Pre-Analysis Plan
Behavioral barriers to energy efficiency adoption in Kenya

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We seek to quantify how behavioral biases and market frictions affect poor households' adoption and usage of energy efficient durables. While a substantial literature studies how behavioral anomalies and failures of rationality—self-control problems, incorrect beliefs, and limited attention—contribute to the energy efficiency gap in the US (see Gillingham and Palmer for a review), little work exists in a development setting. This is important because biases might operate differently in poor environments. It could be that biases are exacerbated by stress or cognitive load associated with poverty (see Haushofer and Fehr for a review), or it could be that because poverty makes large, durable purchases high-stakes, poorer individuals are more likely to make decisions more carefully. Market frictions common in developing settings, like liquidity constraints and asymmetric information, might further exacerbate any failures of rationality. This will be the first paper to rigorously quantify the energy efficiency gap, causally identify the mechanisms driving this gap, and estimate its welfare effects, and it will do so in a high-stakes development setting.

This document details the methodology used for the implementation of the experimental randomization, and outlines the intended analysis of the resulting data. We define the outcome variables and main regression specifications that we intend to follow. However, we anticipate that we will carry out additional analyses beyond those included in this document. This document is therefore not meant to be comprehensive or to preclude additional analyses.

1 Introduction

Over the next 35 years, energy demand in the developing world is expected to increase by more than 40%. To respond optimally, policy makers need to understand the drivers of household adoption of energy efficient durables. While the welfare implications of these policies hinge critically on whether households are adopting optimally, almost nothing is known about whether this is true. While a significant literature has studied this in developed settings, little work exists in the developing world.

Cookstoves provide a useful setting for exploring this question because despite theoretically large savings and significant policy attention, demand and usage remain stubbornly low. Several large-

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scale randomized controlled trials have found weak demand and a lack of usage even for households that do adopt.

One potential explanation that reconciles these findings is that households do not fully internalize the potential energy savings in their decisions. Existing evidence largely comes from work on energy efficiency adoption in developed settings. But while a substantial literature shows that behavioral anomalies contribute to the energy efficiency gap in the US, little work exists in a development setting. Behavioral biases might operate differently in poor environments, and credit constraints might exacerbate any failures of rationality. The literature on technology adoption in developing contexts has also found important scope for behavioral biases. It remains unclear whether behavioral biases affect the adoption of energy efficient durables in developing contexts. In this project we seek to quantify how behavioral biases and credit constraints affect poor households' adoption and usage of energy efficient durables.

We partner with a non-traditional cookstove producer and use a Becker-DeGroot-Marschak (BDM) mechanism to elicit participants' willingness to pay (WTP) for an energy saving durable and estimate the causal effect of ownership on energy savings. In a 2018 pilot, we found substantial scope for behavioral biases or market failures: estimated energy savings are large but uncorrelated with household WTP. In particular, to justify the median WTP of $15 given our estimated savings of $130 within a year with only exponential discounting, participants would need discount factors of approximately 0.86 per week, or indifference between receiving $10 today and $25,500 a year from today. These savings imply an internal rate of return of 27% per month, significantly exceeding the Kenyan cost of credit: M-Shwari, Kenya's largest mobile lending platform, charges 7.5% monthly interest.

On 17 April 2019 we launched a full study in Nairobi with up to 1,000 households to disentangle the likely behavioral and market mechanisms. We quantify under-adoption by comparing household WTP to realized energy savings, and study three potential causes of under-adoption: inattention, credit constraints, and present-bias. We implement a randomized controlled trial that (1) quantifies household under-adoption, and (2) assesses whether inattention, credit constraints, or present bias impede adoption.

2 Experimental Design

This section describes the experimental design and the randomized treatment arms. We plan to enroll up to 1,000 participants to participate in this study. Individuals must:

- reside in one of our primary study areas (all lower-income areas in or around Nairobi, Kenya);
- use a traditional charcoal cookstove as their primary cooking technology;
- spend at least Ksh 300 per week on charcoal; and
- not plan to purchase a Jikokoa in the next 3 months;

to qualify for participation.

2.1 Credit Treatment Arms

To understand the effect of access to credit on WTP, we assign each participant to one of three credit treatment arms:

1. **Loan - Control ("L0"**)
   Participants pay 100% of the price at the time of Visit 2. As an example, a participant in the

Loan Control group might be asked during the BDM: "Would you be willing to pay Ksh 2,000 for the stove?"

2. **Loan - Weekly Payments ("L1")**
   Participants may pay for the stove in 12 weekly payments, starting one week from Visit 2. As an example, a participant might be asked during the BDM: "Would you be willing to pay Ksh 2,000 for the stove? You would pay Ksh 169.67 per week for 12 weeks. Your first payment would be due in one week."
3. **Loan - Monthly Payments ("L2")**
   Participants may pay for the stove in three 4-weekly payments, starting four weeks from Visit 2. As an example, a participant might be asked during the BDM: "Would you be willing to pay Ksh 2,000 for the stove? You would pay Ksh 682 per month for the next three months. Your first payment would be due in four weeks."

None of the participants in L1 and L2 will be required to make any payment on the day of Visit 2. However, they may choose to pay any amount on that day, if they wish. The balance will then be paid in equal instalments. They would not pay interest on the amount paid during Visit 2.

Participants in L1 and L2 may pay ahead of their payment schedule if they choose, but they may not fall behind. The only requirement is that they must have cumulatively paid the scheduled amount by their scheduled payment dates. If the participant falls behind on their payments, this will trigger a series of reminder SMS messages, culminating in the retrieval of the cookstove one week after the participant fell behind if they still have not paid at that point.

Weekly payments begin one week from Visit 2 while monthly payments begin four weeks from Visit 2. A participant in the monthly payments group could therefore choose to pay according to their equivalent in the weekly payments by simply making payments sooner, but the converse is not true. Other than demand for commitment, the monthly scheme is therefore weakly preferred to the weekly scheme. To address the confounding demand for commitment, participants in L2 may choose to opt into L1 after the BDM is completed. They will be informed that they will have this option prior to the BDM.

2.2 Attention Treatment Arms

To understand the effect of inattention on adoption, we assign each participant to one of three attention treatment arms:

1. **Attention - Control ("A0")**
   Participants are informed that the stove manufacturer says that it can be expected to reduce charcoal consumption by 50%. They will be informed of the Ksh equivalent of these savings, based on the participant's stated weekly charcoal spending. They are also given a calculator, and are allowed to use it to perform calculations regarding their expected savings if they choose.
2. **Attention - Benefits ("A1")**
   Participants receive everything that A0 receives. In addition, the enumerator assists them in filling in an Attention Sheet, writing down the amount of money they think they will save each week for the next year if they owned an energy efficient stove. This should be around 50% of their expected spending in each week, and would be higher in weeks where the participant expects to spend more on charcoal for cooking, for example during religious holidays, other festivities, or periods of the year where temporary migrants return to the home. The enumerator then assists the participant in summing up the expected savings for each of

the twelve months, and asks them to think about and write down what they would do with those savings each month. For example, in January they may pay school fees, or in December they may spending money on holiday festivities or travel. Finally, the enumerator assists the participant in summing the expected savings amounts over the whole year.

3. **Attention - Benefits and Costs ("A2")**
   Participants receive everything that A1 receives. In addition, during the BDM they are informed of the cost during each period, alongside the benefit of each period as listed in their Attention Sheet. The cost per period will be calculated and presented in line with the participant's credit treatment group (L0, L1, or L2). The net benefit (cost - benefit) for each period will also be calculated and presented to the participant.

3 Implementation

3.1 Implementation timeline

Participation in the study will consist of three in-person visits held one month apart (thus spanning a two-month period for each participant), as well as a recurring SMS survey that will be conducted throughout the two-month period. This section presents an overview of each visit.

3.1.1 Visit 1

- The participant is enrolled in the study by an enumerator and completes a baseline survey designed to measure energy spending, socioeconomic well-being, and other baseline characteristics.
- The participant completes a stove attribute sheet to determine what attributes they prioritize when purchasing a stove.
- The participant receives a pamphlet containing basic information about the stove, including that the stove manufacturer says that the stove reduces charcoal spending by 50%.
- The participant completes a math test. They are allowed to use a calculator for this.
- The participant answers questions related to their prior beliefs about the health and financial benefits of the stove.
- The participant completes the 3 required effort tasks for the Present Bias measurement and then makes selections for additional effort tasks to be completed during visits 2 and 3.
- The participant selects an investment amount in a game aimed at measuring their risk aversion.
- All participants are informed that we will return in one month and they that will have an opportunity to purchase the stove at that time, although we do not say at what price. They also receive information about the SMS survey, which will begin one week after Visit 1.

Between Visits 1 and 2 the participant receives an SMS once every three days asking them about either their charcoal spending or their matatu usage over the past three days.

One week before Visit 2 the participant receives an SMS reminding them that a field officer will visit them in one week. Participants in one of the installment treatment groups will be informed that they will be allowed to pay in installments.

3.1.2 Visit 2

- The participant makes another 5 decisions, trading off effort tasks between Visits 2 and 3 as part of the Present Bias measurement. The 'decision that counts' is then selected from

among the 10 decisions that the participant made during Visits 1 and 2. The participant then completes the 3 required effort tasks and any additional tasks that were selected.

- The participant receives additional information about the stove.
- The participant completes a practice BDM as well as a TIOLI with a bar of soap and a lollipop (or equivalent goods) to help them understand the mechanism and to confirm that the BDM mechanism reflects TIOLI decisions.
- The relevant attention treatments arms are implemented for the participants in the relevant treatment groups.
- Participants in the credit treatment arms are informed of the payment plan and options available to them.
- We implement a BDM mechanism to elicit participants' willingness to pay for an energy efficient charcoal cookstove.
- The participant answers questions related to their posterior beliefs about the financial benefits of the stove.
- The surveyor and the participant jointly open an envelope containing the participant's hidden BDM price. If the participant's WTP exceeds the BDM price, they receive the stove, which the surveyor carries with them to the participant's residence in a closed bag.
- The participant receives a bucket in which they will collect their used charcoal, which will be used as an additional measurement of charcoal consumption.

Between Visits 2 and 3, all participants receive an SMS once every three days asking them about their charcoal spending over the past three days. Participants in the credit treatment groups make their required payments during this time.

3.1.3 Visit 3

- The participant completes the 3 required effort tasks and any additional tasks that were selected as part of the Present Bias measurement.
- The participant completes an endline survey to measure energy spending and socioeconomic well-being.
- The field officer weighs the charcoal bucket.

Subject to funding constraints participants may continue to receive an SMS once every three days asking them about their charcoal spending over the past three days, for an additional month after visit 3.

3.2 Eliciting prior and posterior beliefs

During Visit 1 each respondent is asked to state their prior beliefs about the stove's energy savings over the first year of ownership. Respondents are first asked to state the absolute minimum and the absolute maximum they would expect to save in the worst and best case scenarios of stove performance, respectively. Then, respondents are asked to allocate 20 beans to a set of intervals that are each Ksh 1,250 wide, with each bean representing a 5% likelihood that they will save an amount in that interval over the first year of ownership. Respondents may only allocate beans to intervals that overlap with the interval between their stated minimum and maximum. We then elicit posterior beliefs after the implementation of the treatments and after the selection of the maximum WTP through the BDM, but before the hidden price z_i is revealed, using an identical mechanism.

We use the midpoint of each interval to define each respondent's beliefs distribution, and we then define μ_i to be the mean and σ_i to be the standard deviation of the distribution of individual i's posterior beliefs about the stove's annual future savings.

3.3 Eliciting willingness-to-pay (WTP) using a Becker-DeGroot-Marschak (BDM) mechanism

We implement a BDM mechanism to elicit each participant's WTP for an energy efficient charcoal cookstove and then randomly assign cookstove ownership across participants.

3.3.1 Methodological overview

The BDM mechanism is implemented in a carefully executed series of steps, as follows:

1. Prior to visit 2, each participant is randomly assigned a BDM Price, according to the distribution of BDM prices (described below). Randomization is stratified on baseline characteristics.
2. The enumerator receives a sealed envelope that contains the BDM price (in Ksh) for the particular participant they are visiting.
3. The enumerator places the closed envelope in plain view.
4. Beginning with a starting price of Ksh 1,500, the enumerator asks if the participant would be willing to purchase the stove for this price. If the participant agrees, the enumerator increases the price to the midpoint of the remaining interval immediately above (starting with a ceiling of the market price of Ksh 2990). If the participant disagrees, the enumerator decreases the price to the midpoint of the remaining interval immediately below. As more questions are answered, the interval becomes smaller and smaller, and after 11 questions the participant will have chosen their maximum WTP to within 1 Ksh. In practice, this works as follows:

    (a) If the envelope said the price was Ksh 1,500, would you choose to purchase the stove?
        i. If yes: If the envelope said the price was Ksh 2,250, would you choose to purchase the stove?
            A. If yes: If the envelope said the price was Ksh 2,625, would you choose to purchase the stove?
                - Etc.
            B. If no: If the envelope said the price was Ksh 1,875, would you choose to purchase the stove?
                - Etc.
        ii. If no: If the envelope said the price was Ksh 750, would you choose to purchase the stove?
            A. If yes: If the envelope said the price was Ksh 1,125, would you choose to purchase the stove?
                - Etc.
            B. If no: If the envelope said the price was Ksh 375, would you choose to purchase the stove?
                - Etc.

    The enumerator then completes a series of questions to confirm that the participant understands their decision, understands the consequences of their decision once the envelope is opened, and allows the participant to change their mind if they decide to do so at this point.

5. Once the participant has confirmed the threshold at which they would no longer be willing to purchase the stove, the participant and the enumerator together open the envelope containing the participant's randomly assigned hidden BDM price.
6. If the participant's maximum WTP is lower than the BDM price in the envelope, the participant will not be able to purchase the stove.
7. If the participant's maximum WTP is at least as high as the BDM price in the envelope, the participant receives the stove that day, paying the price that was written inside the envelope. If the participant is in L0 they must pay the full amount during Visit 2.
8. If the participant is in L1 or L2 they will then be offered the choice to pay any amount during Visit 2, if they choose, and are then reminded of the remaining payments required. Participants in L2 will then be allowed to opt in to the L1 schedule as a commitment device, if they wish.

Because the participant pays the price in the envelope rather than their maximum WTP, this process is incentive compatible, and a welfare-maximizing participant should reveal their true maximum WTP.

3.3.2 Distribution of BDM prices

We designed the distribution of BDM prices to increase compliance and maximize power in the instrumental variables regression while maintaining incentive compatibility, such that every participant has an incentive to name their true willingness to pay, as well as obtaining a meaningful demographic distribution of adopters. This resulted in the following distribution. 5% of participants are allocated a price of Ksh 400, 40% of participants are allocated a price of 1,100 Ksh, 45% of participants are allocated a price of Ksh 2,600, and 10% of participants are allocated a randomly selected price between Ksh 1 and Ksh 2,989. None of these prices exceed the market price of Ksh 2,990, at which price the cookstove is widely available in most relevant stores and supermarkets as of March 2019.

These prices will be randomly assigned to participants after baseline Visit 1. To maximize power, after we collect baseline data we will stratify participant price allocation by baseline characteristics.

3.4 Sample sizes

We plan to enroll at least 903 participants into our study. Figure 1 below displays the targeted sample size for each treatment arm.

Table 1: Sample Sizes

		Credit Treatment Arms			
		Loan - Control	**Loan - Monthly**	**Loan - Weekly**	**Total**
Behavioral Treatment Arms	**Attention – Control**	86	86	86	258
	Attention – Benefits	86	86	86	258
	Attention – Benefits and Costs	129	129	129	387
	Total	301	301	301	903

4 Analysis

We run all regressions specified below at the household level. Unless stated otherwise, all regressions control for baseline charcoal expenditures, baseline household income, and baseline number of household residents. Depending on the level of variation and correlation of demographic variables, we may include more or fewer variables as controls.

4.1 Effect of stove ownership on charcoal expenditures

Our experimental design allows us to estimate the causal effect of ownership of an energy efficient charcoal cookstove on charcoal spending. We employ an instrumental variables approach to estimate the causal effect of stove ownership on charcoal spending, controlling for household WTP. In the first stage we use the randomly assigned BDM price z_i as an instrument for household i's stove ownership d_i. In the second stage we regress average weekly charcoal spending on the predicted value of stove ownership $\hat{d}_i$. Because the BDM price was randomly assigned, this regression identifies a causal effect. Econometrically, this proceeds as follows:

$$(First\ stage) \qquad d_i = \gamma_0 + \gamma_1 z_i + \gamma_2 X_i + u_i$$

$$(Second\ stage) \qquad y_{it} = \beta_0 + \beta_1 \hat{d}_i + \beta_2 X_i + \epsilon_i$$

Where y_{it} is the log of charcoal spending by household i during 3-day cycle $t \in (1, T)$, $3t$ days since adoption of the energy efficient cookstove. z_i is the household's randomly assigned BDM price, and X_i is the vector of baseline characteristics described above. β_1 can be interpreted as the causal effect of stove ownership on weekly energy spending in percentage terms. We cluster our errors by household i.

Our preferred regression uses log of charcoal spending, because the stove is expected to reduce energy charcoal usage by a fixed percentage relative to baseline usage rather than a fixed amount. In the case of frequent 0s in charcoal spending, we implement this transformation using inverse hyperbolic sine (IHS) rather than a regular logarithmic conversion. However, we also run a regression using charcoal spending in Ksh as the outcome variable to place the result in the context of the cost of the stove, which is fixed in Ksh.

We also run this regression estimating causal effects β_{t1} for each of the 3-day SMS cycles separately. This allows us to flexibly test whether the effect of stove ownership changes over time. Econometrically, this proceeds as follows:

$$(First\ stage) \qquad d_{it} = \gamma_0 + \gamma_1 z_{it} + \gamma_2 X_i + \tau_t + u_i$$

$$(Second\ stage) \qquad y_{it} = \beta_0 + \sum_t \beta_{t1} \hat{d}_{it} + \beta_2 X_i + \tau_t + \epsilon_i$$

where z_{it} is equal to z_i in period t and zero otherwise. In this specification, each β_{t1} represents the impact of the stove on charcoal spending in percentage terms $3 \cdot t$ days after adoption of the stove.

If we see significant heterogeneity in LATE estimates across levels of WTP and different complier groups, we will estimate these regressions more flexibly. We will also test for heterogeneity in these estimates by demographic characteristics. Since different treatments may induce different types of individuals to increase their WTP, we will also test whether the impact of the stove differs for compliers of the different treatment groups or individuals with different levels of WTP.

4.2 Testing for barriers to adoption

4.2.1 Primary Predictions

This experimental design allows us to test our primary predictions below by testing the following list of null hypotheses. To be conservative, we use two-sided tests for all predictions.

- **Prediction 1: Attention to benefits**
  An increase in attention to benefits will increase WTP.
  $WTP_i = \beta_0 + \beta_1 \mathbf{I}[A = 1, 2] + \beta_2 X_i + \epsilon_i$
  $H_0 : \beta_1 = 0$

- **Prediction 2: Access to credit**
  An increase in access to credit will increase WTP due to credit constraints and an increased inattention to costs.
  $WTP_i = \beta_0 + \beta_1 \mathbf{I}[L = 1, 2] + \beta_2 X_i + \epsilon_i$
  $H_0 : \beta_1 = 0$

As a robustness check, we will also test $H_0 : \beta_1 = 0$ and $H_0 : \beta_2 = 0$ in the fully interacted specification:

$$WTP_i = \beta_0 + \beta_1 \mathbf{I}[L = 1, 2] + \beta_2 \mathbf{I}[A = 1, 2] + \beta_3 \mathbf{I}[L = 1, 2] \cdot \mathbf{I}[A = 1, 2] + \beta_4 X_i + \epsilon_i \quad (1)$$

4.2.2 Secondary Predictions

We intend to identify the channels through which these treatment arms affect adoption by testing the following mechanism predictions.

- **Prediction S-1: Attention and credit**
  - **S-1-A: Access to credit will increase the effect of attention to benefits.**
    See regression (1) above
    $H_0 : \beta_3 = 0$
  - **S-1-B: Among people paying full attention to benefits and costs in all periods $[A = 2]$, relaxing the credit constraint will affect WTP due to credit constraints alone.**
    $WTP_i = \beta_0 + \beta_1 \mathbf{I}[L = 1, 2] + \beta_2 X_i + \epsilon_i$
    $H_0 : \beta_1 = 0$

- **Prediction S-2: Benefits vs. Costs**
  Among people with full attention to benefits $[A = 1, 2]$ increasing attention to costs reduces WTP.
  $WTP_i = \beta_0 + \beta_1 \mathbf{I}[A = 2] + \beta_2 X_i + \epsilon_i$
  $H_0 : \beta_1 = 0$

- **Prediction S-3: Concentration bias**
  Among people receiving access to credit $[L = 1, 2]$, framing credit payments in smaller, weekly amounts relative to larger, monthly amounts will increase WTP due to concentration bias.
  $WTP_i = \beta_0 + \beta_1 \mathbf{I}[L = 1] + \beta_2 X_i + \epsilon_i$
  $H_0 : \beta_1 = 0$

- **Prediction S-4: Beliefs**
  - **S-4-A: Attention to benefits will increase mean posterior beliefs about future savings.**
    $\mu_i = \beta_0 + \beta_1 \mathbf{I}[A = 1, 2] + \beta_2 X_i + \epsilon_i$
    $H_0 : \beta_1 = 0$
  - **S-4-B: Attention to benefits will decrease the standard deviation of posterior beliefs about future savings.**
    $\sigma_i = \beta_0 + \beta_1 \mathbf{I}[A = 1, 2] + \beta_2 X_i + \epsilon_i$
    $H_0 : \beta_1 = 0$

To test for mechanisms we will conduct additional exploratory analysis, including heterogeneity analysis with respect to:

- Present bias
- Baseline charcoal spending
- Baseline prior beliefs
- Baseline demographics (including income and savings)
- Baseline risk aversion