University of Colorado Boulder

TITLE: PRICES, PEERS, AND PERCEPTIONS: FIELD EXPERIMENTS ON TECHNOLOGY ADOPTION IN THE CONTEXT OF IMPROVED COOKSTOVES

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I. OBJECTIVES

Adoption of many potentially welfare-improving technologies remains frustratingly low in many contexts. Improved cookstoves are a prime example: while cleaner-burning stove technologies have potential health, environmental, and social benefits, efforts to disseminate these technologies have fallen short and the practice of cooking with biomass over open fires remains dominant throughout much of the developing world. **The central aim of this research project is to contribute to a more scientific understanding of the interactions between economic incentives ("prices"), social learning ("peers"), and subjective beliefs ("perceptions") in technology adoption dynamics.** Specifically, this project develops a conceptual model of households' technology adoption and use decisions that motivates exploration of the following research questions:

1. How are prior perceptions of the benefits of a new technology affected by the technology's price? For example, does higher price signal higher quality to target users?
2. How do prior perceptions of a new technology vary based on exposure to peers that have experience with that technology? Specifically, how do peers' adoption and use histories help potential users of a technology learn about product quality?
3. How does peers' experience influence the relationship between price, on the one hand, and perceptions, technology adoption and use outcomes, on the other? Do peer effects increase or decrease the price elasticity of demand for the new technology?
4. How do perceptions of a technology change over time among households that adopt that technology initially? How do these perceptions relate to objective measures of stove performance (e.g., personal exposure to pollutants), and what is the relationship between perceptions and technology *use* over time?

II. BACKGROUND AND SIGNIFICANCE

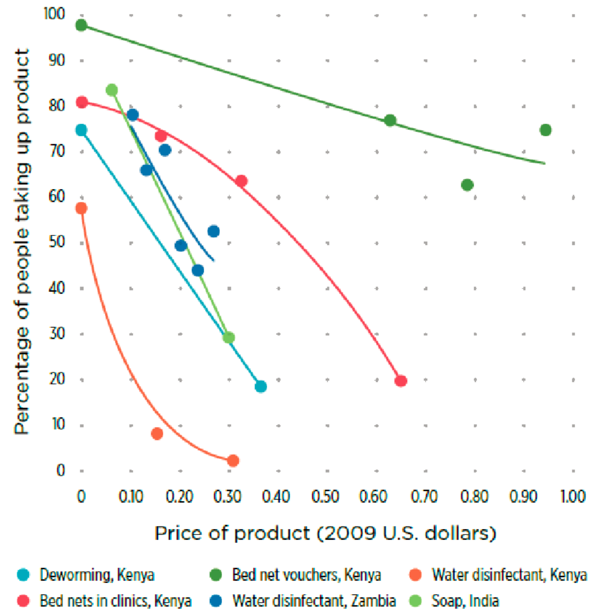
Technology adoption continues be a central research topic in microeconomics because of its importance in understanding economic development and because of the kaleidoscope of models explaining different economic, psychological, and sociological factors at play. Two key strands of literature examine the roles of prices and peer effects on technology adoption.

Prices and technology adoption and use

Setting subsidy and end-user price levels for a new technology reflects a fundamental tension between rapid diffusion and sustainability (Mobarak et al. 2012; Dupas 2014). On the one hand, subsidizing adoption of socially beneficial technologies may be necessary to promote widespread adoption, at least in the short-run. Indeed, recent evidence has shown very high, and even discontinuous, price elasticities of demand for a number of low-cost health technologies in developing countries: new technologies offered at a positive price tend to exhibit much lower demand than identical products offered for free. The most recent World Development Report (World Bank 2015, see Figure 1) details numerous examples of this phenomenon. In one example that is particularly relevant for this proposal, Mobarak and coauthors (2012) analyze a field experiment with the distribution of cookstoves in Bangladesh. The researchers find demand for these modern stoves to be extremely price elastic, with only 5% of households purchasing the stoves with no discount and a 50% discount yielding 8-12% higher demand (relative to the full cost treatment).

On the other hand, many argue that goods given away for free or at low cost will be *used* at lower rates than goods for which users pay higher prices. There are at least two theoretical foundations for this hypothesis. First, price-based incentives for new technologies (or any scarce good) ensure allocation of goods to those valuing them the most (a basic principle in economics). Second, higher prices may lead potential users to perceive that a product is of higher quality (Bagwell and Riordan 1991), thus encouraging higher use. Empirically, however, there is little evidence to support this hypothesized positive relationship between price and technology use. In one of few studies to directly test this hypothesis, Cohen and Dupas (2010) analyze data from a randomized controlled trial of bednet distribution in Kenya in which health clinics distributed bednets freely or partially subsidized at four different end-user price levels (between $0.15 and $0.60 per net). The researchers identify significantly price-elastic demand for bednets: Clinic patients charged the highest price in the experiment exhibited 60% lower demand for bednets relative to the free distribution group. Moreover, despite thorough statistical analysis, Cohen and Dupas do not find evidence that the free distribution group exhibits lower usage rates (conditional on ownership) than the partially subsidized groups. Furthermore, the free distribution group is the only treatment group for which the researchers find a statistically significant health impact (reduced anemia). To our knowledge, these authors did not directly examine the relationship between price and perceived quality of bednets as an intermediate factor affecting product use.

Figure 1: Relationship between price and technology adoption for various health products.



Source: Abdul Latif Jameel Poverty Action Lab 2011.

Thus, empirical evidence to date seems to indicate that highly subsidized or free distribution of health-promoting technologies: a) may be required to promote their initial adoption, and b) does not appear to reduce subsequent technology use (although the latter finding has a thinner evidence base and should be tested more broadly). Yet free distribution strains public resources and may not be sustainable over time or scalable to population-level technology diffusion. Additional work is thus required to examine the dynamics of diffusion over time and space. One particular question involves the possibility that subsidizing adoption to an initial group of users can lead that group's peers to learn about and subsequently adopt a technology and, assuming the technology is useful, positively affect individuals' willingness to pay (WTP) for the technology.

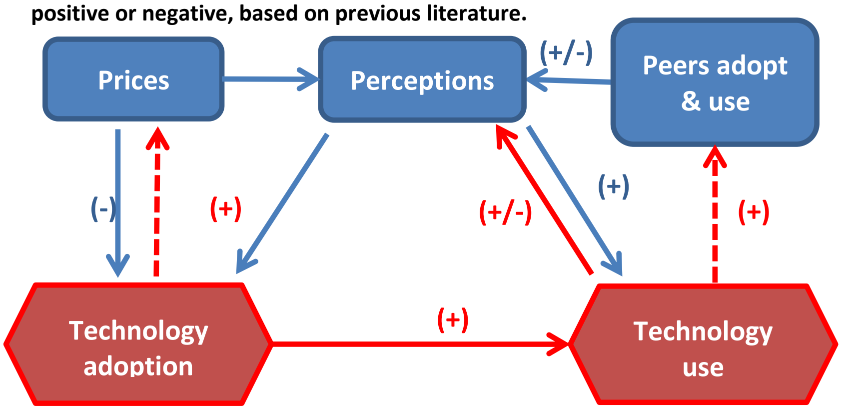
Peer effects and technology adoption

In contrast to prices, peer effects present the possibility of a positively reinforcing feedback for sustaining adoption and takeoff of new technologies. The power of social contagion in technology adoption has been measured in a number of contexts (e.g., Bollinger and Gillingham 2012). In a study highly relevant for the present proposal, Miller and Mobarak (2013) estimate peer effects on efficient cookstove adoption in Bangladesh, by conducting randomized, sequential cookstove rollout first with opinion leaders, then with a first round of randomly selected members of the general population (in the same neighborhoods as the opinion leaders), and then with social contacts of the first round households. Their results suggest statistically significant and positive peer effects from opinion leaders' adoption behaviors (at least in some cases), but social ties to first round participants are found to *reduce* the likelihood of adoption among second round households. The authors' interpretation of this finding is that second round participants held initially high expectations about the modern stoves, and revised these expectations downward via information from social contacts. This negative peer effect finding and its interpretation are similar to

Kremer and Miguel's (2007) analysis of deworming drugs in Kenya. Yet to our knowledge, neither study explicitly measured expectations or beliefs about product quality. Both of these cases highlight the fact that while the increasing availability of experimental data and appropriate econometric methods for analyzing these data have gone a long way toward solving Manski's (1993) "reflection problem" and enabling identification of peer effects, this research has also raised a number of new questions about the causal mechanisms underlying observed effects.

In light of the previous research outlined above, Figure 2 presents our conceptual model using an influence diagram of how we expect prices, peers, and perceptions to interact, based on previous research. Prices can be expected to have both direct and indirect influences on key outcomes (technology adoption and use): The direct effect (the economic "law of demand") is expected to be negative, while it is possible that there is a positive indirect effect on both adoption and use via higher perceptions of technology benefits for higher-priced products. Peer effects can be expected to affect individual adoption and use through effects on individuals' perceived value of the new technology. This effect can be negative or positive.

Figure 2: Influence diagram of the factors of technology adoption dynamics. The solid arrows in the diagram are influences that this study will examine in detail. The dashed arrows are potential confounding feedbacks that our identification strategy will address. The signs in parentheses indicate whether effects are expected to be positive or negative, based on previous literature.



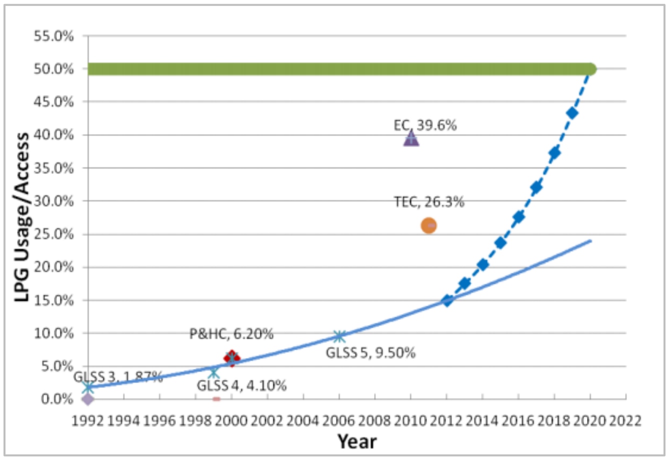
Importantly, the conceptual model in Figure 2 also highlights the potential feedbacks (the dashed arrows) that can confound causal identification, and which our experimental design seeks to address. First, a number of factors determine prices for a new technology in an observational setting, including supply and retail costs. We will address this confounding feedback using prices which are randomly assigned across groups of households. Second, peer effects are well-recognized for their potential to generate positive feedback loops. We will control for this confounder by sampling households neighboring participants a previous study's cookstove intervention, in conjunction with the recruitment of new groups of households unexposed to the technology. This identification strategy for peer effects appears unique compared to previous research (Kremer and Miguel 2007; Bobonis and Finan 2009; Miller and Mobarak 2013).

Finally, an important question for both economics – and more broadly for sustainability science – is how subjective expectations change following technology adoption and subsequent use, and how these revised expectations determine long-term use. For example, we might hypothesize (e.g. based on the Prospect Theory literature (Kahneman and Tversky 1979)) that discovering a new technology to yield smaller than expected benefits may be have a greater downside effect on usage than the upside effect of finding the technology to have greater than expected benefits.

Additional key questions emerging from this model are how the individual factors affecting key outcomes of interest are mediated by the other factors. A standout issue along these lines is the possibility that peer effects may dampen the role of prices in subjective perceptions of technology quality. This is one hypothesis suggested by Ashraf et al. (2013), who conducted an information-based interventions in the case of improved water filter subsidization in Zambia and found that information provision increased the price elasticity of demand, making price subsidies more effective. The authors remain agnostic on the causal mechanisms behind this finding, but suggest that uninformed consumers may use price as an indicator of product quality. Our human subjects research will shed light on these important questions in the context of cookstove adoption decisions in Ghana.

Moving toward clean fuels: Liquefied Petroleum Gas (LPG) for cooking in Ghana

Figure 3: Measurements and projections of LPG access in



In addition to exploring use of improved biomass stoves, this project provides an opportunity to include an intervention component focusing on liquefied petroleum gas (LPG) stoves. While biomass stoves can save fuel and provide moderate improvements in emissions, LPG stoves have a higher potential to achieve health improvements since they emit very low levels of harmful air pollutants. This component of the project adds particular policy relevance in Ghana and internationally. At the national level, Ghana has adopted a goal of expanding LPG access to 50% of the country's population; the target date for reaching this goal was originally 2015, but progress has been slower than hoped, and the target date was revised to 2020 (Ghana Energy Commission 2012) (see Figure 3). National efforts are underway to expand LPG access and use, most notably through the Rural LPG Promotion Program (RLP) (2014). However, progress has been particularly slow in the northern areas of the country. A 2012 report by the Ghana Energy Commission mapped LPG retail filling stations across Ghana (Figure 2), clearly showing the relative scarcity of LPG supply in the northern regions of Ghana compared to the south.

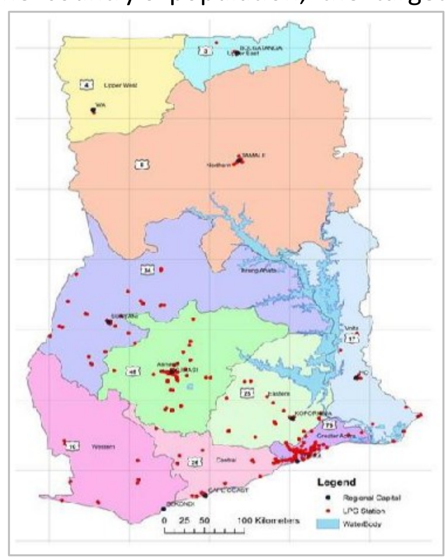


Figure 2: Locations of LPG retail stations across Ghana (Ghana Energy Commission 2012). Upper East region shown in light blue in northeast corner of

Exemplifying Ghana's LPG access challenges, the Kassena-Nankana (K-N) Districts are located in Ghana's Upper East region along the country's northern border. According to 2011-2013 data from a demographic surveillance survey conducted periodically by the Navrongo Health Research Center (Oduro et al. 2012), only 7% of households in these districts use LPG as their main cooking fuel, while 74% rely primarily on fuelwood or crop residue and 18% use charcoal as their main fuel. Use of LPG is concentrated in the central urban areas around Navrongo town, but even in these areas access is not universal: about 1/3 of the urban population uses LPG as their main cooking fuel, while 60% primarily use charcoal. Outside of the central area, only 3% of the population uses LPG as their main fuel.

In the current distribution model for LPG throughout most of Ghana, customers purchase LPG cylinders and then bring them to filling stations to purchase fuel as needed. This distribution model creates challenges for rapid scale-up of supply, since infrastructure costs for building new filling stations are relatively high. An alternative model that could enable more rapid supply expansion would be a cylinder recirculation scheme in which customers pay a deposit for cylinders and exchange empty ones for full ones at more dispersed distribution locations (Ghana Energy Commission 2012). Recirculation has the additional advantage of being safer, since households do not have an incentive to continue to use older cylinders. This model has been piloted in the Accra area and is the model being used for the GRAPHS project in Kintampo (see below). To our knowledge, LPG recirculation has not been implemented in Northern Ghana.

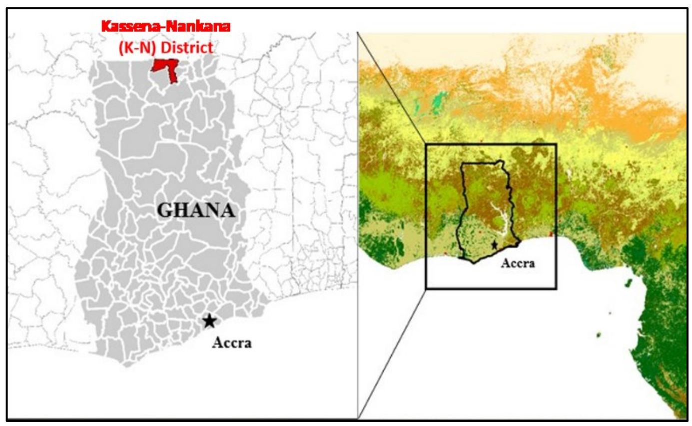
III. PRELIMINARY STUDIES

This research project builds on an ongoing randomized cookstove intervention study: **Research on Emissions, Air Quality, Climate, and Cooking Technologies in Northern Ghana (REACCTING)**. The REACCTING study involves a collaboration among the National Center for Atmospheric Research (NCAR), the University of Colorado-Boulder (CU-Boulder), and the Navrongo Health Research Centre (NHRC). The primary research objective of the REACCTING study is to assess the effectiveness, feasibility, and sustainability of scaling up use of improved cookstoves in Northern Ghana through a coupled natural-human systems approach that explores the linkages among human behaviors (i.e., cooking practices), detrimental air quality at multiple spatial and temporal scales, and health outcomes (respiratory illness and bacterial meningitis).

Study Area

The REACCTING study is being conducted in the Kassena-Nankana (K-N) Districts of Northern Ghana (Figure 3). The climate in this region is hot and arid, with one rainy season lasting from approximately May to October, and the vegetation is dominated by woody shrubs and grassland. Much of the land is used in subsistence agriculture, with millet as the dominant crop. Since 1993, the NHRC has conducted a district-wide Health and Demographic Surveillance Survey (HDSS) (Oduro et al. 2012). According to HDSS data, the total population of the district is about 156,000 (roughly 30,000 households), with about 80% living in areas classified as rural while 20% are in more urban areas, primarily in and around the central town of Navrongo. Eighty eight percent of rural households report using biomass (wood or agricultural waste) as their main cooking fuel, while another 9% rely primarily on charcoal, and only about 3% of households cook primarily with gas or electricity. The traditional cooking method in these rural areas is a three-stone open fire, with many households also using charcoal stoves (Figure 4). Cooking is done both indoors and outdoors.

Figure 3: Location of Kassena-Nankana (K-N) District in Northern Ghana.



New Stove Technologies

Based on extensive feedback from households in the K-N districts that tested several stove models during a pilot phase (2012-2013), two different stove technologies were selected for the REACCTING intervention study: the Gyapa Woodstove and the Philips Smokeless Woodstove (Figure 4). The Gyapa Woodstove was specifically designed for use by populations in the Northern Regions of Ghana by Relief International/Gyapa Enterprises (RI/Gyapa). A similar model was used in a past intervention study in Accra, and saw significant decreases in kitchen CO and PM2.5 levels (Pennise et al. 2009). This model includes a combustion chamber, often called a rocket-stove design, with a ceramic liner on the inside and an outer liner of insulation and saw dust to increase heat retention. Meanwhile, the Philips stove is a gasifier stove produced in Lesotho. This stove is visually perceived as "high-tech," requires power (supplied, in our context, through a small solar panel) to perform properly, and has been observed to be a low emitting technology, Tier 4 stove, during lab testing (Jetter et al. 2012). In addition to designing and manufacturing the Gyapa Wood Stove, RI/Gyapa worked with the study team to design and produce a rebar pot support structure for the Philips stoves to provide more stability and enable the accommodation of larger pots in order to make it more culturally appropriate for local cooking practices (Figure 4).

The inclusion of these two technologies in a single study responds to an ongoing debate over what constitutes an "improved" cookstove, and what technology is likely to have the largest impacts over time. On one side of this debate are those who argue that affordable, locally-produced cookstoves, even while offering modest improvements in efficiency and emissions reduction, can be an effective and feasible first step toward moving households up the "technology ladder" in the long run (Hiemstra-Van der Horst and Hovorka 2008; Hanna et al. 2012; Simon et al. 2014). On the other side are those who contend that only the cleanest, most advanced, and usually imported cooking technologies should be promoted, since these have the highest probability of having meaningful impacts on health and environmental outcomes, and will thus be valued more highly and used more sustainably than stoves that offer only modest improvements over traditional cooking methods (Smith 2012; Subramanian 2014). By comparing these two technologies side by side using a common set of measurements that includes user perceptions, reported and objectively measured stove use, and impacts along multiple dimensions (emissions, personal exposure, household, local, and regional air quality, and health), the REACCTING study provides data that can specifically inform this debate.

Figure 4: Traditional and improved stove technologies being compared in the REACCTING study, shown with Stove Use Monitors (SUMs) attached. Top left: traditional three-stone stove. Top right: traditional charcoal stove. Bottom left: Philips Smokeless Stove, Mad Made in Lesotho (Southern Africa), Cost: ~US$125. Bottom right: Gyapa Wood-Burning Stove. Made in Accra. Cost: ~ Cost: ~US$15-25.

REACCTING Study Sample and Intervention Design

The target population for the REACCTING intervention study was rural households in the K-N District that used biofuels (wood, animal waste, and crop residue) as their main cooking fuel source, and that contained women and young children (demographic groups typically in closest proximity to cooking activities). Data from the HDSS enabled a cluster random selection of households from the district population that met the REACCTING eligibility criteria. The social structure in this region is such that groups of related households live in connected compounds. For the purposes of the HDSS, compounds are grouped into geographic **clusters**, with up to 99 compounds per cluster. These clusters are grouped into five geographic regions: four of these are primarily rural (North, East, South, and West), while the Central region contains Navrongo town and surrounding areas. For the REACCTING sample, we first eliminated households from the Central region, and then we randomly selected <u>25 clusters</u> using population weighting to determine the number of clusters selected per region. Within each cluster, <u>eight households</u> were randomly selected from the population of households that met the study eligibility criteria, resulting in a total sample of 200 households.

The stove intervention of the REACCTING study includes four different intervention arms: Group A received two Gyapa stoves, Group B received two Philips stoves, Group C received one of each type of stove, and Group D serves as the control for the duration of the study, but will receive their choice of stove at the conclusion of the study (the timing of which will coincide with the beginning of the research project described here). Stove stacking (i.e., households using new cookstoves alongside traditional cooking methods) had been observed in prior studies and we had earlier observed multiple stove use by the households in the study area. Multiple stoves were provided to each intervention household to increase the probability that households would begin to substitute away from traditional stoves rather than simply adding a new stove to their cooking technology mix. Randomization into intervention groups was done at the cluster level: i.e., within each of the 25 clusters, there are 2 households in each of the 4 REACCTING intervention groups.

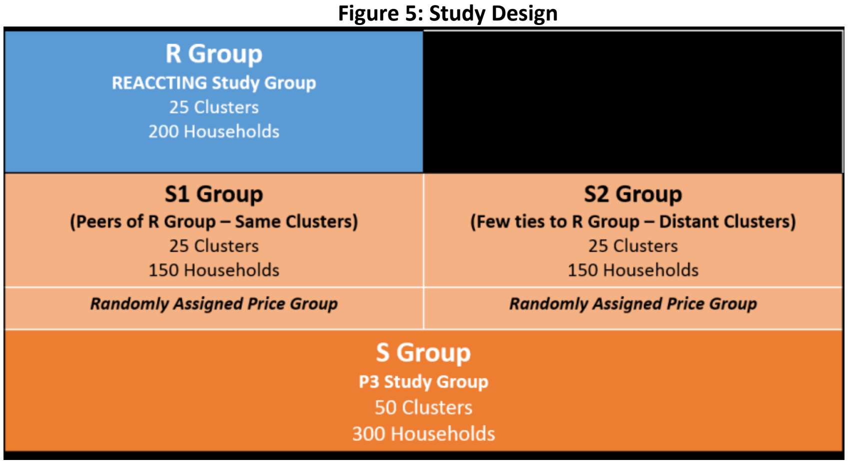
REACCTING Preliminary Results

Data collection and analysis for the REACCTING project is ongoing. Preliminary data analysis suggests that households in the three intervention groups have been using their new stoves and have decreased their use of traditional stoves, though these effects vary across the different intervention arms: Groups A (two Gyapa) and C (one of each stove) have reduced their use of three stone fires more than Group B (two Philips). Of particular interest for the research described in this protocol are the results assessing demand and willingness to pay for new stoves. Data collected at the beginning of the REACCTING study (before households received new stoves) and at multiple points after households had been using their stoves indicate that respondents have a high *stated* willingness to pay for their stoves (i.e., more than $100 on average). Comparing these stated values with actual willingness to pay through the follow-up study will be very interesting.

IV. RESEARCH STUDY DESIGN

Component #1: Biomass stove intervention in rural areas – P3 Bio

Figure 5: Study Design



To test the study hypotheses and systematically address interactions among prices, peers, and perceptions, we leverage the random introduction of stoves to the REACCTING households and implement a set of price experiments among new groups of households with varying levels of social ties to that initial group. For the purposes of this design, we refer to the REACCTING study sample as the R Group. Newly enrolled households that will be the primary focus of this *Prices, Peers, and Perceptions* (P3) study, are referred to as the S Group. A preliminary study design is summarized in Figure 5. This design independently and exogenously varies both exposure to peers with prior improved cookstove experience and the price of these technologies in order to assess how these different treatments shape perceptions, stove adoption, and stove use outcomes.

Stove Selection

The design of our intervention requires that we offer stoves that are similar to those offered for the REACCTING study, since we are measuring whether exposure to these technologies through peers influences adoption decisions. However, our experience in the REACCTING study revealed some key challenges with both the Gyapa and Philips stove models, such that we have elected to use slightly different stove models for this project. Through initial lab testing at CU as well as consultation with individuals in the study area, we have selected the Greenway Jumbo stove as a rocket-type stove, similar to the Gyapa, and the ACE1 stove as a forced-draft stove, similar to the Philips.

Peer Effects

Random variation in exposure to peers with cookstove experience will be accomplished through selection of S Group households that vary in terms of their proximity and social contacts with the R Group. The **S1** subgroup will be drawn from the <u>same clusters</u> as the R Group households (25 R Group clusters). S1 group households will thus be located in close physical proximity to R Group households with new stove experience, and are expected to have several social ties to these households. Meanwhile, the **S2** subgroup will consist of 25 clusters randomly selected from the area of the K-N Districts outside of a certain buffer distance from the R Group clusters. Data from the REACCTING study and additional pretesting will be used to select a buffer distance that minimizes the expected number of ties between R and S2 Group households; given that there are more than 300 clusters in the district and only 25 were included in the R Group, these ties are expected to be minimal (and will be measured as part of our data collection). Because the R Group clusters were randomly selected initially, and the S2 clusters will also be randomly selected, the study design ensures that in expectation the only differences between S1 and S2 group households is the former's higher level of exposure to peers with cookstove experience, enabling us to test the impacts of this exposure on our outcomes of interest (perceptions and technology adoption and use).

Prices

To examine the effects of price (and the interactive effects of prices and peers) on perceptions and technology adoption, both S1 and S2 Groups will be randomly subdivided into multiple price treatment groups. The price randomization will be done at the cluster level – i.e., all households in a cluster will be offered stoves at the same price. Using data from the REACCTING study and pretesting activities, we will set a range of prices for both types of stoves being offered. We will then generate a factorial design that creates different combinations of prices for the two stoves, and randomize these price levels across clusters, balancing prices across **S1** and **S2** clusters. The number of replicates for each price level will be determined to maximize the information expected to be generated from the intervention, using modeling based on parameters derived from pretesting data.

At the given price level, households will choose whether they would like to receive/purchase no stoves, one stove, or two stoves. In addition, households will be able to choose *which type(s)* of stoves they would like: the Gyapa-type (Greenway) or the Philips-type (ACE) stove.

Varying price levels is necessary to our research design and central to our ability to generate one of the key study benefits, namely, information on households' willingness to pay for clean cookstoves in this region. At the same time, we recognize that offering households stoves at different prices has the risk of being seen as creating an unequal burden or inequitable benefits for study participants. Regarding the *burden* for respondents, we emphasize that respondents will be free to choose whether or not to purchase stoves at the given price. This will be emphasized throughout the study, at enrollment and at the time when stoves are offered, and every attempt will be made to ensure that respondents do not feel undue pressure to select to buy a stove. Furthermore, price levels will be set for the two stoves based on an initial phase of focus group and pretesting. Stove prices will be set at or below the actual stove costs –

that is, households will not be asked to pay more than the stoves are actually worth. Finally, we will offer financing options to respondents to allow them to pay for their stoves over time. This may allow some households who would like to buy stoves but face credit constraints in the short term to do so, reducing the burden of paying for stoves all at once.

Since some households will be offered stoves for free while others will be offered stoves at positive prices, the benefits will be *unequal* across participants. However, these prices will be varied *at random*, such that the benefits will not be *inequitable*: at the outset of the study, all respondents will have an equal chance of being assigned to different price levels. This study design will be clearly explained to participants at the outset, as described in the Recruitment section (VIII) and specified in the Consent Form. Randomization of clusters to different price levels will be done in a participatory and transparent manner – for example, we may conduct the randomization during a meeting involving representatives from the different clusters, allowing these individuals to draw numbers out of a hat to determine their clusters' stove price levels, and videotaping this process so that it is available to show respondents concerned about the fairness of the price assignment.

Analysis of Key Research Questions and Power Calculations

Econometric analysis of data from the experiments will estimate regression models for three key outcome variables: stove adoption, use, and perceptions of quality (pre- and post-adoption). Multiple indicators of each of these outcomes will be possible. For example, adoption measures can include binary indicators for purchase / receipt of *any* stove, as well as indicators for the number and type(s) of stoves selected. Stove use measures will come from surveys and electronic monitors, and can be specified at the stove or household level over various time periods (e.g., reported use on previous day from survey vs number of uses over a month from SUMs). Perceptions measures can include overall favorable / unfavorable ratings as well as more continuous measures from Likert-scale and/or subjective expectation responses.

Using the cluster-randomized assignment of selected households to different price treatments along with prior random selection of the REACCTING study clusters (and subsequent inclusion of non-REACCTING households), we will estimate a variety of reduced-form and potentially structural models using the exogenous variables of stove price, as well as cluster-level prior adoption and usage. These models will be used to investigate the validity of the broad conceptual model, to test specific research hypotheses emerging from the formal economic model in Section 4.1, and to explore additional research questions, including the relationship between perceived stove quality and instrument-based measures of personal exposure to emissions.

The study's power to detect significant effects will vary depending on the specific outcome variable used (e.g., easier to detect effects for continuous vs binary variables), the cell sizes (smaller for interactions than for main effects), and the effect sizes, which are always difficult to estimate *a priori*. Table 1 shows power estimates for a sample of possible analyses under different assumptions.

Table 1: Power to detect sample of possible treatment effects under different assumptions

Effect	Outcome variable	Assumed effect size across groups being compared	Power to detect
Main effect of price on adoption	Purchase / receipt of any stove by household (binary)	100% in P0 (N=70) vs 75% in P1 (N=84)	0.999
		100% in P0 (N=70) vs 50% in P2 (N=140)	0.999
Main effect of price on stove use	Reported use of stove on day prior to survey (binary)	50% in P0 (N= 70) vs 75% in P2 (N=140) *(positive price effect)*	0.965

Main effect of price on perceived quality	Continuous stove quality index (0 to 100) from Likert-scale questions (Assuming normal dist. with std. dev. of 25 pts)	75 pts in P1 (N=84) vs 65 pts in P0 (N=70) *(positive price effect)*	0.800
Main effect of peers on adoption	Purchase / receipt of any stove by household (binary)	75% in S2 (N=147) vs 60% in S1 (N=147) *(negative peer effect)*	0.838
Main effect of peers on perceived quality	Continuous stove quality index (0 to 100) from Likert-scale questions (Assuming normal dist. with std. dev. of 25 pts)	50 pts in S1 (N=147) vs 60 pts in S2 (N=147) *(negative peer effect)*	0.96
Interactive effect of peers' experience and price on adoption	Difference in purchase / receipt of any stove at high price between peer-exposed vs unexposed groups, assuming P0 adoption is 100% in S1 and S2	Within P2 group, 60% drop in demand in S1 (N=70) vs 40% drop in demand in S2 (N=70) *(higher price elasticity within peer-exposed group)*	0.7112

Component #2: Liquefied Petroleum Gas (LPG) – P3 Gas

Phase 1: Characterizing LPG Supply and Demand

Activity 1.1: **LPG Supply Chain Analysis.** *Purpose:* To describe the current LPG supply chain serving the K-N, including sources and costs of LPG stoves, cylinders, and fuel, and to analyze barriers and opportunities for scaling up and transforming the supply chain to expand access.

For this activity, we will identify all retail centers in the K-N selling LPG stoves or cylinders, as well as retail LPG filling stations throughout the Upper East region. Surveys will be conducted with all retail operators to measure: i) location (GPS coordinates), ii) type(s) of products sold; iii) hardware and fuel prices (measured at multiple time points to monitor price volatility); iii) sources of products and fuels supplying the retail center; iv) perceived problems or issues with the supply of products from the retailer's perspective, including uncertainty in supply or cost; v) perceived levels of demand in the local area and potential strategies for increasing demand, including price-related incentives and social or peer-to-peer marketing approaches; vi) potential opportunities and barriers for expanding operations into new areas, including peri-urban and rural areas; and v) potential for shifting to cylinder recirculation as opposed to the current cylinder refilling model.

Activity 1.2: **LPG Demand Assessment.** *Purpose:* To describe current patterns of LPG use for household cooking in the K-N, and to assess opportunities and barriers for expanding LPG adoption.

For this activity, we will begin by using existing data on household locations, cooking practices, and detailed socioeconomic indicators from the NHRC's district-wide demographic surveillance survey (DSS) to analyze how LPG use varies spatially and according to household characteristics (e.g., education, socioeconomic status). This analysis will also include information collected in Activity 1.1 to assess how LPG use is related to distance from LPG supply centers. The DSS data will be managed by the NHRC team, following the institution's guidelines for management of this dataset. The NHRC collects the DSS data for the purposes of understanding population characteristics and trends over time, such that the analyses conducted as part of this project fall within the purposes outlined when the data was originally collected. Furthermore, the analyses conducted for this study will not use identifiable information about participants.

We will also use the DSS data to randomly sample of 300 households in the district, stratified to represent LPG users and non-users in urban and peri-urban areas. These households will complete the same baseline survey as the rural P3 Bio households, which will include modules that measure current cooking practices, including stove and fuel stacking (i.e., use of multiple types of stoves and/or fuels), as well as perceived barriers to LPG adoption, including price, savings/credit constraints, access/availability, and other perceptions (e.g., safety concerns).

Phase 2: Experimental Interventions to Increase LPG Adoption

Activity 2.1: **Intervention Development and Implementation.** *Purpose:* To design and implement a set of supply- and demand-focused interventions intended to increase LPG adoption in the K-N.

All of the 300 urban and peri-urban households surveyed in Activity 1.2 will be enrolled in the Phase 2 interventions, in which different stove-fuel packages will be offered. The packages that will be offered are shown in Figure 6.

Figure 6: LPG stove packages

Package Components:		Package Numbers: 1	2	3	4	5	6
	2 Burner Stove	✓	✓				
	1 Burner Local Stove			✓	✓		
	15 kg cylinder + regulator + hose (recirculation)	✓	✓	✓	✓	✓	✓
	4 Fuel Refill Vouchers	✓	✓	✓	✓	✓	✓
	Home Delivery	✓		✓		✓	
	Market value:						
	GHC	550	550	500	500	450	450
	USD	$140	$140	$125	$125	$110	$110

To generate willingness to pay (WTP) estimates and assess how LPG purchases vary with price, we will follow a method used in other economic studies of health-related technologies, known as a (modified) Becker-Degroot-Marshack (BDM) mechanism (Becker et al. 1964; Levine et al. 2012; Guiteras et al. 2014). In the first stage, a participant indicates her WTP (i.e., submits *bids*) for a set of different potential LPG stove packages. In the second stage, the researcher randomly draws one stove package, along with a random *offer price* for that package. If the bid amount is greater than the offer price, the participant has the option to purchase the stove package at the offer price. If the offer price exceeds the bid, the participant does not purchase the stove. Economic theory suggests that this procedure incentivizes participants to indicate their true WTP. The method also maximizes the statistical power of the study, by capturing more variation in WTP than alternative approaches.

In addition, a post-purchase marketing intervention will be randomly assigned to half of study participants that buy stoves. Many prior studies, and our own work, have shown that even households that have LPG stoves usually continue to use traditional stoves alongside their cleaner stoves. Households assigned to the post-purchase marketing arm will receive text messages and in-person visits encouraging them to use their LPG stoves more and their charcoal and wood stoves less. We will analyze whether these treatments influence stove use rates (measured through surveys and stove use monitors) and perceptions of the stoves (measured through the endline survey).

Project Timeline

The proposed research will take place over a three year period, with activities in each year indicated in Table 2. **Table 2: Timeline of project activities**

PROJECT WORKPLAN												
	Year 1 Sept 2015-Aug 2016				**Year 2 Sept 2016-Aug 2017**				**Year 3 Sept 2017-Aug 2018**			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Preparation, including IRB approvals	■	■	■	■								
Survey Development and Intervention Planning			■	■	■	■						
LPG Supply Survey				■								
Household Surveys						■		■				■
P3 Bio Intervention												
- Stove meetings, offers made, orders							■					
- Stoves delivered, payments collected									■	■	■	
P3 Gas Intervention												
- Stove meetings, offers made, orders									■			
- Stoves delivered, payments collected										■	■	
Instrument-based measurements									■	■	■	■
Data analysis							■	■	■	■	■	■
Dissemination												
- Preparation of reports and peer-reviewed publications								■	■	■	■	■
- Presentation at scientific conferences									■	■	■	
- Workshop in study area												■

V. FUNDING

This research is being funded by the National Science Foundation's Economics program and the National Institutes of Health's Clean Cooking Implementation Science Network.

VI. ABOUT THE SUBJECTS

Component #1: P3 Bio

As shown in Figure 5, a total of 300 households will be enrolled in the P3 Bio component of the study. In each household, the primary cook (typically female, aged 18-55 years old) will serve as the main study participant. In households where another male household member makes financial decisions, we will conduct a secondary survey with this individual as well. We anticipate that all of these households will complete the study. The study population includes two main ethnic groups: Kasem and Nankam. The population will be split roughly evenly between these two groups.

Table 3: Subject Populations

Subject Population(s)	*Number to be enrolled in each group*
Group S1: Rural households from the same clusters as REACCTING study households	*150 households*

Group S2: Rural households from different clusters from REACCTING study households	*150 households*

Inclusion / Exclusion Criteria

Sample selection will proceed in two phases. First, clusters will be selected for inclusion in the study. All of the 25 REACCTING study clusters will be included to form the S1 group clusters. GIS mapping will then be used to *exclude* clusters that are close to those S1 clusters (using a buffer distance determined using preliminary data on social ties), and 25 S2 group clusters will then be randomly selected from the remaining clusters.

Second, the required number of households will be selected from each cluster. We will use the same inclusion and exclusion criteria used to select households in the existing REACCTING study. Using data from the district's demographic surveillance survey, a sample frame of eligible households will be created using the following inclusion criteria:

- Classified as "rural"
- Uses biofuel as main cooking fuel source
- Has woman in household aged 18-55 and at least one child under five (since women and children are the most vulnerable to cookstove smoke)

S1 group households will be selected using GIS data to identify the *nearest neighbors*, meeting the above eligibility criteria, of each of the 6 REACCTING households that received stoves in that cluster during the REACCTING intervention phase. In the non-peer clusters, 6 seed households meeting the above eligibility criteria will be randomly selected, and then S2 group households will be selected as the nearest neighbors of those seed households. This procedure is used to create as similar as possible selection criteria and sampling methods between the peer (S1) and non-peer (S2) groups.

Component #2: P3 Gas

This component of the study involves two subject populations: LPG suppliers, and urban households. For the supply survey, all LPG refilling stations in the Upper East Region, and all retail shops selling LPG stoves or cylinders in the K-N Districts, will be eligible for inclusion in the study (16 businesses in total).

For the urban households, we will use the same demographic inclusion criterion as in the rural sample (at least one woman in household aged 18-55 and one child under five). As in the rural areas, we will first randomly select clusters from the urban area, and then randomly select households within each cluster, for a total of 300 households in this component. These subjects will complete an initial baseline survey (Activity 1.2) and will then be enrolled in the intervention (Activity 2.1) and follow up data collection. In the urban area, the majority of respondents belong to the Kasem ethnic group. As above, the primary cook is the primary participant, and if another individual in the household is responsible for making financial decisions for the household, this individual will also complete household surveys and will be present when stove offers are made.

VII. VULNERABLE POPULATIONS

- *Not applicable.*

VIII. RECRUITMENT METHODS

P3 Bio and P3 Gas Household Recruitment

Study households will be randomly selected from the sample frame of eligible households constructed using the methods described in Part VI. Following local customs for conducting research in this area, community entry and engagement activities will be conducted in all study clusters prior to beginning research activities. The study's community entry, education, and engagement activities are designed to serve at least three key objectives. First, we understand the need to respect local customs and obtain the proper permissions to conduct our study in each area. To this end, we will hold community entry meetings and engage local chiefs and sub-chiefs to explain the objectives of our study and enlist their support in carrying out these objectives. NHRC collaborators with extensive knowledge of the local context and norms will lead this effort. In addition, while our study will deal extensively with female household members who are most closely involved in cooking activities, interviewers and other study personnel will also engage household heads to fully inform them of the study's methods and objectives.

A second objective of the community entry and engagement activities is to address any concerns participants may have and foster trust in the study's objectives and fairness. Through the community entry meetings described above, we will explain our methods as transparently as possible and communicate with leaders and participants at various levels. For example, one question that might arise is why certain clusters or households have been chosen for inclusion in the study. Through our community entry activities, we can explain that this selection was done randomly. Since women will be heavily involved in the study, we also want to ensure that these women are approached in a respectful way and that they feel comfortable raising any concerns, they may have. For this reason, we will also use the community entry meetings to identify local women groups and engage them in the community outreach processes.

The study's experimental manipulation of stove price will also be clearly explained during the community entry and recruitment activities. For P3 Bio, we will tell participants the price of the two stoves, and then explain that households in different clusters will be offered varying discounts to purchase the stoves if they choose. We will also explain that these discounts are set randomly, and will randomize the stove discounts transparently during the community entry phase with the participation of representatives from different clusters. (For example, this may be done by allowing representatives from the different study clusters to draw numbers out of a hat to determine their clusters' price levels.) Regarding the peer effect manipulation, we will disclose to participants that we are conducting the study in different areas, and that stoves have already been distributed to some households through a prior study that was conducted in some but not all of these areas. For P3 Gas, we will explain that the LPG stove-fuel packages being offered are available in the market (and tell households the market value of the packages). The auction mechanism will be clearly explained, with an emphasis on the randomized nature of the offer prices and the importance of stating one's true willingness to pay. As long as participants report their willingness to pay accurately (i.e., do not overstate their willingness to pay), they will not be required to pay more than the amount they are willing for any of the stove packages.

Following community entry, households that have been randomly selected from each cluster will be visited by the survey interviewers. These interviewers will inform the households of their selection for inclusion in the study, describe the study purpose and procedures, and obtain informed consent from participants. Interviewers will make it clear that participation is purely voluntary and will not coerce participation in any way. No written / visual recruitment materials will be used; interviewers will approach recruits in person (following standard practices in this area). A list of replacement households from each cluster will be randomly draw along with the initial recruits; households that elect not to participate (or are not available / cannot be located) will be replaced with households from this list.

P3 Gas Supply Survey Recruitment

For the LPG supply survey, NHRC interviewers will visit each business, ask to speak to the owner or manager, and explain the purpose of the survey. These individuals will then be read the informed consent statement, and will indicate whether they agree to participate in the survey.

IX. COMPENSATION

Small in-kind tokens of appreciation are offered to study participants as compensation. These include items such as bags of rice, bars of soap, or cell phone credits. As with all aspects of the field work, we defer to our local collaborators for guidance on appropriate, non-coercive methods of compensation for study participants.

X. CONSENT PROCESS

Informed consent will be obtained for all study participants at the outset of this study. Given that the study poses minimal risks to participants, oral consent will be obtained. The enclosed consent statement describes the purpose of the research and the research design, including the design of the experimental manipulations of price and peer effects, and each of the data collection activities, including the purpose of the data collection, what will be required of the participant, and any anticipated risks and/or benefits. After each consent statement is read, the participant will be asked whether or not they agree to participate in that data collection activity, and the response will be recorded by the data collector. Participants will be assured that they may decline participation in certain data collection activities, specifically photographic monitoring for a 48 hour period, while still agreeing to participate in all other study activities. All participants will be given contact information for the study personnel. Consent will be sought before pictures of participants are added in reports and publications.

Consent statements, along with surveys and other materials, will be translated into the two local languages (Kasem and Nankam). For some urban households and LPG supply surveys, some participants are likely to opt to take the survey in English. Following NHRC practices, translations are done orally and are developed and agreed upon by interviewers prior to the inception of the surveys. These translations are typically not written down.

XI. PROCESS TO DOCUMENT CONSENT IN WRITING

We are requesting a waiver of documentation of informed consent. This research poses no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context.

XII. PROCEDURES

Household-level Interventions and Data Collection (P3 Bio and P3 Gas)

The study's data collection instruments are summarized in Table 4, and the list of procedures, visits, and time constraints are listed in Table 5.

Several data collection methods will be used to measure key outcomes of interest.

1) Household surveys: A baseline survey will measure household composition and demographics, attitudes and priorities, cooking behaviors (including type(s) of stoves used, fuel use, foods cooked, who cooks within household), knowledge and perceptions of issues related to cooking practices, demand for new stoves, and self-reported health measures. One short follow up survey will cover households' stove perceptions. A full survey, covering the same questions as the baseline survey, will be repeated at the end of the study.

2) Stove use monitors: In a subset of study households, stove use monitoring equipment will be attached to all stoves in the household (including traditional/old stoves and stoves distributed as part of the study intervention). These monitors will provide measurements of stove temperature every 5 minutes in order to indicate when each stove is in use over a given period. Study personnel will visit homes every 3 months to make sure these monitors are intact and working and to download data from the monitors.

3) Personal exposure measurement: In each study household, we will measure personal exposure to cooking emissions for the household's primary cook. Three types of equipment may be used to measure exposure: 1) "CO tubes," or small plastic tubes the size of a small pencil that are filled with a material that changes color based on how much carbon monoxide is in the air. The tubes are either attached to the participant's shirt collar using a plastic clip, or worn as a necklace. 2) A small electronic device the size of a mobile phone that measures and records the amount of carbon monoxide it is exposed to. This device is also worn on the shirt or clipped to the pants/skirt. 3) A filter sampler that collects small particles on a filter. This device includes batteries and a pump that need to be stored in a small bag worn around the waist, and it makes a quiet humming sound. This equipment is worn for 48 hours at each monitoring visit, and personal exposure monitoring will be conducted every three months in the same subset of households with stove use monitoring.

4) Short term stove use and proximity monitoring: In a subset of the households participating in personal exposure measurements, we will collect validation data for when stoves are being used and when participants are near these stoves. Obtaining this data will be accomplished through taking photographs in intervals (either every 30 or 60 seconds) of the two main cooking areas in a household over a 48-hour period. The equipment used will be two wildlife cameras equipped with infrared LEDs for night vision and timestamp capabilities placed on a tripod approximately 10 feet away from the two main cooking areas. The night vision should be of no concern for participants as this feature uses dim red lights that are minimally visible. Photographs will be collected for 48 hours. The field team will record which stoves are monitored so that during image processing a record can be made for each timestamp of (1) Are any of the cookstoves in this cooking area considered 'on' at this time? and (2) Is the primary cook visible near this cooking area and are they wearing the personal exposure equipment? After taking note of every time the primary cook is wearing the personal exposure equipment in the frame and which stoves are lit at which times, all images will be deleted. All that will remain is a database of stove 'on' times that will be compared to temperature data from corresponding stove use monitors and participant 'nearby' cooking area times that will be compared to proximity data.

Following their recruitment into the study by interviewers at the time of the baseline survey, households will be instructed to attend a stove demonstration meeting at a location near their house (in their cluster). Interviewers will provide information on the time, date, and location of these meetings. At the meeting, the stove and fuel options will be presented and demonstrated to participants. As noted above, the P3 Bio intervention will use two stoves similar to the REACCTING stoves (Greenway Jumbo and ACE1). The market value of the Greenway stove is about $30, and the ACE (including a small solar panel and light) costs about $80. REACCTING results, pretesting and focus group activities in the study area will be used to determine appropriate price points / discount levels for the study design such that we would expect to see variation in price across the different experimental price groups. In the urban sub-sample, the P3 Gas participants will be shown the components of the LPG stove and fuel packages (see Figure 6).

For the P3 Bio study, participants will select stoves at the conclusion of their small group meeting. At the prices assigned to each cluster, participants can elect to purchase a total of 0, 1, or 2 stoves, of either type (Greenway or Jumbo). Participants will be informed that the project team must order stoves from their manufacturers and that the stoves will take 2-3 months to arrive in Ghana after the orders are made. TOnce participants have made their selection, they will sign or thumbprint an agreement that specifies the types of stoves they have agreed to purchase, the purchase price, and the payment schedule.

For the P3 Gas intervention, stove offers will be made using a (modified) Becker-Degroot-Marshack (BDM) mechanism (Becker et al. 1964; Levine et al. 2012; Guiteras et al. 2014). Project staff will visit each participant in their homes, following the group information meeting, and conduct the following procedure. First, the auction mechanism is explained to the participant, and two practice rounds are conducted using small token items (soap, small bags of rice). Next, the stove auction proceeds in two stages. In the first stage, the participant indicates her WTP (i.e., submits *bids*) for each of the 6 LPG stove packages (Figure 6). She may elect NOT to bid on any package for which she has no interest. In the second stage, the researcher randomly draws one stove package from the set of packages the participant chose to bid on, along with a random *offer price* for that package. If the bid for that package is greater than the offer price, the participant must purchase the stove package at the offer price. If the offer price exceeds the bid, the participant does not purchase the package. If the participant wins the auction, she will sign an agreement stating which package she will receive, the amount to be paid, and the payment schedule.

For both P3 Bio and P3 Gas, the first payment for any stove packages purchased will be due once the stoves are delivered to the household, and the participant will have 6 months after that point to complete all payments. If all payments are not completed within 6 months, all payments that have been made to that point will be returned to the participant, and the project team will recover the stoves. This will be explained to participants before stove orders are made, and the agreements will specify the payment schedule.

Table 4: Data collection instruments

Name of instrument/tool/procedure	***Purpose (i.e. what data is being collected?***	***Time to Complete***
Surveys	*Collect data on social networks, stove perceptions, stove use, self-reported health symptoms and expenditures, socioeconomics*	*1 hour*
Stove Use Monitoring	*Collect data on stove temperature continuously for all stoves in a subset of study households*	*Set-up: 30 min Visits to download data: 30 min*
Personal Exposure Monitoring	*Collect data on cook's exposure to pollutants*	*Equipment worn for 48 hours every 3 months*

Table 5: Respondent visits and time commitments

Visit #	*Procedures/Tools*	*Location*	*How much time the visit will take*
Visit 1	• *Explain study, informed consent* • *Complete baseline survey*	*Respondent's home*	*1-2 hrs*
Visit 2	• *Attend stove demonstration* • *Make stove selection*	*Central location in cluster* *For P3 Gas: stove selection occurs during separate home visit*	*1 hr*
Visit 3 (Subset of households)	• *Set up stove use monitors (SUMs)*	*Respondent's home*	*30 min*
Visit 4 ***(Subset of households)***	• *Personal exposure monitoring* • *Download SUMs data*	*Respondent's home*	*30 min*
Visit 5	• *Conduct follow-up survey #1*	*Respondent's home*	*30 min*
Visit 6 ***(Subset of households)***	• *Personal exposure monitoring* • *Download SUMs data*	*Respondent's home*	*30 min*
Visit 7	• *Conduct follow-up survey #2*	*Respondent's home*	*30 min*
Visit 8 ***(Subset of households)***	• *Personal exposure monitoring* • *Download SUMs data*	*Respondent's home*	*30 min*
Visit 9	• *Conduct endline survey* • *Download SUMs data (if applicable)*	*Respondent's home*	*1 hr*

LPG Supply Survey

For the LPG supply survey, business owners / managers will conduct one 30 min survey during a single visit in their place of business.

XIII. SPECIMEN MANAGEMENT

➢ *Not applicable.*

XIV. DATA MANAGEMENT

Table 6: Data management plan

Data Type	Samples	Format	Metadata	Access Policies	Usage Policies	Plan for Archival
Survey Data	Household-level social network, perception, behavioral, health,	ArcGIS, CSV, DTA (Stata)	Units, lat/lon of compounds/ houses	Team access only to full dataset with identifiers / De-identified data open access with	Non-commercial use only	CU password protected computer

	demographic, and socioeconomic data			registration / statement of interest		
Stove Use Data	Time series measurements of stove temperature	ASCII, CSV, EXCEL, MAT (Matlab)	Units, variables (compounds, stove type) methods, uncertainty	Open access with registration/ statement of interest	Non-commercial Use Only	CU password protected computer and servers
Personal Exposure, Proximity, and Air Quality Data	48 hr real-time personal CO data; 48-hr integrated personal $PM_{2.5}$ samples; time series of individual proximity to stoves/sources; household environment CO, CO_2, and $PM_{2.5}$ samples (NO and VOCs in subgroup)	CSV, TXT, EXCEL, MAT, (Matlab)	Units, variables, (Lat/lon of measurements, characteristics) methods, uncertainty and calibrations	Team access only to full dataset with identifiers / De-identified data open access with registration / statement of interest	Non-commercial use only	CU password protected computer and servers
Short Term Stove Use and Proximity Data	48 hours of 30-second-interval photographs	JPG	Timestamp, Date, Temperature	Team access only to full dataset with identifiers/ De-identified data open access with registration / statement of interest	Non-commercial use only	CU password protected computer and servers

Types of data

The raw data generated by the proposed research includes (a) quantitative social survey data and analyses; (b) time series measurements of stove temperature from the Stove Use Monitors (SUMs), and (c) personal exposure, proximity to stoves, and microenvironmental (near-stove) air quality data. Surveys will be conducted using paper hard copies generated using the Remark Office OMR software, a "scan-tron" like format that allows responses on subsequent .pdf files to be read in to Excel files automatically. Air quality data will be collected from the instruments in the field in the form of raw sensor signals, typically voltages, with time stamps. In addition to this field data, we will also be routinely compiling calibration data for each sensor. This calibration data will be in the same format as the field data.

Data Storage and Archival

All data will be backed-up on a daily basis using the University of Colorado's network resources. All researchers working on the project (PI and co-PIs, senior personnel, graduate students, undergraduates, and other collaborators) will have access to generated computer files and results. Access to the data will be maintained for three years after the completion of the project. If long-term retention is deemed necessary, options for such archiving will be explored at a later time.

Hard copies of the social surveys will be scanned into .pdf files, which will be transmitted to shared secure online servers. Hard copies will then be stored at the NHRC for a period of three years, after which they will be destroyed. Scanned files will be read into Excel/csv format using the Remark Office OMR software, and data will be stored on CU password protected computers. Identifying information for survey participants (e.g., names and addresses of individuals) will be used only in the data collection stage, and will be removed from survey datasets once data collection is complete.

Data collected by the instruments in the field will be transmitted immediately after retrieval from the field to the PIs' accounts. Once received, the electronic data will be stored on the PIs' computers and a back-up disk drive in the PIs' offices as well as on the CU Department of Mechanical Engineering's server. The sensor calibrations will be generating using the calibration raw signals along with the known concentrations given to the sensors. We will also derive uncertainty estimates from these fitted relationships. The raw signals from the Pods will be processed using sensor calibrations.

Data Sharing

The data will be made available via conference presentations, workshops and peer-reviewed publications. The results will be submitted for publication immediately after a sufficient level of analytical detail has been achieved through experiments and data analysis. No fee will be charged for access to the data other than applicable publication subscription fees charged by peer-reviewed journals or proceedings copy fees charged by conferences. The data will be open to wider use at the time of the publication.

During the project, digital records will be stored briefly on the hard drives of personal computers before being uploaded to servers maintained and backed up by the University of Colorado that is managed according to IRB requirements. The data will be saved to these dedicated servers to ensure preservation of the data collection and results. This server can be accessed from off-site and is password protected and thus, the data will not be cleaned prior to posting. However, all data will be de-identified as described above, prior to making it available to the public. Once expunged of all personally identifiable information and immediately after publication, digital records will be made public through requesting access.

No other permission restrictions will be placed on the data. The data will present interest to academic researchers who may adopt the methodology established for the study in their experimentation, to water treatment utilities who consider additional treatment in response to perturbations, to regulatory agencies, and to the general public concerned about water quality. There are no reasons why the data collected in the proposed study could not be shared or re-used.

All collected data will be saved in local hard drives accessible to the PI and involved students. Apart from the archived copies kept by the PI, electronic files will be saved in servers at CU Boulder. The data will be entered into a format that can be shared and does not require specialty software. Examples of such file formats are Microsoft Excel or PowerPoint. The data will be kept for a minimum of five years after completion of the project as specified in the data management requirements of the grant guidelines.

XV. WITHDRAWAL OF PARTICIPANTS

Subjects may withdraw at any time without penalty.

XVI. RISKS TO PARTICIPANTS

There are two broad categories of risks to participants in this study: risks associated with the study intervention (distribution of new cookstoves), and risks associated with data collection activities.

Risks associated with the study intervention:

- One key risk would be that emissions, exposure, and/or air quality would get *worse* as a result of using the new stoves. This could happen if households are cooking on more stoves for longer periods, or if newer stoves are used improperly or don't work as intended.
- By their nature, the stoves also present a fire hazard. If used improperly, participants could also spill or burn their food.
- The risks associated with LPG stoves are somewhat different from those of the biomass stoves. Specifically, if used incorrectly, LPG stoves carry the risk of large accidents (explosions). These safety concerns are an important consideration, and one reason why some households have currently avoided adopting LPG.
- Due to the random selection of households into the study and the random assignment of participants into "treatment" and "control" arms, there is also a risk of jealousy/social discord among study arms charged a positive price for the stoves vs being offered stoves for free.

Risks associated with data collection:

- The household surveys pose minimal risks to participants. They do not cover highly sensitive topics, and respondents may refuse to answer any question.
- Stove use monitoring: The temperature monitors attached to stoves and the air quality monitors installed near cooking areas pose minimal risks to respondents. There is a small risk that electronics could break, causing smoke or fire.
- Personal exposure measurements: These measures also pose minimal risks to respondents. Electronic monitors carry a small fire/smoke risk if the equipment breaks.
- Short term stove use and proximity measurements: The wildlife camera monitoring poses minimal risks to participants. A small risk of privacy invasion exists: participants may be embarrassed to be seen conducting day to day activities in their home by research staff, and/or be worried that these photos will be given to others outside of the research team, which could also cause embarrassment.

XVII. MANAGEMENT OF RISKS

Risks associated with the study intervention:

- Risk that exposure gets *worse* as a result of using the new stoves: Steps that we will take to reduce this risk include: a) conducting lab tests with the stoves prior to deployment using local fuels to ensure that the stoves do reduce emissions under lab conditions of stoves; b) training households on their use (e.g., the Philips stoves require less fuel than one might expect, and overfilling them can lead to excessive smoke emissions); and c) monitoring study data and taking steps to amend the study design if data indicate significantly worse outcomes in one of the intervention arms relative to the control group (e.g., substituting cleaner stoves in that intervention arm or, in an extreme case, ending the study).
- Fire hazard (biomass stoves): Participants will be trained on how to use the stoves properly to avoid fire escaping from the stove and to avoid burns and food losses.
- LPG stove risks: We are taking the following steps to reduce the specific safety risks presented by the LPG stoves being used in this component of the project:
    - EDUCATION: Participants will receive instruction on proper, safe use of LPG at multiple timepoints. Group sensitization meetings will be held in each cluster to present the stove package and explain how to properly use LPG stoves. Project staff will also meet individually with households to make the stove offers, and will address safety concerns during these meetings. Finally, training on proper use will be provided when stoves are

delivered to households, and follow-up visits will be conducted to inspect stoves and ensure that best practices are being followed.

  - TECHNOLOGY CHOICE AND DELIVERY MECHANISMS: As noted earlier, the current model of LPG distribution in Ghana involves households purchasing and refilling LPG cylinders. This is thought to lead to potential problems, since households may prefer to use cylinders as long as possible rather than replacing them when they start to wear out. For all households receiving stoves and cylinders in this study, we will instead use a cylinder recirculation model: the refilling station will maintain a stock of filled cylinders (and connecting hoses), and participants will swap empty cylinders for full ones. The refilling station will inspect cylinders for leaks and other issues. This is the international best practice, and Ghana has announced its intention to move toward this model nationwide in the future. Thus, our study participants should face lower LPG-related risks compared to the status quo in this region.

- Risk of jealousy/social discord due to randomization: Steps that will be taken to mitigate this risk include: a) randomizing stove price at the cluster level so that households near one another are charged the same price for their stoves; and b) holding public meetings and following local "community entry" best practices to clearly explain study design at the outset, including making the randomization process transparent as possible to reduce perceptions that the study is "unfair."

Risks associated with data collection:

- Household survey poses minimal risks to participants: To the extent that any information is sensitive, the steps described in Part XX will ensure that the data is not made publicly available in a way that could link responses to any individual participant. Interviewers will be trained in proper survey administration techniques and attitudes to ensure data quality and avoid social desirability bias (particularly relating to use of and attitudes toward the new stoves).
- Stove use monitoring: Participants will be informed of the risk of malfunctioning equipment and a protocol will be established for contacting study personnel if any of the equipment appears to be malfunctioning. Confidentiality of stove use data will be maintained – in particular, interviewers will not have access to this data when administering household surveys (which also ask about stove use) so that interviewers can ask questions without the respondent feeling like they are being given a "test" with right and wrong answers.
- Personal exposure measurements: As above, participants will be advised to be on the lookout for the small risks of malfunctioning equipment.
- Short term stove use and proximity measurements: The risks to participants' privacy from the photographic data will be addressed by only allowing team members to view these photos for the purposes of coding stove use and participant location, and deleting all photographs immediately after image processing, which will be done as soon after data collection as possible. Participants and those in the area will also be informed of the photographs before data collection begins, so those around have the opportunity to change any personal behaviors they do not wish to be seen on camera. Participants may continue any activities they are comfortable with.

XVIII. POTENTIAL BENEFITS

There are several potential benefits to participants. All households will have a possibility of receiving new stoves. This new technology has potential time and fuel savings as well as possible health benefits for participants.

Household members will also be involved in the research process throughout the study. We will fully inform participants about the instruments we are using and the objectives of the research, and will be open to suggestions about ways to improve our research methodology or measurement routines. We may also enlist households' participation in disseminating our results to the broader community.

XIX. PROVISIONS TO MONITOR THE DATA FOR THE SAFETY OF PARTICIPANTS

Where possible, interim analyses of personal exposure will be conducted to check whether exposure to pollutants significantly increases in groups with different types of new stoves. If this is found to be the case, this information will be provided to participants and households will have the option to return their new stoves (and receive refunds in cases where stoves were purchased). Other adverse events (e.g., broken stoves) will be reported to Maxwell Dalaba (NHRC) for appropriate follow-up and management.

XX. PROVISIONS TO PROTECT THE PRIVACY INTERESTS OF PARTICIPANTS

Data collection will occur only in contexts in which the subject is aware of and approves of the activity. Household surveys will occur in or near respondents' homes only when and if respondents have agreed to be surveyed. Similarly, respondents will be informed of and will consent to use of stove use monitors, personal exposure monitors, and cameras prior to any data collection using these instruments.

XXI. MEDICAL CARE AND COMPENSATION FOR INJURY

- *Not applicable.*

XXII. COST TO PARTICIPANTS

Households' use of the new stoves requires use of fuel (mainly wood or biofuel); however, these are fuels that the household would be using in the absence of our study, and in theory the new stoves will use less fuel than households' existing stoves.

P3 Bio households will be offered stoves at a positive price. In order to receive stoves, households will have to pay for them. However, households will not be required to purchase stoves. Every attempt will be made to make it clear to participants that purchasing stoves is completely voluntary.

P3 Gas households are being offered stove – fuel packages, and will have the option of purchasing these packages, which will incur costs. However, these packages will be subsidized relative to their market value, and the bidding mechanism should ensure that no participants will pay more than they are willing and able for these products.

XXIII. DRUG ADMINISTRATION

- *Not applicable.*

XXIV. INVESTIGATIONAL DEVICES

- *Not applicable.*

XXV. MULTI-SITE STUDIES

This study is being conducted through a collaboration among CU-Anschutz, CU-Boulder, North Carolina State University (NCSU), and the Navrongo Health Research Centre (NHRC).

Institutional roles are outlined in Table 7.

Table 7: Institutional roles and responsibilities

Institution	Key Personnel	Role
CU-Anschutz	Katherine Dickinson (PI)	Coordinate collaboration among project team members, lead experimental design and social survey data collection and analysis, advise and mentor RAs.
CU-Boulder	Michael Hannigan (Co-PI)	Lead collection of instrument-based data (stove use, exposure, etc.) and analysis, advise and mentor graduate RAs.
NCSU	Zachary Brown (Co-PI)	Collaborate on experimental design and social survey data collection; lead econometric data analysis, advise and mentor graduate RA.
NHRC	Maxwell Dalaba (Co-I)	Direct field activities, oversee data collection and stove distribution, and collaborate on data analysis and dissemination, including public outreach.

In addition to being reviewed by CU-Boulder, the study protocol will be reviewed by the IRB of the NHRC. The protocol was submitted on July 1, 2015, and the NHRC's approval letter has been submitted to CU's IRB when it is complete. Co-PI Brown is requesting that NCSU use an IRB Authorization Agreement to cede oversight to CU-Boulder. PI Dickinson changed institutions in 2017 and is requesting an IRB Authorization Agreement to cede oversight to CU-Boulder for the remainder of the project period.

XXVI. SHARING OF RESULTS WITH PARTICIPANTS

The research team will engage communities in the study area in the interpretation and dissemination of research results. In the final year of the study, a workshop will be held with study participants and community leaders to summarize key findings for the study and discuss possibilities for scaling up clean cookstove adoption within the region.

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