USD)	0.01 (0.01)	−0.03 (0.00)					
WTP (USD)	−0.01 (0.01)	0.02 (0.00)	−0.00 (0.01)	−0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.00 (0.00)
Bought cookstove (=1)	−1.89 (0.28)		−2.28 (0.29)	−0.50 (0.07)	−0.48 (0.08)	−2.50 (0.42)	−0.56 (0.09)
Observations	7,853	913	7,853	7,853	796	6,979	6,979
Control mean	5.72		4.97	2.16	1.55	5.30	2.21
Socioeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Data source	SMSs	Midline	SMSs	SMSs	Buckets	SMSs	SMSs

Notes: Results from an instrumental variables (IV) regression that uses the (randomly assigned) BDM price as an instrument for stove adoption to estimate the causal impact of adoption on weekly charcoal expenditures. Columns 1 and 2 present the ordinary least squares (OLS) and first-stage estimates, respectively. Column 3 uses weekly charcoal expenditures in US dollars as the outcome variable. Column 4 uses the inverse hyperbolic sine (IHS) conversion of the US dollar amount. A 0.50 IHS reduction corresponds to a 39 percent reduction relative to the control group. Column 5 uses the IHS of the weight of the charcoal bucket one month after stove adoption as the outcome variable. Columns 6 and 7 conduct the same analyses as columns 3 and 4 respectively, but using data from the SMS survey conducted one year after the main visit. Socioeconomic controls include baseline savings, income, risk aversion, credit constrainedness, number of adults and children. In regressions using SMS data, errors are clustered by respondent. Standard errors in parentheses.

instrument for adoption. Table 2 presents the results (online Appendix Figure C3 displays them graphically). In the first stage in column 2, the BDM price strongly predicts adoption. Column 3 shows that adoption reduces charcoal spending by US\$2.28 per week.²⁷ The 50 log point reduction corresponds to a 39 percent decrease in charcoal consumption.²⁸

Column 5 shows that adoption causes a 38 percent reduction in total ash generated between visits 2 and 3. This matches the independent estimate from the SMS data. Converting weekly charcoal spending (in Kenyan shillings) to kilograms (kg) of charcoal purchased using local charcoal market prices, and comparing kilograms of charcoal purchased with kilograms of ash generated from charcoal usage, identifies a charcoal-to-ash conversion ratio of 1.7 percent. This matches the physicochemical properties of charcoal (FAO 1987).

It is worth putting these savings into perspective. US\$2.28 per week corresponds to US\$119 per year—one month of income for the average respondent. Net present value²⁹ (NPV) after two years of stove ownership is US\$174 for the average respondent. Given that most respondents are on the steep part of the utility function, the marginal utility from these savings is likely large. When asked how they spent their

²⁷ One might be concerned that some of this reduction in spending is due to the burden of the stove purchase on the household budget. This is weighed against by the fact that the effect remains stable more than a year later when total savings have outstripped cost of the stove and the similarity of the effects across treatment arms (online Appendix Table D2).

²⁸ To accommodate values of 0, we use an inverse hyperbolic sine (IHS) transformation to estimate the impact in proportional terms (Burbidge, Magee and Robb 1988). IHS is defined as: $\sinh^{-1}(x) = \log(x + (x^2 + 1)^{1/2})$.

²⁹ $NPV_i = [\sum_{t=1}^T \delta^t \psi_{it}] - P_E$; ψ_{it} are savings. We use annualized δ of 0.9 discounted weekly and $P_E =$ US\$40.

charcoal savings, 50 percent of respondents report buying more food, 23 percent report paying school fees, and 14 percent report buying household items such as soap or clothes.

Our empirical estimates of charcoal savings align closely with ex ante engineering predictions. Burn previously estimated that the Jikokoa uses 45 percent less charcoal than a traditional Kenyan stove (Ashden 2015). Our point estimate is a 39 percent reduction with a 95 percent confidence interval of 29–47 percent. We therefore cannot rule out that the engineering estimates accurately predict realized savings. This departs from Christensen et al. (2022); Fowlie, Greenstone, and Wolfram (2018); Burlig et al. (2020); and Gillingham and Palmer (2014), who find realized energy efficiency savings lacking when compared to engineering estimates in high income contexts. This may be due to the inelastic demand for cooking, the homogeneity of the technology, or the simplicity of its implementation. Our estimate is also significantly larger than those in many papers studying the adoption of improved cookstoves.³⁰

Relative to a retail price of US\$40, these savings constitute an average internal rate of return (IRR) of 295 percent per year.³¹ Table 3 shows that the IRR is larger than most relevant alternative investments likely available to households, including investments in business, agriculture, and education, according to recent literature. Research in the United States has even found *negative* IRR for household investments in energy efficient technologies (Fowlie, Greenstone, and Wolfram 2018).

B. Environmental Externalities

The median household in our sample spends US\$255 on charcoal per year. At local prices this corresponds to 849 kg of charcoal. The stove's 39 percent reduction then corresponds to 7.0 metric tons of CO₂e in avoided emissions over two years of usage.³² Using the EPA (2016) estimate for the 2020 social cost of CO₂ of US\$42, stove adoption generates US\$295 in CO₂e emission reductions (US\$265 discounted). Focusing on only the environmental benefits, investing in a Jikokoa reduces greenhouse gas emissions at a cost of US\$5.70 per ton of CO₂e.

Anthoff, Hepburn, and Tol (2009) argue that the social cost of carbon will vary substantially depending on the income of the country to which the estimates are normalized, and the locally relevant social cost of carbon (SCC) should be used to determine each country's optimal abatement. Given low incomes in sub-Saharan Africa, the SCC would be lower than the US EPA SCC. Given the lack of accepted regional SCCs, we refrain from quantifying this, noting only that this will increase the importance of private benefits relative to social benefits.

³⁰See Pattanayak et al. (2019); Hanna, Duflo, and Greenstone (2016); Levine et al. (2018); Mobarak et al. (2012); Burwen and Levine (2012); Beltramo and Levine (2013); and Chowdhury et al. (2019) for examples.

³¹The IRR corresponds to the discount rate where the NPV of an investment, from time 0 to infinity (we assume two years of use), equals 0. Specifically, IRR equals δ such that $[\sum_{t=1}^T \delta^t \psi_t] - P_E = 0$.

³²The production of charcoal emits 7.2–9.0 KG of CO₂e, per kilogram of charcoal (FAO 2017). The combustion emits a further 2.2–2.6 KG (Bhattacharya, Albina, and Salam 2002). We use the midpoints in our calculations.

TABLE 3—EMPIRICAL RATE OF RETURN ESTIMATES FROM SELECTED LITERATURE

Authors	Year	Country	Annualized IRR (percent)
Berkouwer and Dean	2019	Kenya	294
<i>Energy Efficiency</i>			
Allcott and Greenstone	2017	USA	−4
Fowlie, Greenstone, Wolfram	2018	USA	−10 to 0
Davis, Martinez, Taboada	2018	Mexico	less than-8
<i>Firms</i>			
Bigsten et al.	2000	Africa ^a	10–35
McKenzie and Woodruff	2006	Mexico	36–180
McKenzie and Woodruff	2008	Mexico	240–396
De Mel, McKenzie, Woodruff	2008	Sri Lanka	55–63
Kremer, Lee, Robinson	2013	Kenya	113
Fafchamps et al.	2014	Ghana	180
Banerjee and Duflo	2014	India	105
Blattman, Fiala, Martinez	2014	Uganda	30–50
Blattman et al.	2016	Uganda	8–24
<i>Agriculture</i>			
Udry and Anagol	2006	Ghana	30–50
Duflo, Kremer, Robinson	2008	Kenya	52–85
<i>Education</i>			
Bigsten et al.	2000	Africa ^a	1–5
Duflo	2001	Indonesia	8.8–12
<i>Other</i>			
Baird ^b	2016	Kenya	32
Haushofer, Shapiro ^c	2016	Kenya	15

Notes: This table shows annualized internal rate of return (IRR) estimates from recent literature. The IRR corresponds to the interest rate where the NPV of an investment, from time 0 to infinity, equals 0. Conversion between monthly and annualized IRR conservatively (and in line with the literature) assumes no reinvestment.

^aCameroon, Ghana, Kenya, Zambia, Zimbabwe

^bDeworming

^cUnconditional cash transfers

C. Time Savings

Table 4 presents results from an instrumental variables regression, using the randomly assigned price as an instrument for adoption, to estimate the causal impact of adoption on nonfinancial outcomes. Column 2 estimates a one hour daily reduction in cooking time.³³ Online Appendix Figure C4 displays the distribution of daily cooking time by treatment.

Valuing the stove's benefits through the time savings mechanism requires valuing participants' time, which is complex. For example, Goldszmidt et al. (2020) find that Americans value an hour of time approximately equivalently to the median hourly wage, while Hussam et al. (2021) find significant asymmetry in how individuals value time spent working versus time spent idling, which is how time spent waiting for a stove to light up may be perceived. Absent other quantitative estimates of participants' value of their time, we use median earnings of US\$3 per day and

³³Likely driven by a reduction in the time spent lighting charcoal, which is time-consuming for traditional *jikos*.

TABLE 4—NONMONETARY OUTCOMES: DRIVERS AND IMPACT OF STOVE ADOPTION

	WTP	Minutes	Adoptions	Health symptoms index			Health symptoms	
	(USD)	cooking	in	(one-month follow-up)			index (one-year follow-up)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Health beliefs (index)	−0.01 (0.62)							
Savings beliefs (USD)	0.02 (0.01)							
Jikokoa (=1)		−56.31 (14.51)	−0.17 (0.16)	−0.52 (0.10)	−0.56 (0.11)	−0.51 (0.11)	−0.56 (0.09)	−0.57 (0.10)
Continued old stove use (=1)					0.17 (0.09)	0.15 (0.09)		0.05 (0.10)
Charcoal usage (KG/month)						0.05 (0.01)		
Observations	924	924	924	924	924	924	855	855
Control mean	11.88	192.09	0.32	−0.00	−0.00	−0.00	0.00	0.00
Socioeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Column 1 tests whether baseline beliefs about financial and health benefits affect WTP. Columns 2 through 6 present causal estimates of the impact of stove adoption on various outcomes measured one month after adoption, using the randomly assigned price as an instrument for adoption. Adoptions in network indicates whether any of the respondent's friends, family, or neighbors purchased the Jikokoa in the past one month. The health index consists of self-reported health and respiratory symptoms for the primary cookstove user and any children (if applicable). The index is standardized for the control group to have a mean of zero and a standard deviation of one. A higher value indicates more respiratory symptoms, and thus, poorer health. Columns 7 and 8 report health outcomes one year after adoption. Socioeconomic controls include baseline savings, income, risk aversion, credit constrainedness, number of adults and children. Standard errors in parentheses.

assume daily earnings scale linearly with hours worked starting at an eight-hour work day. When calculated in this manner, the time savings correspond to US\$0.34 per day, or 105 percent of median financial savings.

D. Health and Other Omitted Nonfinancial Attributes

Columns 4 through 8 of Table 4 show that adoption of the Jikokoa causes a 0.5 standard deviation improvement in self-reported health in the one-month and one-year endline surveys. In-person surveys to measure physiological health outcomes in 2020 to 2021 had to be canceled due to COVID-19 safety considerations. These health outcomes are therefore self-reported and should be interpreted cautiously. We furthermore exclude health benefits from our welfare totals because there is substantial uncertainty in valuing medical costs, value of statistical life, and disability-adjusted life years.

Most respondents report that space heating generated by stove usage helps keep them warm. However, less than a third of respondents report ever burning charcoal purely with the goal of heating their living space, and while charcoal spending is uncorrelated with temperature, this may still be an upper bound since the endline survey was conducted in June to July, Nairobi's coldest months. We therefore exclude heating cobenefits when enumerating benefits.

Two-thirds of respondents who adopted the stove said they did not change which foods they cook, and 72 percent said they cook the same quantity of food as before.

60 percent said that food cooked with the energy efficient stove tasted better, and only one person said the food tasted worse.

To study network effects, we evaluate whether households in geographic or social proximity to respondents in our sample have the Jikokoa. Column 3 of Table 4 documents no increased ownership by neighbors, friends, or family of the respondent in the month after adoption. This provides further evidence that the binding constraint is not information or perceptions of stove quality.

E. Long-Term Impacts

Prior studies of efficient cookstoves often found declines in usage and benefits over time due to technology breakdown, poor maintenance, or user tastes (Pillariseti et al. 2014; Hanna, Duflo, and Greenstone 2016). To test this, we resurvey respondents and conduct a charcoal SMS survey 12–14 months after the main experiment.³⁴

Out of the 517 stove adopters resurveyed one year later, 508 (98 percent) still had the Jikokoa. Reasons for loss include theft, fire, nonpayment repossession, and giving the stove away voluntarily. Twenty-seven percent of adopters still had a working traditional *jiko* at home, 47 percent said their *jiko* had broken and they simply did not replace it, and 22 percent had given their old *jiko* away as a gift. Only one person said they had sold their *jiko*, which is not surprising given the lack of a secondary *jiko* market, likely due to its fragility and low cost.

Columns 6 and 7 of Table 2 show that 12 months after adoption, the stove continues to reduce charcoal spending by US\$2.50 per week, a 43 percent reduction (56 log points) relative to the control group. Savings appear constant over the long term. This improvement on previous cookstove technologies may be attributable to the Jikokoa's ease of use and similarity to traditional *jikos*. It is also more durable, and adopters in Nairobi have access to free repair services.³⁵

We find suggestive evidence of a positive impact on long-term financial assets, in particular for respondents who at baseline had positive savings in a SACCO group, mobile money account, or formal banking account (Appendix Table B1). Among those with positive savings at baseline, we find a 75 percent (56 log point) increase in savings, driven by larger SACCO payouts.

None of the 385 participants who did not purchase a Jikokoa during visit 2 had bought one by visit 3. One year later 16 had bought one (4.5 percent), five of them having (at least partly) borrowed funds to afford it. After visit 3, Burn released a new model of the stove that was smaller and only cost US\$30. As a result, most respondents who bought the stove outside of the experiment paid less than US\$40.

F. Heterogeneity

The stove appears to benefit almost all adopters. Unconditional local quantile treatment effects estimated using the method proposed by Frölich and Melly (2013) show that the effect is relatively homogeneous across the charcoal spending

³⁴Of the 955 participants who completed visit 2, 866 (91 percent) completed the one-year endline survey.

³⁵Respondents can call the Jikokoa service number to locate their nearest repair shop. Damaged from customer misuses does not qualify for repair. This service is therefore not expected to induce moral hazard.

distribution (online Appendix Figure C5). Sorted group average treatment effects estimated using the method in Chernozhukov et al. (2018) finds the most heterogeneity possible using baseline observables (online Appendix Figure C6).³⁶ While the confidence intervals are wide, the point estimates suggest the entire sample benefits from adopting the stove.

G. Ruling Out Welfare-Reducing Attributes

If stove adoption causes unpredictable negative impacts, increased adoption may reduce welfare. We rule this out for several reasons. First, the relationship between WTP measured during the BDM mechanism and stated endline WTP elicited is similar for respondents who adopted the stove and those who did not (Appendix Figure A6). Substantial learning of any welfare-reducing hidden attributes after adoption is therefore unlikely. Second, during the endline survey 99 percent of stove adopters say they recommend the stove to friends and family members. Less than 1 percent had ever considered selling it.³⁷ Finally, by investing in the stove a household may forgo an alternate investment with higher returns. Table 3 documents that alternative investments that this population may have access to are unlikely to generate higher returns than the energy efficient cookstove.

H. Ruling Out a Rebound Effect

A rebound effect occurs when efficiency improvements from technological progress are partly offset by increased usage, thus potentially increasing usage of the input (Jevons 1866). This can be due to an income effect—individuals use savings from the investment to use the appliance more—or a substitution effect—usage of the appliance is now relatively cheaper (Borenstein 2015). Increased usage would reduce net savings, but increase utility derived from the technology, which would need to be factored into welfare calculations.

Rebound is likely small in this context for three reasons. First, cooking is inelastic: a regression of log of time spent cooking on log of income yields a coefficient that is not statistically different from zero. In the endline survey, 72 percent of adopters report no change in the amount of food they cook; 22 percent state that the amount “increased slightly,” but may do so without cooking for longer or using more charcoal, instead simply adding more food into the pot they were already cooking with. Second, a rebound effect would generate a wedge between engineering estimates and realized energy efficiency gains. To the contrary, our empirical estimates align closely with ex ante engineering predictions. Finally, a rebound effect would increase time spent cooking, whereas we find a *decrease* of 54 minutes per day.³⁸

³⁶We use least absolute shrinkage and selection operator (LASSO) on half the sample to predict charcoal spending with and without the stove based on baseline observables. In the other half of the sample, we predict the treatment effect for each individual as the difference between these two predicted spending levels. We use this predicted treatment effect to split the sample into thirds and estimate the treatment effect for each group. Repeating this process over 1,000 random splits stratified by WTP and taking the medians gives the estimates in the figure.

³⁷To limit experimenter demand, field officers repeatedly reminded the respondent that they were part of a university research team, independent from the cookstove company, and that responses were anonymous.

³⁸Rebound may also increase energy usage by increasing usage of other energy-consuming durables due to an income effect, however in this context the cookstove is each household’s primary energy-consuming durable.

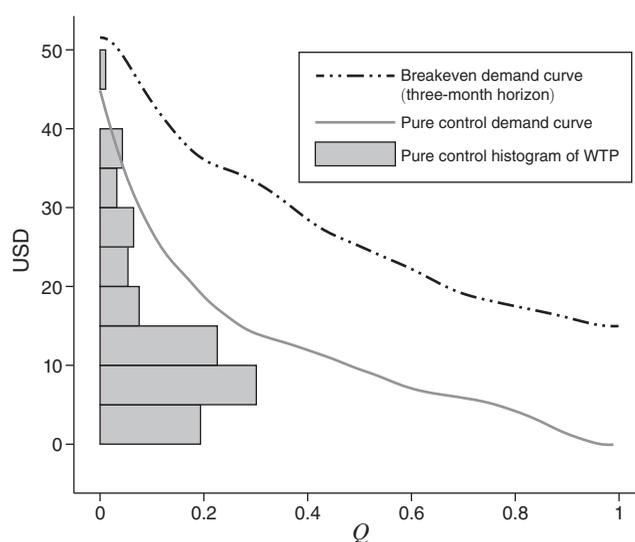


FIGURE 5. UNDERADOPTION OF THE ENERGY EFFICIENT TECHNOLOGY

Notes: The histogram represents WTP elicited through the BDM mechanism for the control group, and the smooth line represents the corresponding demand curve. The dotted line represents the breakeven demand curve for all agents, if agents were willing to pay precisely their savings over a three-month period. The gap between the two curves can be interpreted as underadoption of the energy efficient technology. The breakeven demand curve assumes annualized discount rates $\delta = 0.9$. Online Appendix Figure C8 presents robustness checks for annual discount factors $\delta = 0.5$ and $\delta = 1$.

I. Attrition

Selective attrition might bias results. We test for attrition and do not find meaningful variation. Of the 1,018 respondents who were enrolled during visit 1, 955 (94 percent) completed visit 2 and 924 (91 percent) completed visit 3. Attrition for surveys and median SMS response is balanced across all socioeconomic and treatment groups except age and stove adoption status (online Appendix Table D3), and we find limited attrition in the SMS survey (online Appendix Figure C7).

V. Results: Drivers of Adoption

Average WTP for the stove is US\$12. This is lower than average discounted savings of US\$214, and substantially lower than total private and social benefits of US\$700. Figure 5 displays the histogram of WTP for the pure control group, and the corresponding demand curve, defined $Q(P_E) = \Pr(P_E \leq WTP_i)$. Households are not able, or not willing, to pay for an investment with average financial returns of 295 percent per year that are relatively homogeneous across agents.

We compare this against a hypothetical breakeven demand curve. A fully rational, unconstrained risk-neutral agent's WTP equals the sum of expected discounted savings. Aggregating across participants yields a breakeven demand curve defined by $Q(P_E) = \Pr(P_E \leq \sum_{t=1}^T D(t) \psi_{it})$. To estimate ψ_{it} we apply the 39 percent reduction in spending estimated in Section IVA to each respondent's baseline charcoal spending. We assume exponential weekly discounting $D(t) = \delta^t$, with an annualized discount factor of 0.9, and compute the expected discounted savings over the

TABLE 5—THE IMPACTS OF CREDIT AND ATTENTION ON WTP (USD)

	(1)	(2)	(3)	(4)	(5)
Credit	12.54 (0.67)	13.07 (1.23)	11.16 (1.81)	15.02 (1.69)	10.66 (1.46)
Attention to benefits	0.44 (0.83)	-0.71 (1.43)	-0.52 (2.20)	-0.28 (1.91)	-0.33 (1.43)
Attention to costs	-0.27 (0.77)	2.50 (1.31)	3.62 (2.14)	1.66 (1.65)	2.40 (1.30)
Attention to benefits × credit		1.76 (1.75)	1.23 (2.73)	1.51 (2.31)	1.39 (1.75)
Attention to costs × credit		-4.19 (1.61)	-3.29 (2.59)	-4.83 (2.05)	-2.16 (1.84)
Time inconsistent					-2.58 (1.09)
Time inconsistent × credit					4.62 (1.50)
Attention to costs × time inconsistent × credit					-3.37 (1.57)
Observations	955	955	411	544	955
Control mean	12.12	12.12	13.14	10.98	13.14
Sample	Full	Full	TI = 0	TI = 1	Full

Notes: This table shows the causal impact of credit (pooling the two credit treatment arms) and attention treatments on WTP elicited during the BDM mechanism. For the “attention to benefits” treatment, the indicator variable “attention to benefits” is set to one and the indicator variable “attention to costs” is set to zero. For the “attention to benefits minus costs” treatment, both indicator variables are set to one. Agents are defined as exhibiting time inconsistency (TI = 1) if they choose to postpone effort tasks during visit 2. Socioeconomic controls include baseline savings, income, risk aversion, credit constrainedness, number of adults and children. Following Dizon-Ross and Jayachandran (2022) we control for WTP elicited during the practice BDM round (for soap or a bottle of lotion), which improves statistical precision slightly. Standard errors in parentheses.

three months that the loan relaxes credit constraints.³⁹ The difference between the breakeven demand curve and the control demand curve in Figure 5 indicates significant underadoption.

A reduction in the wedge between the two demand curves caused by a treatment addressing a particular constraint or bias can be interpreted as its contribution to the underadoption gap. Sections VA and VB investigate how credit and attention affect this gap. Section VC discusses loan repayment patterns, and Section VD discusses how risk aversion affects adoption.⁴⁰

A. Credit Doubles WTP, While Attention to Benefits Has No Impact

Table 5 presents the results. Access to credit increases WTP by US\$12.54, or 103 percent relative to the control group, closing the underadoption gap.⁴¹ Figure 6 presents these results graphically.

³⁹Due to the short time horizon, results are robust for $\delta = 0.5$ and $\delta = 1$ (online Appendix Figure C8). Even using the more conservative discount parameters estimated by Balakrishnan, Haushofer, and Jakiela (2020) using a money now/money later design ($\delta = 0.942$ per week, $\beta = 0.924$), low control WTP cannot be explained by time preferences alone.

⁴⁰These analyses match those proposed in the Pre-Analysis Plan, available in the online Appendix.

⁴¹Table B2 in the Appendix provides a full breakdown of primary treatment effects.

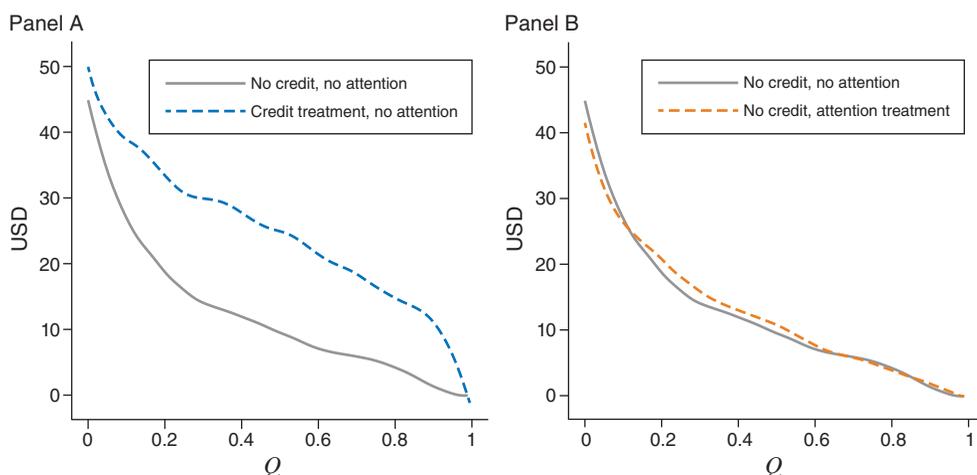


FIGURE 6. IMPACTS OF EXPERIMENTAL TREATMENTS ON WTP

Notes: Graphs show the cumulative distribution of WTP for the control and treatment groups for both experimental treatments. Panel A presents results by credit treatment status among people in the attention control group only. Panel B presents results by attention treatment status among people in the credit control group only. Access to credit increases WTP by US\$13 (104 percent relative to control). Attention to benefits does not affect WTP.

The stove's rate of return is higher than local lending rates. This suggests that these constraints are due to more than inefficiently high costs of borrowing. One possibility is that credit providers are choosing to ration by quantity rather than price. A related possibility is that agents are sufficiently present biased that they fail to maintain liquid buffer stocks. This would both prevent them from having cash on hand to finance stove adoption, and would lead to lines of credit being allocated to smoothing shocks Kremer, Rao, and Schilbach (2019).

Credit alone appears to be sufficient to fully close the energy efficiency gap over the three-month period of the loan. However, given that the term of the loan is limited, the loan does not allow households to fully leverage all future savings to finance stove adoption. The three month loan was not sufficient to increase WTP to market prices. At a price of US\$40—the market price at the time of the study—0.6 percent of those in the credit control and 6.9 percent of those in the credit treatment are willing to adopt the stove. At a price of US\$30—the market price of the new model Burn introduced after the experiment, set with affordability in mind—6.9 and 34.2 percent, respectively, would. A longer term loan that allowed households to use more savings to finance the purchase could increase WTP further.

The attention treatment has zero impact on WTP.^{42,43} This may be because this is a high-stakes decision: when mistakes are costly, an individual living in poverty may be relatively more attentive to adoption decisions (Shah, Shafir, and Mullainathan 2015; Fehr, Fink and Jack 2022). Interestingly, this lack of response is in spite of

⁴² Given that our *attention to benefits* treatment was designed in part to address concentration bias, it is reassuring that we also do not find any evidence of concentration bias in costs. We discuss this further in Section VB below.

⁴³ The estimates in column 3 of Appendix Table B2 rule out an effect larger than US\$1.70.

a 0.2 standard deviation increase in stated beliefs about savings (online Appendix Table D4). Given the lack of impact of the attention treatment on WTP, and the heavy handed treatment, the increase in stated beliefs may be the result of experimenter demand.

There is no relationship between WTP and stove benefits, whether expected or realized (online Appendix Figure C9), even among those offered credit. Subjects' beliefs about average savings may be well calibrated but they may fail to appreciate heterogeneity in individual circumstance. Some evidence for this comes from our subjective belief data. In the attention control group at the second visit, the average respondent's median belief is that they would save US\$89 over the next year by purchasing the stove; however, the average standard deviation of their beliefs was US\$15. Respondents appear reasonably correct on average, but exhibit significant uncertainty about their beliefs.

B. *The Psychology of Credit*

Credit changes the structure of costs: it postpones costs to the future, and reduces the maximum cost incurred in any single period. In addition to relaxing credit constraints, credit may therefore work in part through psychological channels.

First, we consider whether the impact of credit is mediated by inattention to future costs. Column 2 of Table 5 shows that attention to future loan payments reduces the impact of credit on WTP by US\$4.19. Relative to an impact of credit on WTP of US\$12.54 on agents in the control group,⁴⁴ inattention contributes around one-third of the total impact of credit. This mechanism is economically meaningful. The large impact of credit is thus in part driven by inattentiveness to costs when these are incurred in the future.

Attention to costs among the credit control group has a moderately positive impact (US\$2.50) on WTP, significant at the 10 percent level. These individuals may observe that costs will be incurred in only a single period, whereas benefits will be accrued over many periods, making the adoption decision look more attractive.

There is suggestive evidence that the impact of inattention on credit is linked to time inconsistency (see Section III E for more detail on measuring time inconsistency). While we unfortunately have too many violations of monotonicity to be confident in these results, an interesting pattern emerges when focusing on the easiest decisions where the subjects faced a one-to-one trade-off in effort tasks. Columns 3 and 4 of Table 5 show that the effect of credit and the mediating impact of being reminded of future costs are both stronger for agents exhibiting time inconsistency. Column 5 presents the triple interaction. Agents may be revising down effort tasks at visit 2 because they do not attend to future costs rather than due to their time preferences. Future research should investigate this question more completely.

⁴⁴One may be concerned that highlighting the future costs may have changed respondents' beliefs about the likelihood of the enforcement of repayment. We think this is unlikely as the repeated visits by the team had already signaled we were serious about following up with the respondents, and for those in the other attention treatments we still explained the repayment system before eliciting WTP. We also find no evidence of this ex post as repayment rates across the attention arms are indistinguishable.

Second, we test for concentration bias by comparing WTP under weekly and monthly loan deadlines. Respondents paying with weekly deadlines are willing to pay on average US\$1.03 more for the stove than those paying with monthly deadlines (online Appendix Figure C10 and column 8 of Appendix Table B2). While this is consistent with theory, it is economically small and not statistically significant. This suggests concentration bias is not at play in a meaningful way, and respondents are largely able to correctly perceive the size of costs, regardless of how these are presented to them.

C. Repayment and Default

Respondents are free to choose the frequency and amount of each payment, but are required to meet cumulative minimums by the relevant deadlines. Respondents who miss a deadline are reminded via repeated SMSs in the following days. Most respondents pay within three days of their official deadlines. By the end of the payment period, the median respondent who adopted the stove and was in the credit treatment group had paid 98 percent of their price; 13 percent had paid less than 10 percent and the mean repayment rate was 72 percent.

These repayment rates are roughly in line with repayment rates among existing lending agencies. BRAC (one of the world's largest microlenders) reports repayment rates of around 98 percent in Bangladesh. However, they define repayment as having paid off the loan within a year of its disbursement, regardless of the frequency or size of missed payments during that one-year period: shorter-term repayment rates are closer to 90 percent. BRAC's Liberia, Sierra Leone, and Uganda offices report 86, 82, and 93 percent repayment rates, respectively. Kenya's Akiba Mashinani Trust reports repayment rates of 90 percent for livelihood loans and 76 percent for housing loans.

The most serious concern for our study is whether this default was strategic rather than caused by shocks to individuals' ability to repay. If individuals in the credit treatment were planning to strategically default on the loans, they would inflate their WTP in order to maximize their chance of adoption since they do not plan to pay the price in any case. The first piece of evidence against widespread strategic default is that most default is not immediate (Appendix Figure A7). If individuals were planning on defaulting at the time of elicitation, they should not have paid any amount, rather than partially repaying the loans and then defaulting.

To ensure that our estimated effects of credit are not driven by such inflation, we would ideally remove strategic defaulters from the sample. Unfortunately not all of these individuals can be identified: only participants who actually adopted the stove in the credit treatment had the ability to default. Moreover, because the actual price paid was randomly assigned, some individuals in the sample may have defaulted if they had been assigned a higher price, or not defaulted if they had been assigned a lower price. To work around these limitations, we incorporate default in several ways. Credit significantly increases WTP across all approaches (online Appendix Figure C11 and Appendix Table B3).

In our first approach, we look at the actual amount paid by each participant. We code those who didn't adopt as making zero payment. Because both the credit treatment and credit control faced the same hidden price distribution, any increase in

payments received must be due to increasing true WTP. This is a strict lower bound on true WTP, and is therefore the most conservative method. The credit treatment more than doubles the amount paid, from US\$3.56 to US\$7.51.

In our second approach, for those who adopted and paid less than the randomly assigned price, we replace their elicited WTP with the actual amount repaid. For those who repaid in full or did not adopt, we use their elicited WTP. This approach reduces underestimation of WTP relative to the first approach since it both allows nonadopters to have positive WTP and takes as valid the elicited WTP for those that did not default. However, it means individuals who drew a low price but who would have defaulted at a higher price, or nonadopters who would have defaulted if they'd adopted, are included at their elicited WTP.

In our third approach, we deflate the elicited WTP of the credit treatment group by the average default rate. This approach assumes that the average default rate we see across prices within the credit treatment is constant across all individuals in the credit treatment. An alternative way of viewing this approach is as deflating by the interest rate the bank would need to charge in order to break even on its loans.

Finally, we drop all those in the credit condition who defaulted, and include only those who either did not adopt, or who adopted with a loan that they fully repaid. This is the most generous of the approaches because it assumes that the only defaulters in our sample are those who were observed defaulting.

By all of these metrics, those in the credit treatment group still demonstrated a significantly greater WTP than those in the noncredit group. Using the estimate in column 3, which yields the most conservative results and assumes all default is strategic, credit still increases WTP by US\$4.52. Strategic default could thus account for at most US\$7.94 (64 percent) of the full US\$12.46 treatment effect on WTP (column 1 of Appendix Table B3).

D. Risk Aversion

Under uncertainty, risk aversion can reduce technology adoption (Oliva et al. 2020). Column 1 of Table 6 demonstrates that, even after controlling for socioeconomic characteristics like income and baseline savings, the WTP of agents exhibiting risk aversion is on average US\$1.46 lower.

This raises the question of whether risk-averse agents view the loan as a form of insurance. Participants in our study do not face any financial or other penalties for payment delays, other than having to return the stove if they cannot continue the payments.⁴⁵ Our credit may therefore be attractive to respondents who are risk averse, in which case the impact of credit on WTP would be larger for risk averse agents. To the contrary, column 2 of Table 6 indicates that risk aversion does not affect the impact of credit. The low risk of credit may be less important in this context because respondents in the credit control group also had the option to return the stove at no cost under Burn's warranty program.

⁴⁵ Carney et al. (2018) call this a *new-asset collateralized loan*. Once agents adopt, their reference point changes and repayment increases as the endowment effect applies to the new asset. Their predictions match what we observe.

TABLE 6—RISK AVERSE AGENTS HAVE LOWER WTP (USD),
BUT RESPOND SIMILARLY TO CREDIT

	(1)	(2)
Credit	12.54 (0.67)	12.43 (1.18)
Risk aversion	−1.46 (0.69)	−1.57 (1.17)
Risk aversion × credit		0.17 (1.43)
Belief about stove durability (years)	0.34 (0.15)	0.34 (0.15)
Observations	955	955
Control mean	12.12	12.12
Sample	All	All

Notes: This table shows results from a regression estimating how risk aversion and beliefs about stove durability affect WTP. Risk aversion affects WTP directly but does not meaningfully affect the impact of credit. Socioeconomic controls include baseline savings, income, risk aversion, credit constrainedness, number of adults and children. Following Dizon-Ross and Jayachandran (2022) we control for WTP elicited during the practice BDM round (for soap or a bottle of lotion), which improves statistical precision slightly. Standard errors in parentheses.

VI. Policy Implications

The International Energy Agency (2018) estimates that 44 percent of all global emissions reductions by 2040 could come from energy efficiency gains. We demonstrate that there are energy efficiency opportunities that lower emissions and generate not only aggregate welfare benefits but private financial benefits for households. This presents a unique opportunity for sustainable development.

The energy efficient technology in this paper is privately profitable, and households attend to these savings, but credit constraints prohibit adoption for most agents. These results have implications for the effectiveness of climate policies in low-income contexts, including subsidies for energy efficient technologies, interventions designed to draw attention to savings, and carbon taxes.

A. Technology Subsidies and Carbon Taxes

In a first-best setting, a Pigouvian tax on the emitting good efficiently corrects for negative externalities (Pigou 1920). Low- and middle-income country governments are increasingly implementing carbon taxes to reduce emissions of greenhouse gases and local environmental pollutants. For example, South Africa, Chile, and Mexico have all enacted a carbon tax since 2014, each covering at least 40 percent of domestic greenhouse gas emissions (World Bank 2020). In this study's context, a carbon tax would increase the cost of charcoal. The resulting increase in potential energy savings would incentivize the adoption of the energy efficient stove.

However, an agent facing binding credit constraints cannot respond optimally to this incentive. A carbon tax is therefore unlikely to achieve optimal abatement. Worse, a carbon tax would have important equity implications by increasing energy prices, in particular for those with the tightest credit constraints, who are often the poorest and therefore also have the highest energy burden.

Instead, a subsidy on the energy efficient technology could generate large welfare gains. By lowering the cost at adoption, a subsidy could target credit constrained agents more effectively than a tax. The demand curve among the control group indicates that introducing, for example, a US\$30 subsidy would increase adoption from less than 0.6 percent to 54.5 percent (Figure 6). Given the low fraction of subsidies that are inframarginal to adoption, such a subsidy would have large welfare returns. Assuming no correlation between credit constrainedness and charcoal usage,⁴⁶ and factoring in private savings and avoided environmental damages, a subsidy for the energy efficient cookstove would generate US\$19 of welfare gains for every US\$1 of government expenditure.

B. *Increasing Attention*

Given the lack of response to an intense intervention designed to draw attention to potential energy savings, it is unlikely that adoption can be promoted through interventions designed to draw attention to savings beyond existing marketing approaches. Other psychological interventions may still be helpful. For example, a decision aid designed to help households allocate credit across different investment opportunities may yield higher returns for the household. Future work should investigate this possibility.

C. *Expanding Access to Credit*

Expanding access to credit could increase adoption, but this depends on the source of the credit constraints. If lenders are engaging in quantity rationing and individuals are optimally allocating the credit they have access to, then expanding access to credit will likely increase adoption given the high rate of return. On the other hand, if households are credit constrained due to self-control problems, then expanding the quantity of credit may not increase adoption. In this world, households may choose to use the additional credit to smooth the shocks to consumption that they face due to their inability to maintain a buffer stock of savings (Kremer, Rao, and Schilbach 2019).

A related question is why profit maximizing firms are not offering product-specific credit. As in the experiment, these targeted expansions of credit would sidestep concerns about misallocation of credit. Informal conversations with decision makers in the sector suggest that of primary importance are fears of overextension if technology firms expand into the credit sector. The primary strength of energy efficient technology companies is developing and marketing these technologies—extending into activities beyond this scope may jeopardize the quality of those products. Furthermore, a large gap exists between the formal and informal sectors. A manufacturing company interested in offering credit to its customers may be more likely to partner with an existing formal banking institution, but the population studied in this

⁴⁶The subsidy's effectiveness will depend on the extent to which the subsidy targets high charcoal users. If these are negatively correlated, a policymaker might combine a subsidy with a carbon tax to incentivize higher users. The relative sizes of the tax and the subsidy will depend on the size of the externality, the size of credit constraints, and the correlation between usage and credit constraints (Allcott, Mullainathan, and Taubinsky 2014).

paper is almost entirely served by informal financial services providers. Novel technological advances such as remotely threatening the shutoff of solar panels could effectively act as collateral (Gertler, Green, and Wolfram 2021), but penetration of this technology is still too limited to enable widespread credit for the Jikokoa.

In addition, the high default rates may make extensive lending prohibitively expensive. The loans offered in this experiment charged an interest rate of $r = 1.16$ percent per month, or 3.5 percent over the three months. Lenders could charge higher interest to recover losses from these high default rates.⁴⁷ Across all respondents who adopted the stove in the credit treatment groups, on average 72 percent of the loan was repaid. Thus, a lender would need to charge an interest rate of 39.2 percent ($0.72 = \frac{1}{1+r}$), on top of the market lending rate of 1.16 percent, for a total interest rate of 40.3 percent. In the data, however, repayment rates are not constant: respondents with a higher price have lower repayment rates. When controlling for price, WTP is not correlated with repayment rate, suggesting price itself is the mechanism. The high breakeven interest rate of 40.3 percent would likely cause higher default rates, in turn requiring a higher interest rate. Extrapolating observed patterns in this way reveals that there is no interest rate at which a lender could breakeven for any price above US\$15.

D. The Policy Interpretation of Willingness-To-Pay

Policymakers and researchers often infer welfare gains of a product or intervention from beneficiary WTP. In the context of environmental and health economics, WTP is often used to value environmental attributes or individual health outcomes. However, market frictions may create a wedge between WTP and *ability to pay* (ATP). Banerjee (1997) discusses how credit constraints can increase the gap between WTP and ATP and exacerbate red tape in the context of government bureaucracy. Given how constrained the subjects in our experiment are—as measured both by their response to a three month loan and our back-of-the-envelope calculations of private benefits—revealed preference methods may substantially underestimate realized welfare gains. These results should caution policymakers and researchers from relying on WTP measures for welfare estimates in this and similar settings.

VII. Conclusion

Some energy efficiency investments can enable sustainable development by lowering greenhouse gas emissions while simultaneously generating significant private financial savings for poor households. These unique opportunities to reduce greenhouse gas emissions at negative cost can meaningfully help reduce poverty.

We demonstrate this in the context of an energy efficient household technology in Nairobi, Kenya. We estimate that the technology reduces household charcoal spending by 39 percent, saving the average household US\$117 per year. At a retail price of US\$40, this corresponds to an IRR of 295 percent per year. Qualitative evidence suggests significant gains in well-being. More than 60 percent of respondents

⁴⁷ While the 1.16 percent interest rate cap was repealed in November 2019, in practice many lenders were able to recover higher revenues even while it was in place, by charging additional “service fees.”

report using the savings for critical household expenditures such as food items and child school fees. This means governments looking to reduce poverty by increasing household adoption of profitable technologies may find that stove subsidies are an efficient means of improving welfare. The stove also generates significant carbon emissions reductions of US\$147 per year. Despite this, participants in the control group are only willing to pay US\$12 for the stove.

In contrast to many papers in the energy literature and the development literature that would predict significant behavioral biases, we find that an intense intervention designed to increase attention to energy savings had no effect on WTP. This may be due to the decision's high financial consequences: the median respondent saves one month of income per year. There is modest evidence in the literature that when stakes are higher, cognitive performance among the poor improves. It may also be that energy expenditures are easier to track when inputs and outputs are strongly correlated—charcoal usage is relatively easy to track as its sole usage is for charcoal cookstoves.

On the other hand, access to credit more than doubles WTP for the stove, suggesting households are significantly credit constrained. The first best policy would be to increase energy efficiency through credit, but this may be difficult to implement in practice due to information asymmetry and adverse selection in credit markets, and the informal nature of many low-income economies. We also show that inattention to future periods can affect the use of credit, suggesting that simply expanding access to credit may not lead to the efficient outcome.

Low and middle-income countries are expected to propel future energy demand. Energy efficiency is often touted as a technology that can benefit households financially while also reducing carbon emissions, yet adoption remains low. We illustrate that policymakers cannot rely on households to adopt privately cost-saving energy efficient technologies. Subsidized credit, or subsidies for energy efficient technologies, could effectively target credit constrained agents by lowering the upfront cost of adoption. Such policies would allow low-income households to take advantage of technologies that are already available to them, improving environmental outcomes at negative cost and generating significant financial benefits for the poor.

APPENDIX

Panel A



Panel B



FIGURE A1. JIKOKOA MARKETING MATERIALS

Notes: Panel A displays the Jikokoa for sale in a store. Panel B displays the flyer given to study participants. The flyer was crafted using standard Jikokoa marketing materials. To reduce information asymmetries prior to the start of surveying, all participants received this leaflet containing information about the Jikokoa stove at baseline. The graphic with charcoal tins indicating that the Jikokoa uses only 50 percent of a regular stove was designed to be understandable by literate and illiterate respondents.

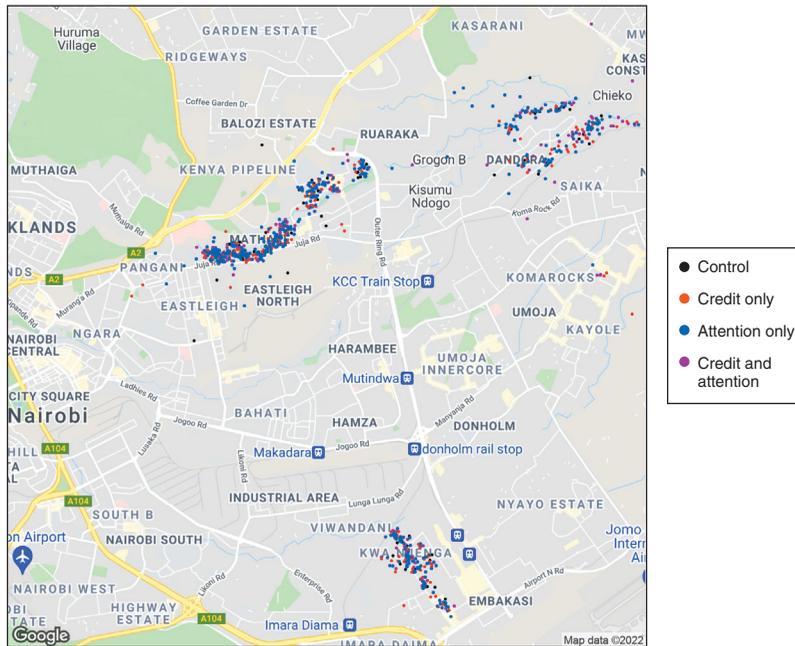


FIGURE A2. RESPONDENT LOCATIONS

Notes: The 1,018 respondents enrolled in our study reside in one of four low-income neighborhoods in the eastern part of Nairobi: Dandora, Kayole, Mathare, and Mukuru. Respondents are randomly allocated to credit and attention treatment arms prior to the start of visit 2.

Attention Sheet			
Respondent ID: 181301214121	Akiba ya mwaka kwa Jumla: 14,980 (KES)		
	Akiba inayotarajiwa wiki hii (KES)	Akiba ya kila mwezi inoyotarajiwa (KES)	Ungefanyaje na fedha hii mwezi huu?
Wiki 1, kuanzia 03 Juni 2019	350	1400	Kununua Chakula
Wiki 2, kuanzia 10 Juni 2019	350		
Wiki 3, kuanzia 17 Juni 2019	350		
Wiki 4, kuanzia 24 Juni 2019	350		
Wiki 5, kuanzia 01 Julai 2019	210	1050	Kununua Watoto text books
Wiki 6, kuanzia 08 Julai 2019	210		
Wiki 7, kuanzia 15 Julai 2019	210		
Wiki 8, kuanzia 22 Julai 2019	210		
Wiki 9, kuanzia 29 Julai 2019	210		

FIGURE A3. ATTENTION SHEET

Notes: This figure displays the first nine weeks of the attention to benefits sheet as completed by a respondent. They are first asked to write down how much they expect to save each week, which may vary due to variations in for example social and work engagements. They then calculate and write down the total expected savings for each month, and what they would do with these savings. Finally, respondents calculate their total annual savings by adding all 12 monthly amounts, and write this at the top of the sheet. *Kununua chakula* = buy food. *Kununua watoto text books* = buy the children textbooks. Respondents in attention treatment groups A1 and A2 complete this sheet for all 52 weeks. Forty-seven percent of respondents filled in the sheet entirely on their own; 31 percent of respondents filled in the sheet themselves, but required guidance by the field officer. The remaining 22 percent of respondents were illiterate and the field officer filled in the numbers on their behalf, while discussing the answers with the respondent. Responses are statistically indistinguishable across these three groups. KES 100 ≈ US\$1 at the time of surveying.

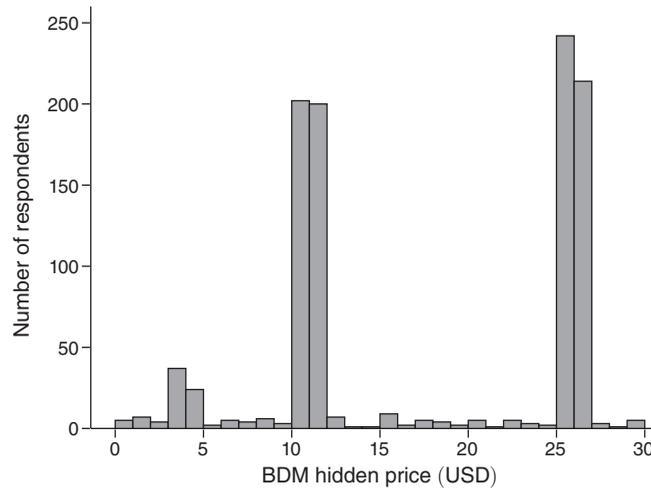


FIGURE A4. BDM HIDDEN PRICE DISTRIBUTION

Notes: The distribution of prices P_i used in the BDM elicitation mechanism. Six percent of participants are allocated a price drawn from $U[3.50, 4.50]$, 39 percent of participants are allocated a price drawn from $U[10, 12]$, and 44 percent of participants are allocated a price drawn from $U[25, 27]$. The remaining prices are drawn from a uniform distribution over the entire interval $U[0.01, 29.99]$. Respondents buy the stove if and only if $WTP_i \geq P_i$. For more detail see online Appendix F.

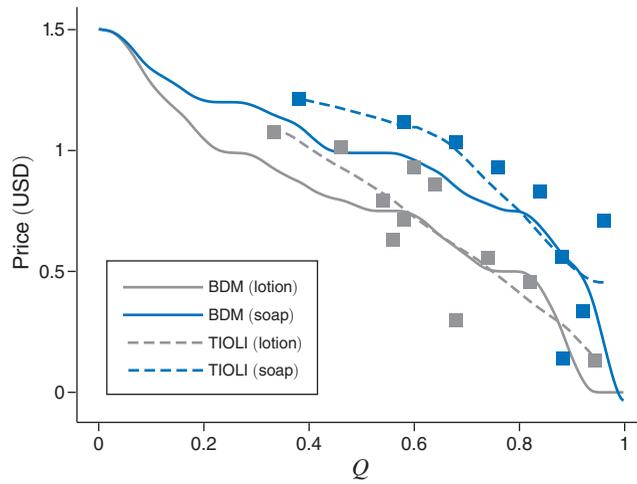


FIGURE A5. BDM AND TIOLI DEMAND CURVES

Notes: Prior to the start of the BDM each respondent completes two practice exercises, one for a bottle of lotion and one for a bar of soap. These items are commonly used by our respondents and widely sold for a retail price of \$1.19 and \$1.48, respectively. Each respondent is allocated a random price $P_L \sim N(0.74, 0.35)$ for the lotion, truncated at US\$ [0.01, 1.10], and a random price $P_S \sim N(0.89, 0.42)$ for the soap, truncated at US\$ [0.01, 1.30], reflecting their respective retail prices. (On the first three days of implementation, the practice prices for the lotion and soap were lower, averaging around US\$0.47 and US\$0.51 respectively. Because of higher than expected demand for both products, we increased prices to the higher amounts starting on the fourth day.) Fifty percent of respondents were first asked to respond to a TIOLI offer for purchasing the lotion, and were then asked to complete a practice BDM exercise with the soap. The remaining 50 percent first responded to a TIOLI offer for the soap and then completed a BDM exercise with the lotion. We leverage this cross randomization to test whether TIOLI and BDM elicit the same demand curves. The BDM demand curve is defined as $\Pr(WTP \geq P_i)$. The TIOLI demand curve takes average adoption rates across intervals of 50 observations. The overlap of the two curves suggests that the BDM mechanism elicits WTP responses that are in line with respondents' real behavior during a TIOLI decision. A statistical test cannot reject that average take-up within most price bins is equal for both elicitation methods. The full script for the TIOLI and BDM practice rounds can be found in the online Appendix.

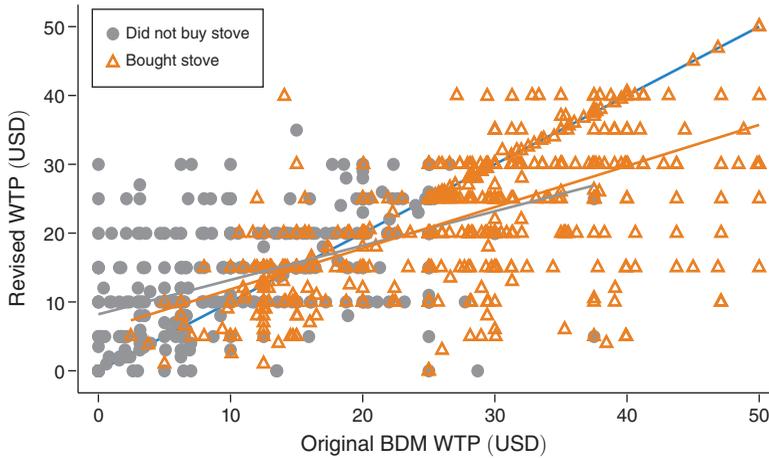


FIGURE A6. CHANGE IN WTP FROM MIDLINE TO ENDLINE

Notes: Respondent WTP as measured during the BDM mechanism and as stated during the endline survey. The 45 degree line is displayed in blue: respondents on this line stated the same WTP during the BDM and in the endline survey. Conditional on BDM WTP, stove adoption is random. Endline WTP is similar for stove adopters and nonadopters. This rules out substantial learning or hidden attributes.

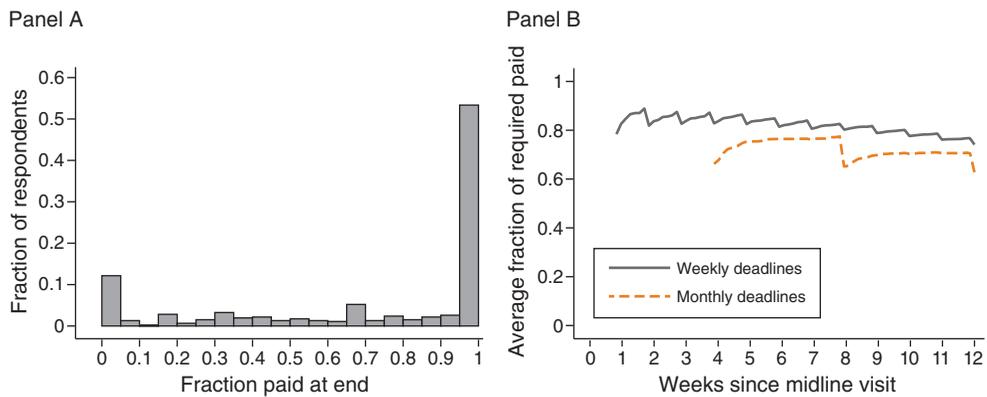


FIGURE A7. LOAN REPAYMENT PATTERNS

Notes: Panel A displays a histogram of fraction repaid made by those in the credit treatments. Panel B displays the average fraction of the required amount that respondents had paid for every day of the three-month payment period. These data exclude six respondents who returned the stove.

TABLE B1—CAUSAL IMPACT OF STOVE ADOPTION ON LONG-TERM FINANCIAL ASSETS

	Mobile savings			Formal savings		
	USD (1)	>0 (=1) (2)	log(USD) (3)	USD (4)	>0 (=1) (5)	log(USD) (6)
<i>Panel A</i>						
WTP (USD)	0.04 (0.07)	-0.00 (0.00)	0.00 (0.01)	0.09 (0.08)	0.00 (0.00)	0.02 (0.03)
Bought cookstove (=1)	1.57 (2.05)	0.12 (0.07)	0.36 (0.42)	-1.01 (2.47)	-0.02 (0.03)	-0.07 (0.93)
Observations	822	822	372	838	838	59
Control mean	5.28	0.43	1.37	3.72	0.08	2.87
Socioeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes
	SACCO			Total savings		
	USD (1)	>0 (=1) (2)	log(USD) (3)	USD (4)	>0 (=1) (5)	log(USD) (6)
<i>Panel B</i>						
WTP (USD)	0.01 (0.33)	0.00 (0.00)	0.00 (0.01)	0.15 (0.35)	0.00 (0.00)	-0.00 (0.01)
Bought cookstove (=1)	14.58 (9.59)	0.11 (0.07)	0.18 (0.20)	15.43 (10.13)	0.11 (0.06)	0.56 (0.29)
Observations	829	829	436	792	792	580
Control mean	34.72	0.51	3.65	41.25	0.71	3.01
Socioeconomic controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Results from IV regression using BDM price as an instrument for stove adoption to estimate the impact on savings. In panel A, columns 1–3 consider savings in mobile banking accounts and columns 4–6 consider amounts in formal banking savings accounts. In panel B, columns 1–3 consider money that is available for withdrawal for savings and credit cooperative organization (SACCO), merry-go-round, and rotating savings and credit association (ROSCA) participants, and columns 4–6 consider their sum. In panel B, column 6, a log increase of 0.564 corresponds to an increase of 76 percent. Socioeconomic controls include baseline savings, income, risk aversion, credit constrainedness, number of adults and children, and mean and standard deviation of health beliefs. Data for the outcome variables is from the one-year endline survey. Standard errors in parentheses.

TABLE B2—IMPACT OF EXPERIMENTAL TREATMENTS ON WTP (USD)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Credit (pooled)	12.46 (0.67)		13.00 (1.24)					
<i>Credit (C1 only)</i>				12.99 (0.77)		12.99 (0.78)	12.95 (0.92)	
<i>Credit (C2 only)</i>				11.92 (0.78)		11.93 (0.78)	11.51 (0.93)	−1.03 (0.79)
Attention (pooled)		0.21 (0.82)	0.84 (1.21)					
<i>Attention (A1 only)</i>					0.38 (0.98)	0.52 (0.84)		1.09 (1.04)
<i>Attention (A2 only)</i>					0.09 (0.90)	0.20 (0.76)	−0.23 (0.77)	−0.65 (0.95)
Attention (pooled) × credit (pooled)			−0.76 (1.48)					
Observations	943	943	943	943	943	943	663	628
Control mean	12.33	20.45	12.12	12.33	20.45	24.58	20.75	20.75
Sample	Full	Full	Full	Full	Full	Full	A1 and A2	C1 and C2

Notes: Impact of pooled treatments on WTP. Socioeconomic controls include baseline savings, income, risk aversion, credit constrainedness, number of adults and children. Following Dizon-Ross and Jayachandran (2022) we control for WTP elicited during the practice BDM round (for soap or a bottle of lotion), which improves statistical precision slightly. Standard errors in parentheses.

TABLE B3—ROBUSTNESS OF CREDIT TREATMENT EFFECTS TO DEFAULT

	WTP (1)	Payments received (2)	Replacing with amount paid for defaulters (3)	Deflating by average default rate (4)	Dropping defaulters (5)
Credit (pooled)	12.46 (0.67)	3.95 (0.51)	4.52 (0.75)	5.47 (0.55)	9.32 (0.74)
Observations	943	943	943	943	680
Control mean	12.33	3.56	12.33	12.33	12.33

Notes: Robustness of the effect of the credit treatment on willingness to pay adjusting for default in various ways. Column 1 replicates the main effect of credit on WTP presented in Appendix Table B2. Column 2 looks at the amount of money paid counting those who did not adopt as zero. Column 3 replaces willingness to pay with the amount paid for those that defaulted. Column 4 deflates WTP in the credit treatment by the average rate of default. Column 5 drops defaulters from the sample. Standard errors in parentheses.

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