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Preferences for Improved Cook Stoves: Evidence from North Indian Villages

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Abstract

Because emissions from solid fuel burning in traditional stoves impacts global climate change, the regional environment, and household health, there is today a real fascination with improved cook stoves (ICS). Nonetheless, surprisingly little is known about what households like about these energy products. We report on preferences for ICS attributes in a large sample of 2,120 rural households in north India, a global hotspot for biomass fuel use as well as its negative consequences. Households have a strong preference for traditional stoves, but are willing to pay (WTP) about $10 and $5 for realistic reductions in smoke emissions and fuel needs on average, respectively, or about half of the price of less expensive ICS. Still, preferences for stove attributes are highly varied, and related to household characteristics (e.g. expenditures, gender of household head, patience and risk preferences). These results suggest that households exhibit cautious interest in the promise of ICS, but that there remain significant barriers to achieving widespread adoption. Therefore the policy community must reinvigorate a supply chain that (a) experiments with product attributes and (b) segments the market based on consumer education, wealth and location, in order to scale up ICS distribution and deliver household and global benefits.

Keywords: Air pollution, greenhouse pollutants, preferences, discrete choice, South Asia

1. Introduction

The use of solid biomass or coal fuels for basic household cooking and heating remains widespread throughout the world, and represents approximately 15% of global energy use (Legros et al., 2009; Smith et al., 2000). These fuels are often burned in cheap but highly inefficient stoves, which damages the global climate system because of emission of greenhouse pollutants and gases such as black carbon and ozone precursors (Bond et al., 2004; Ramanathan and Carmichael, 2008). Additionally, this inefficient biomass fuel burning also harms regional air quality, local forest environments, and household health (Bruce et al., 2006; Ezzati and Kammen, 2001; Martin et al., 2011). These harmful effects and the unsustainability of traditional stoves have prompted great interest in, and a new push towards development and dissemination of more efficient and cleaner-burning improved cook stoves (ICS) such as gas-, electric-, or cleaner biomass-burning technologies (GACC, 2010; World Bank, 2013).

In the energy policy community, ICS are viewed as a potential mechanism for reducing energy poverty and attaining energy security around the world (Bazilian et al., 2010; Birol, 2007; Pachauri and Spreng, 2011). However, most of the recent push for widespread promotion of ICS in less developed countries stems from concerns over the role played by traditional cooking technologies in climate change. Black carbon (also known as soot) emissions from the use of traditional biomass cookstoves and diesel engines are the second largest contributor to global warming (Ramanathan and Carmichael, 2008). Research from 2009-2011 by Project Surya in Uttar Pradesh, India, which is located near the sample interviewed in this particular study, has demonstrated increased black carbon concentration in air during periods of intensive traditional mud stove use (Praveen et al., 2012; Ramanathan and Balakrishnan, 2007). This research has also shown that black carbon reductions vary significantly across different biomass-burning ICS models, and that only certain types of these technologies (e.g., forced draft stoves equipped with a fan) are effective (Kar et al., 2012; Ramanathan et al., 2011; Rehman et al., 2011). These studies suggest that mitigation of black carbon and other short lived climate pollutants (SLCPs) through various measures, including widespread replacement of traditional stoves with more efficient models, could reduce global warming and end-of-century sea level rise by as much as 20 percent (Hu et al., 2013).

Well before the interests in how traditional stoves contribute to climate change, much attention was paid to their contributions to forest degradation and deforestation (because of high fuel requirements) and to respiratory illness (Ezzati and Kammen, 2002; Pant et al., 2014). Household air pollution is thought to kill more than 3 million people each year, and is today the leading cause of death in South Asia (Lozano et al., 2012; Murray et al., 2013). Yet despite the very large health risks associated with traditional stoves, adoption of cleaner burning biomass stoves has been slow, and new technologies have not reached scale. Beyond well-known problems of high costs and a weak supply chain, researchers and practitioners have claimed, without a great deal of systematic evidence from rigorous field studies, that the existing range of biomass ICS prototypes were not sufficiently adapted to local cooking requirements and user preferences (GACC, 2011; Jeuland and Pattanayak, 2012; Lewis and Pattanayak, 2012; Shell Foundation, 2013; Singh and Pathy, 2012). Meanwhile, the most widely accepted ICS technologies such as LPG and electric stoves remain costly for poor households, and lack a robust and strong supply chain in rural areas.

In response to these observations, field-based empirical research has begun to raise important questions about specific diffusion and dissemination strategies for biomass-burning ICS. While there is some evidence that demand for such stoves is limited (Larson and Rosen, 2002), more recent notable studies from East and West Africa reveal successful promotion under some conditions, at least in the short-term (Bensch and Peters, 2012; Levine and Cotterman, 2012). In fact, the range of recent and sometimes contradictory findings on ICS adoption highlights several points that have previously been emphasized in the broader literature on demand for environmental health improvements. First, the demand for such health improvements is often low, and is related to consumers' diverse preferences, circumstances and constraints (Pattanayak and Pfaff, 2009). For example, households cannot be expected to adopt a stove that is inconvenient to use or that is insufficient for their specific cooking needs, even if it is highly efficient. Second, this heterogeneity (across communities and individuals) translates into substantial variation in the real costs and benefits of ICS (Jeuland and Pattanayak, 2012; Whittington et al., 2010). Third, household decisions about whether or not to adopt and continue to use ICS may not always follow from simple comparisons of economic costs and benefits. Lack of user awareness, peer influences, credit constraints, uncertainties (especially related to servicing and maintaining ICS prototypes), risk aversion and impatience, all influence decisions about whether or not to adopt an unknown technology, with highly uncertain returns (Beltramo et al., 2014; Liu, 2011; Tarozzi et al., 2011). Part of the solution has to lie in learning to engineer and adapt stoves and services to local cooking requirements and conditions. Perhaps nowhere is the scale of this challenge greater than in India, the largest potential market for such technologies and one of the world's hot spots for biomass burning in inefficient cookstoves. Progress in India has been particularly slow with only several tens of thousands of stoves sold in each of 2011 and 2012, even though globally sales were in the millions (Colvin et al., 2013; GACC, 2012).

This paper explores how differences in attributes of biomass-burning ICS and characteristics of rural poor Indian households explain the variation in demand for four important features: price, number of cooking surfaces, amount of smoke emissions, and amount of fuel required. We analyze these preferences using data on revealed and stated preferences collected from 2,120 households located in two states – Uttar Pradesh (UP) and Uttarakhand (UK). Surveys provide basic information on household socio-demographics and on perceptions, ownership and use of different stoves and fuels, and therefore allow us to assess what types of households already use clean-burning stoves. All households also participated in a decision exercise in which they selected their preferred stove options in a series of discrete choice tasks; the analysis of these stated preference choices serves as the basis for assessing the heterogeneity in respondents' tastes (McFadden and Train, 2000).

Existing studies on the demand for ICS have largely ignored user preferences and focused on the demand for a single pre-selected technology with a specific set of features, or sought to isolate differences in demand by varying technologies across the arms of an experiment rather than allowing users to choose the technologies they prefer from a menu of options (Bensch and Peters, 2012). In the real world, however, households choose from an array of cooking technologies, of which biomass-burning ICS are only one of many potential options. An advantage of discrete choice preference elicitation is thus to allow consumers to explicitly consider the tradeoffs between stove alternatives with different levels of various ICS features.

Respondents select their preferred option in each of a series of choice tasks; analyzing the patterns underlying those choices then generates more complete information on the relative importance of different stove features within a sample of respondents.

Our paper makes several potential contributions to the design and implementation of energy policies for households in the developing world. First, we add to the thin literature on preferences for household energy products by being the first to examine how much key players in the ICS scale-up conundrum – rural Indian households – are willing to pay for specific ICS attributes such as reductions in emissions, inconvenience, and fuel needs. Second, by analyzing how choice patterns vary across different subgroups of our sample, we are able to see whether preferences appear to be related to observable household characteristics. Third, our regressions allow us to examine the degree to which these same observable household characteristics (e.g., socio-economic characteristics or risk preferences) are correlated with revealed preferences patterns in the data. These contributions collectively highlight important demand-side features: such features are critical for developing energy products and segmenting markets, and understanding them is necessary for wide spread dissemination and diffusion of ICS. Thus, our results regarding preference heterogeneity suggest that future ICS interventions must develop salient promotion messages and allow target beneficiaries to choose among products. Such a strategy is particularly salient for our study region where the energy use behaviors of nearly a quarter billion people potentially alter a range of local health, regional environment and global climate outcomes (Bhojvaid et al., 2014).

2. Methods

2.1. Research site and household sampling

We implemented a large-n survey with 2,120 households living in 66 Census-delineated villages in two states of India – Uttar Pradesh (UP) and Uttarakhand (UK) – to collect the data analyzed in this research. Geographical and social differences between UP and UK led to somewhat different sampling strategies in the two states. In UP, we worked in the main Gram Panchayat (GP) revenue village within the typical Census delineated-community and also sampled in 1-3 other randomly-selected satellite villages, depending on the size of the GP. Thirteen households were randomly selected in each sub-cluster using the right hand rule and selecting every n^{th} household (n was obtained by dividing sub-cluster population by 13, but did not exceed 8).

In UK, sub-clusters often contained only a handful of households. This created more variation in the number of sub-clusters sampled in each village. In small Census communities, a minimum of 20 surveys were collected; in medium ones 30; and in large 40. If a village was divided into distinct geographical sub-units (e.g., half the village was to the north of the main road, half the village was to the south), the target number of surveys was split equally among these units. Upon arrival in the village, total population was divided by the target number of surveys and every n^{th} household (no more than every 8th house) was surveyed until the target was reached. This strategy ensured that surveys were collected throughout the entire extent of the village. Interviews took place from June to early July in UP, and July to early August in UK.

Efforts were made to survey each randomly selected household. If they were unavailable on the day of fieldwork, or if they refused to participate, neighboring houses were randomly selected instead. Field supervisors performed household introductions, recorded GPS coordinates and elevation data, and oversaw quality control checks. The main household questionnaire was pre-tested prior to the initiation of fieldwork in approximately 200 households in UP (5 villages) and UK (4 villages). Respondents (both the male and female head of the household) answered questions on environmental and stove-related perceptions, household socio-demographics, stove and fuel use, and socio-economic characteristics, and participated in a stove decision exercise. Women answered questions related to socio-demographics, stove and fuel use, whereas men completed the decision exercise, socio-economic, and time and risk preference sections. Environmental and stove-related perceptions questions were randomized ahead of time to the male or female head of the household, subject to his/her availability (which was recorded on the survey form). If one of these two was unavailable for the survey, the other completed all sections. In this way, perceptions information was collected from 67% of primary cooks (always female), 25% from the head of the household (generally male), and 8% from both the male head of household and primary cook.

We asked all respondents to answer a series of hypothetical questions designed to elicit risk and time preferences. In the time preference module, respondents answered two hypothetical questions with a tradeoff between less money (1000 Rs. or roughly $20) received immediately (tomorrow) and more money (2000 Rs.) received after 12 months. For those selecting the former, the amount received later was increased to 2500 Rs. and the question was repeated. For those selecting the latter, the amount received later was decreased to 1500 Rs. In the risk module, respondents were presented with pairs of tradeoffs between a certain amount (500 Rs.) and a 50-50 chance of lesser and greater amounts with expected values of 600 Rs. first, 750 Rs. for those choosing the certain amount in the first question, and 500 Rs. for those choosing the uncertain amount in the first question.

2.2. The stove decision exercise

The attributes included in the stove decision exercise, and their levels, were selected following a series of eleven focus groups conducted with over 100 respondents in villages similar to sample villages (Table 1). Attributes eliminated due to lack of clarity or salience to respondents included time savings, operation and maintenance requirement, fuel loading approach, lifespan of the stove, and type of fuel allowed. We used SAS software to select efficient combinations of attribute levels for measuring main effects.

At the start of the stove decision exercise, the different stove alternatives (biomass-burning ICS or traditional stove) were described to respondents in detail, both orally and using pictures of the relevant technologies, and each of the attributes was explained by the enumerator using a specific script accompanied by pictorial representations. At the end of this description, all respondents completed a 4 question comprehension test. If a respondent answered any questions incorrectly, the relevant description was repeated and the enumerator again verified comprehension before proceeding. Next the respondent was reminded of his/her budget constraint, was told that the ICS options would last 3 to 5 years and cost roughly 250 Rs. per year to maintain, was assured that there were no right and wrong answers, and was reminded that the exercise was purely hypothetical. In each of four choice task completed during the survey, respondents were presented with two improved stove alternatives and the traditional stove option, and were asked to select their preferred option. An example of one such task, and important features of the design are summarized in Figure 1 and Table 1. Following each choice task, debriefing questions were asked to probe the decision-making process and assess the certainty of the respondent answers.

2.3. Analysis of discrete choice data

Discrete choice and conjoint methods are widely used to estimate consumer preferences for multi-dimensional goods and services for which well-developed markets may not yet exist (Carson et al., 1994; Hanley et al., 2001; Louviere et al., 2000). Though several applications of these methods exist for household energy demand and preferences for technologies that improve environmental health (Cai et al., 1998; Goett et al., 2000; Poulos et al., 2012; Snowball et al., 2008; Yang et al., 2007), only one study has been conducted for ICS (Johnson and Takama, 2012). That study considered average preferences for smoke reductions and safety improvements (burn and explosion risk reductions) for different income groups (low, middle, and upper-income) in small samples of respondents from three less-developed countries (Ethiopia, Tanzania and Mozambique). Unfortunately, it does not provide insight on whether households care more about specific features of ICS technologies (e.g. smoke, convenience, fuel use), and how these preferences for attributes vary by household type.

The framework for analysis of the discrete choice data collected in this study is based in random utility theory. We model the repeated household choices from among different combinations of alternatives that vary according to well-defined levels of 4 attributes: price, fuel requirement, smoke emissions, and number of cooking surfaces. The random utility model assumes that the indirect utility associated with a particular alternative can be written as a function of its attributes, and household characteristics:

$$U_{jt}^{i} = V^{i}\left(p_{jt}, \beta_0^{i}, X_{jt}, \beta^{i}, Z^{i}\right) + \varepsilon_{jt}^{i}\ , \qquad (1)$$

where:

U_{jt}^{i} = the utility of household *i* associated with cooking alternative *j* in a choice set, where *t* indexes the number of independent choice occasions;

$V^{i}(\cdot)$ = the non-stochastic portion of the utility function for household *i*;

p_{jt} = the price of cooking alternative *j* in task *t*;

β_0^{i} = a parameter which represents the marginal utility of money for household *i*;

X_{jt} = a vector of non-price attribute levels (including the alternative-specific constant or ASC for a specific technology) for cooking alternative *j* in task *t*;

β^{i} = a vector of parameters which represent the marginal utility for household *i* associated with the different non-price attributes of the alternatives;

Z^{i} = a vector of characteristics for household *i*; and

ε_{jt}^{i} = a stochastic disturbance term.

Assuming that households maximize utility within a given choice task, they will select alternative *j* from among the set of *K* alternatives presented to them if and only if alternative *j* provides a higher overall level of utility than all the other alternatives, i.e. if $U_{jt}^{i} > U_{kt}^{i}$ for all *j* in set *K*, where $j \neq k$, such that $V_{jt}^{i} - V_{kt}^{i} > \varepsilon_{kt}^{i} - \varepsilon_{jt}^{i}$. Assuming a linear specification of utility $U_{jt}^{i} = \beta^{i}X_{jt} + \beta_0^{i}p_{jt} + \varepsilon_{jt}^{i}$ and a Type 1 extreme-value error distribution for the disturbance term, the probability that alternative *j* will be selected from choice set *t* corresponds to the standard conditional logit model (McFadden, 1981). The model is estimated using maximum likelihood; the values of the coefficient values β_0^i and β^i are selected to maximize the likelihood that one would observe the choices actually observed in a given sample of respondents.

In this paper, we relax the restrictive assumption of the conditional logit that requires a set of fixed β coefficients, and instead apply a generalized multinomial (or random parameters, or mixed) logit model.[1] The mixed logit allows for unobserved heterogeneity in tastes across individuals, by specifying household-specific stochastic components η^i for each of the estimated coefficients β in the model. The probability that alternative *j* will be selected from choice set *t* can be written:

$$\text{Prob}[C^i = (C_{j1}^i, \dots, C_{jT}^i)] = \prod_{t=1}^{T} \frac{\exp\left[V_{jt}^i(\beta^*)\right]}{\sum_{\mathrm{k}=0}^{\mathrm{K}}\left[V_{kt}^i(\beta^*)\right]}, \tag{2}$$

where $\beta^* = \left(\beta + \eta^i\right)$. The stochastic portion of utility includes an individual-specific η^i term, which flexibly accommodates correlations both across alternatives and choice tasks. The coefficients β^* are estimated using simulated maximum likelihood (Revelt and Train, 1998), and we explore the implications of different distributional assumptions (normal and lognormal) for η. The ratios of coefficients derived from the model then yield the marginal utility to individual *i* for an additional unit of a particular attribute, in money terms.

2.4. Data and study hypotheses

Using the data available from the detailed household survey, we consider the variation in preferences for household cooking technologies across different groups in our sample. In the results, we first consider the correlates of use of non-traditional stoves such as LPG. We then present full sample outcomes from the stove decision exercise (conjoint exercise) and other preference questions, based on two measures of demand. The less conservative analyses include all preferences expressed in the choice tasks, specifically responses to the question: "Which stove do you prefer: Improved Stove 1, Improved Stove 2, or Traditional Chulha?"[2] The more conservative treatment of demand for improved alternatives in addition requires a "Yes" response to the follow-up question: "If you had the possibility to purchase this stove at the price stated, would you be willing to make that purchase, if the payment was required at the time of purchase?" In the conservative analysis, we also exclude the roughly 15% respondents who failed to correctly answer any one of the four comprehension questions. In the results, we compare these more and less conservative responses only for the full-sample analysis, and

[1] There are several problems with the conditional logit. First, individual characteristics do not naturally appear in the calculation of choice probabilities, since they are invariant across choice tasks. Second, the independence of irrelevant alternatives (IIA) assumption of the model requires that the ratio of probabilities for any two alternatives be independent of the attribute levels in other alternatives within a choice set. Finally, conditional logit models do not account for correlation across respondent choices, and assume that all differences in individual tastes are accounted for by the model specification that relates choice probabilities to attributes.

[2] Prior to this question, all respondents were reminded to consider their household budget carefully when choosing their preferred options. The specific text in the questionnaire was: "There are no wrong or right answers to these questions. When you make your choice, keep in mind your household budget and your other financial constraints. You should consider carefully whether the benefits of an improved stove would be worth paying for their cost, in terms of stove cost and maintenance requirement. Remember that the improved stoves last 3 to 5 years and cost about 250 Rs. per year to maintain."

thereafter present the more conservative estimates, which we consider more reliable and less subject to hypothetical bias (Murphy et al., 2005).

We also consider in more detail whether the demand for stove attributes or type might be related to observable respondent characteristics, by interacting attribute levels and the ASC with dummy variables for a particular class of characteristics (e.g., respondent gender, geography, existing ownership and knowledge of clean stoves, and patience and risk aversion as derived from the hypothetical tradeoffs described in Section 2.1).

3. Results

3.1. Household characteristics, baseline cooking behaviors, and awareness of improved stoves

The household survey data are summarized in Table 2. In 64% of surveys, the respondent for all questions was a woman (primary cook and/or female head of household). Interviews with the remaining 36% generally included both a male head of the household and the primary cook, depending on the questions being asked (see Methods). The average household size at the time of the survey was 5.3 people. Most households in the sample (and all in UK) are Hindu, and about 15% in UP are Muslim. Overall, 51% of households are in the open/general caste category, 27% are scheduled caste, and 20% are in other backward castes.

Sample households are generally rural, poor, and primarily agricultural. Over half of the survey population reported being below the poverty line (36% reported being above the poverty line; and 9% do not know or refused to answer), and 81% of households own their own cropland. Thirty percent do not have electricity (55% of surveyed households in UP are in this category), and only 12% report having electricity all the time (0% in UP). Twenty-nine percent of households reported having at least one person sick with a cough or a cold in their household in the two weeks prior to the survey, and 28% of these had several sick persons (overall prevalence of respiratory illness was 9.4%). Among sample respondents, reported rates of disease were higher in UP than in UK.

At the time of the interviews, sixty percent of households had a single pot traditional mud stove (*mitti ka chulha* or *anghiti*), and another 10% had a multiple pot traditional stove. Other stoves owned by households included the traditional 3-stone stove (24%), LPG stove (20%), traditional metal sagarh stove (10%). A few households had kerosene pump stoves (17 households) or biogas stoves (11 households). The average number of stoves owned by each household was 1.16. Nearly all (93-98%) households owning LPG and traditional stoves reported using these in the week prior to the survey, and almost all LPG-owning households were stackers (only 7% of these did not also use their traditional stoves on a daily basis). In UK, households reported total stove use time to be 5.7 hours/day; in UP this average was 2.1 hours per day.[3] Respondents identified that the three best aspects of traditional stoves were (ranked in order): the taste of the food (87%), the cost of the stove (48%), and the ability to cook all foods (11%). The four worst features identified were the smoke that is produced (75%), the heat given off by the stove (36%), the cleaning requirements (27%), and the amount of fuel required (20%).

[3] The timing of the surveys, and climatic conditions, were somewhat different in these two locations. In UP, surveys were mostly conducted during the hot and early monsoon season (in June and early July), whereas in UK, surveys took place during the monsoon season.

The most commonly used fuels by households, many of whom regularly used multiple types, were firewood (97%), dung (40%; 78% in UP), LPG (19%, 9.6% in UP) and kerosene (15%; 22% in UP), the latter primarily as a lighter fluid (i.e., to start fires).[4] Seven percent of households reported burning crop residues or twigs (14% in UP), and 2% used leaves. Nearly all users of firewood and dung had such fuels in their house at the time of the interview (99% and 98% for these, respectively); 85% and 80% of households using LPG and kerosene had some on hand, respectively.

The main respondent in each household was asked whether he/she had heard or knew about each of three negative impacts of traditional stoves and biomass fuels, on health, on local forests, and on air quality and/or climate. Awareness of the negative health effects was highest (68%), followed by local environment and forests (54%), with only 38% recognizing outdoor air pollution and/or climate change. Women or primary cooks reported greater awareness of these three types of impacts. Awareness of health impacts was greater in UP, whereas awareness of environmental impacts was higher in UK. Knowledge of ways to mitigate impacts was more limited. Only 39% of respondents had heard of stoves that produce less smoke than others at the time of the interview, and only 41% believed that some fuels produce less smoke than others when burned. Thirty-three percent of respondents believed their actions could have medium or large effects for mitigating either health (22%), local forest (23%), or global climate impacts (13%).

3.2. Factors associated with the use of alternatives to traditional stoves

We present two probit regressions related to the use of alternatives to traditional stoves in our sample: a) ownership of clean-burning stoves (LPG, kerosene, biogas or biomass-burning ICS); and b) reported use of such stoves in the week prior to the survey (results from OLS regressions with alternative measures of use, e.g., hours of cooking on clean stoves or % of total cooking time using clean stoves, were not substantively different). Though we cannot claim causal relationships due to the cross-sectional nature of these data, cleaner stove ownership or use is positively associated with higher socio-economic status (e.g., higher reported relative wealth, general caste status, higher head of the household education, and higher expenditures, though the latter is not statistically significant) and is higher in households who believe that clean stoves or fuels can have a positive effect on health, the local environment, or air quality / climate (Table 3). Households with older or female household heads and with greater numbers of young children are more likely to own and use clean stoves and fuels, as are those reporting higher costs of firewood, perhaps because they gain more from conserving fuel or because they are wealthier.[5] Larger households and households located in villages with higher costs of LPG, on the other hand, are somewhat less likely to own a clean stove. Finally, we find a negative association for ICS ownership and use with risk-taking preferences, using responses to the hypothetical gambles described in Section 2.1.

3.3. Preferences for ICS: Results from analysis of discrete choice data

[4] There may have been underreporting of kerosene if households did not consider this use as a lighter fluid as warranting mention in the fuels survey.

[5] Reported village-level costs for firewood varied from 280 to 1315 Rs. (or $5.4 to $25.30) per quintal (100 kg).

The coefficients for different specifications of the logit models for the responses to the stove decision game all have the expected signs: alternatives with higher prices, emissions and fuel requirements were less likely to be selected by respondents, whereas alternatives with a greater number of cooking surfaces were more likely to be selected (Table 4). In addition, the standard deviations for all random parameters are highly significant, suggesting that preferences are highly variable. Using the most conservative measure of stated demand – for which households were asked to confirm their WTP for the upfront cost of their favored option – approximately doubles the respondents' estimated price response and reveals a strong predilection to opt for a traditional stove (as indicated by the large positive coefficient for the traditional stove alternative). This is in contrast to a less conservative measure which simply asked respondents to indicate their preferred option without confirming their willingness to purchase it. The implied marginal WTP obtained from the conditional logit and the two specifications of the mixed logit model (with normal and lognormal random parameters for price) are only similar in this conservative model specification. The differences between the implied WTP from the lognormal and normal specifications of the mixed logit model using the less conservative measure of demand suggest that these coefficient estimates may be sensitive to responses in the tails of the distribution, perhaps due to yeah-saying at high ICS prices.

In the overall sample, comparison of the part-wise utilities for a single unit change in the levels of the various attributes suggests that a 33% reduction in smoke emissions (equivalent to 1 unit in the stove decision game) is most valuable to households on average, followed by the addition of one extra cooking surface and finally a one-unit (33%) decrease in fuel requirements (Figure 2). The large coefficient on the traditional stove type (i.e., the alternative-specific constant) indicates an average preference for traditional stoves that outweighs the value of a 1-unit reduction in smoke emissions plus fuel consumption by a factor of 2; the implication is that many respondents would likely need to see large reductions in these levels or otherwise be strongly lobbied to see value in adopting an improved stove. However, given the heterogeneity detected by the random parameters model, it should not be surprising that the overall sample results mask important variation in this attribute ranking. Sub-group analysis along other dimensions – gender, geography (state), and baseline stove use – shows that a variety of observable characteristics of households are in fact correlated with these preferences (Table 5). Most of the sub-group heterogeneity is concentrated on the price, smoke and fuel use attributes, and less on the number of pots or stove type.

In addition, though considerable heterogeneity remains in each of the subgroups, women respondents appear to be more price responsive, by 26-33% relative to the average (Columns A and B). The price coefficient for respondents from female-headed households is not significantly different from that of male-headed households, however, their WTP for other attributes is lower (i.e. the estimated coefficients for the other attributes are lower than the average). There is a roughly 20% stronger preference for traditional stoves among households in UK, who also place less emphasis on the other attributes and have lower implied WTP for all attributes (especially fuel requirement and smoke emissions reductions), compared to those in UP (Column C). Households already owning clean stoves are less price responsive and place reduced weight on traditional stoves (by about 30%), but also value reduced smoke emissions less by about 20% (Column D). Interestingly, households that were aware of clean-burning stoves had lower demand for the improvements promised by the biomass-burning ICS options (Column E); this is consistent with the regression results in Table 3 and may reflect dissatisfaction with clean stoves among such households. Households in the lowest expenditure quartile of the sample have stronger preferences for traditional stoves (by more than 50% relative to the rest of the sample).

We also considered the choices made by respondents with different expressed risk and time preferences, using the same method applied above, and found that more patient and more risk-taking households were generally less price sensitive than others (Columns F and G). However, these households also placed greater weight on the traditional stove options, and risk-taking households in addition valued reduced smoke emissions at only about one third the level of the average household.

4. Discussion

The heterogeneity in perceptions, behaviors and ICS preferences presented in our analysis highlights a set of important demand-side factors that should be considered by institutions seeking to promote household energy products such as ICS. The implications of such heterogeneity may be partly responsible for the contradictory findings articulated in recent studies discussing the demand for biomass-burning ICS, as well as the benefits they deliver (Bensch and Peters, 2012; Hanna et al., 2012; Levine and Cotterman, 2012; Mobarak et al., 2012). We argue that the confusing picture emerging from such studies suggests the need for more careful consideration of household preferences and the mechanisms of adoption in stove (and other environmental health) interventions, and calls for more appropriate and targeted approaches (Shell Foundation, 2013; Singh and Pathy, 2012). Indeed, those pursuing efforts to scale up ICS interventions must acknowledge and strive to understand and adapt to the range of incentives, constraints, and preferences facing specific communities and households (Pattanayak and Pfaff, 2009).

We considered evidence of this heterogeneity using approaches based on revealed and stated preferences. Our analysis of the revealed preference data – on current ownership and use (mostly of LPG stoves) – provides descriptive evidence on the statistical associations between a range of household characteristics and fuel or stove-related factors. This evidence contributes to a small but growing literature on the determinants of adoption of cleaner cooking technologies ((Lewis and Pattanayak, 2012). We find that adoption of clean technologies is positively correlated with relative wealth and education, and negatively correlated with household size, perhaps because it is difficult to cook for many people on ICS or because household size itself is correlated with lower socio-economic status. ICS owners are also more likely to believe that their actions can mitigate the negative health or environmental effects of traditional cooking technologies. We also find higher rates of ownership and use of ICS among rural households interviewed in UK (where 31% own ICS) than in surveyed areas of UP (where 12% own ICS). Finally, female-headed households are more likely to own and use ICS (at 23%) compared with male-headed households (at 16%). Overall, these findings provide support to a growing consensus that affordability and unfamiliarity with ICS benefits are important barriers facing these technologies, and that existing models may not be suitable for some types of households or locations (Lewis and Pattanayak, 2012; Rehfuess et al., 2013).

We also adapted a stated preference method used in the marketing and planning literature to uncover patterns in household preferences for new biomass-burning stoves. These patterns reveal that survey households on average have a strong preference for traditional stoves and have greater WTP for smoke emissions reductions than for decreased fuel requirements or increased convenience (number of cooking surfaces). This average, however, masks important heterogeneity. Various sub-groups of households have very different opinions of ICS features, which is largely consistent with the findings on clean stove ownership discussed above. In particular, women respondents appear somewhat (26-33%) more price responsive on average, and female headed households have 30-40% lower WTP for ICS features, perhaps reflecting their greater financial constraints, or for female headed households, their greater likelihood of already having clean stoves. Poorer (lower-expenditure) households have a stronger preference for traditional stoves, again suggesting greater barriers to adoption among poor households, as has been found in other studies (Johnson and Takama, 2012). There is also a stronger preference for traditional stoves in UK, where households place less emphasis on smoke emissions and fuel reductions. These results may reflect the value of heating from traditional stove options in UK, where the winters are much colder due to high elevation. Households already owning clean stoves appear to place less weight (by about 20%) on additional reductions in smoke emissions, perhaps because they already possess a stove with lower emissions. Awareness of clean stoves is also related to lower demand, perhaps because such households were dissatisfied with the biomass-burning alternatives presented in the discrete choice experiment.

Finally, we find that typically unmeasured household characteristics such as risk and time preferences are correlated with both clean stove ownership and use, and with the stated preferences revealed by the DCE. In particular, more patient respondents are less price sensitive (by about 20-40%), perhaps reflecting the fact that they place greater relative weight on long-term health and fuel savings benefits than other households. Risk-takers, on the other hand, are less likely to both own and use ICS currently, care much less about smoke emissions, and are more price-sensitive. Additional study of the extent to which such inherent preferences can constrain adoption of ICS, and under what conditions, seems warranted.

We note that our findings were obtained from the population of two large north Indian states, whose households have their own peculiar cooking with traditional stoves and fuels. Though this study design limits the generalizability of our findings, it also provides several important advantages. First, combined, these states have a population of 210 million, roughly two-thirds the size of the entire US or 40 percent of all of EU. Second, the restricted range of the study meant that we were able to carefully prepare surveys that were relevant to the survey population, and well-tuned to our research objectives. This is particularly important for developing nuanced preference questions and methods in focus groups, and then testing them systematically through formal pre-tests. Second, though we cannot claim a representative sample from UP and UK, the generalizability of our findings, and the ability to consider important dimensions of contextual and preference heterogeneity, is enhanced by the fact that we deliberately sampled households in two very distinct geographical zones – the foothills of the Himalaya and the Gangetic plains – who faced different fuel and cooking realities. This strategy allowed us to exploit variation in factors such as the extent of LPG stoves ownership, the cost of fuel collection, and socio-economic status, that are highly relevant to demand for cleaner cooking technologies.

5. Conclusions and policy implications

If critical environmental and health goals are to be achieved, household energy needs must be addressed, especially those related to reductions of biomass fuel use by households in developing countries, via changes in cooking technology and user behavior. To consider the potential of such changes, this paper explored preferences for existing and potential improved cooking technologies in a large and diverse sample of households living in northern India, which is a global hotspot for climate-damaging emissions and unsustainable harvesting of biomass fuels. Widespread adoption and use of ICS in this and similar locations remains elusive, and markets for such technologies are currently thin or nonexistent. For example, while hundreds of millions of Indian households own and use traditional stoves, only several tens of thousands of stoves were sold in the country during 2011 and 2012 (Colvin et al., 2013; GACC, 2012).

Analysis of data on household energy choices, especially stove ownership, shows that ICS (nearly all LPG stoves) are owned by only about 20% of households, who have greater wealth, education and smaller families compared to non-owners. The analysis of preferences further suggests that there is significant unmet demand for the purported benefits of ICS, which is somewhat tempered by households' strong predilection to use traditional stoves. On average, survey respondents were willing to pay (WTP) about $10 and $5 for realistic reductions in smoke emissions and fuel needs, respectively, which is nearly equal to the manufacturing cost of a cheaper biomass ICS. This average demand nonetheless masks considerable variation in willingness to pay. In particular, demand for biomass-burning ICS is lower (greater) among poorer households, women, and in households who already own a clean stove or are less risk averse. Traditional stoves also have important advantages in providing heat in the mountainous location in our survey. Our analysis therefore provides a nuanced understanding of the potential for adoption of clean stoves in the survey communities, and suggests that widespread dissemination would likely only be achieved with additional intervention (e.g., social marketing or price reductions) designed to stimulate demand. This conclusion is also supported by the fact that biomass-burning ICS technologies have achieved zero penetration in markets in our study sites. This absence suggests that the latent demand has not yet proven sufficient to overcome the significant supply-side challenges of reaching remote rural areas, and that supply cost may therefore need to be reduced if the market for ICS is to take off.

In conclusion, our results suggest that many households exhibit cautious interest in the promise of new energy products and services, but that there remain significant supply and demand-side barriers to achieving their widespread diffusion. Perhaps because of distribution and transaction costs in setting up a market for products such as ICS, the existing unmet demand for alternative cooking technologies in our study sites has not been sufficient to motivate development of the required supply chain for their delivery. Given the lack of previous research on the importance of preferences, part of the problem may be that previous costly promotion efforts have not been sufficiently tailored to the households who are most likely to adopt these new technologies. In addition, motivating the large numbers of households who are skeptical or disinterested in ICS would likely require intensive promotion and marketing, for which the business case is unclear. If objectives to quickly scale up ICS are to be met, therefore, the policy community must work towards a reinvigorated supply chain and empowerment of micro-institutions seeking to promote ICS. Such an effort could (a) foster or subsidize small-scale experimentation that is sensitive to the diversity of preferences for product attributes such as price, emissions, and fuel needs, and (b) enhance profitability by contributing to research that would help segment the market based on characteristics such as education, experience, wealth and location. Only then will ICS allow for improvement of household health and regional environmental outcomes, and the capture of short-term global climate gains.

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Tables and Figures

Table 1. Summary of discrete choice experiment design

Attributes	Levels	Traditional stove level
Price (Rs.)[a]	500 1000 2500	0
Required fuel amount	1 3 4	3
Smoke emissions	Low High Highest	Highest
Number of cooking surfaces	1 2	1

Notes: [a] $US ≈ 52 Rs.

Table 2. Sample descriptive statistics

	Overall		UP		UK	
Variable	Mean (s.d.)	N	Mean (s.d.)	N	Mean (s.d.)	N
Below poverty line	64%	1918	71%	888	57%	1030
Relative wealth: 6 step perception scale	2.0 (0.9)	2117	1.8 (0.9)	1056	2.1 (0.8)	1061
# Rooms	3.6 (2.3)	2111	2.7 (1.7)	1051	4.6 (2.4)	1060
Toilet use/ownership	47%	2120	8%	1057	85%	1063
Head of household						
Is female	18%	2095	8%	1041	27%	1054
Age (years)	50 (14)	2083	47 (14)	1035	53 (14)	1048
Education (years)	5.0 (4.8)	2082	4.1 (4.9)	1038	5.8 (4.6)	1044
Respondent						
Household head	54%	2120	55%	1057	53%	1063
Primary cook	83%	2120	88%	1057	77%	1063
Only female respondent	64%	2092	56%	1039	73%	1053
Caste type						
General	49%	2120	26%	1057	72%	1063
Scheduled caste	26%		27%		24%	
Scheduled tribe	1%		1%		1%	
Hindu	93%	2118	85%	1055	100%	1063
Household size	5.3 (2.4)	2120	5.7 (2.7)	1057	4.8 (2.1)	1063
# Children under 5	0.5 (0.8)		0.5 (0.8)		0.5 (0.8)	
% with respiratory disease, past 2 wks	9%	2120	11.5%	1057	7.3%	1063
Most patient	33%	2078	18%	1037	48%	1041
Most risk-taking	29%	2069	15%	1023	42%	1046
Electricity:						
Constant	12%	2080	0.2%	1050	24%	1030
Intermittent	56%	2080	45%	1050	69%	1030
If intermittent, hours/day supply	14.4 (7.6)	1443	6.7 (3.2)	469	18.1 (6.1)	974
Took a loan in past year	14%	2120	13%	1057	15%	1063
Stove ownership						
Traditional stove[a]	97.4%	2120	97.6%	1057	97.3%	1063
LPG stove	20.0%		11.4%		28.5%	
Kerosene	0.8%		0.0%		1.2%	
Biogas	0.5%		0.0%		1.0%	
Median use among owners (hrs/day)						
Traditional stove	3.3	2066	1.6	1032	5	1034
LPG stove	3.1	423	4.2	120	2.6	303
Kerosene	0.7	15	-	0	0.8	13
Biogas	1.6	11	-	0	1.6	11
Fuel use						
Firewood	96.6%	2120	95.8%	1057	97.4%	1060
Crop residue	7.1%		14.1%		0.2%	
Dung	39.2%		78.5%		0.2%	
Kerosene	15.1%		22.0%		8.2%	
LPG	18.8%		9.6%		27.8%	
Electricity	0.5%		0.4%		0.6%	
Biogas	0.5%		0.0%		0.9%	
Fuel Price						
Price LGP cylinder (in 1000 Rs.)[b]	0.48 (0.1)	2120	0.5 (0.1)	1057	0.45 (0.06)	1063
Report high fuel price	0.55 (0.5)		0.55 (0.5)		0.55 (0.50)	
Awareness of impacts of traditional stoves						
Health	68.2%	2120	74.8%	1057	61.7%	1063
Local forests/environment	54.1%		49.7%		58.4%	
Air quality/climate change	38.5%		38.4%		38.7%	
Aware of clean stoves	39.4%	2120	53.8%	1057	25.1%	1063
Aware of clean fuels	41.3%	2120	51.7%	1057	31.0%	1063

Notes: [a] Traditional stoves include: mitti ka chulha (mud stove), anjeti, 3-stone fire, and sagarh (coal stove).
[b] At the time of the baseline survey in 2012, US$1 = 52 Rs.

Table 3. Clean stove ownership and use[a]

Variable	**A.** Own clean stove Probit		**B.** Used clean stove (past wk) Probit	
	Coef.	St.Err.	Coef.	St.Err.
Relative wealth	0.54***	0.07	0.51***	0.07
log(Expenditures)	0.09	0.07	0.10	0.07
# Rooms	0.05**	0.02	0.05**	0.02
Head of HH education	0.05***	0.01	0.05***	0.02
Primary cook education	0.05***	0.01	0.04***	0.01
General caste	0.11	0.12	0.17	0.13
HH size	-0.09***	0.02	-0.08***	0.02
# Children under 5	0.15**	0.06	0.15**	0.06
HH took loan in past year	0.03	0.13	-0.02	0.15
Female respondent only	0.12	0.08	0.07	0.08
Female-headed HH	0.33***	0.11	0.39***	0.12
Age of head of HH	0.01***	0.00	0.01**	0.00
Hindu	0.20	0.21	0.23	0.26
Report high price of fuelwood	0.18**	0.09	0.17**	0.09
Price LPG	-3.36***	0.72	-3.20***	0.74
Uttar Pradesh (state dummy)	0.75***	0.17	0.71***	0.18
Awareness of clean stoves	-0.19	0.14	-0.17	0.15
Can have medium/high impact	0.29**	0.13	0.20	0.14
HH uses/owns toilet	1.17***	0.16	1.25***	0.16
Most patient	0.04	0.10	0.01	0.09
Most risk-taking	-0.24***	0.09	-0.22**	0.09
Constant	-2.67***	0.76	-2.90***	0.81
Observations	1,830		1,828	
Pseudo-R^2	0.350		0.352	

Notes: [a] *** p<0.01, ** p<0.05, * p<0.1; standard errors clustered at the hamlet level

Table 4. Results for basic discrete choice models[a]

Variable	**A.** All choices Conditional logit		**B.** All choices Mixed logit normal st.errs.		**C.** All choices Mixed logit lognormal st.errs.		**D.** "Would pay upfront" choices[b] Conditional logit		**E.** "Would pay upfront" choices[b] Mixed logit normal st.errs.		**F.** "Would pay upfront" choices[b] Mixed logit lognormal st.errs.	
	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.
Coefficient estimates												
Price (Rs)[c]	-0.0004***	0	-0.0007***	0	1.34***	0.073	-0.0005***	0	-0.0014***	0	0.56***	0.087
St. dev. - Price			-0.0006***	0	1.06***	0.061			0.0013***	0	1.65***	0.072
Fuel requirement	-0.23***	0.015	-0.46***	0.025	-0.46***	0.025	-0.155***	0.018	-0.41***	0.031	-0.40***	0.030
St. dev. – Fuel			0.36***	0.046	0.36***	0.047			0.27***	0.071	0.28***	0.064
Smoke emissions	-0.48***	0.034	-0.96***	0.055	-0.96***	0.055	-0.378***	0.043	-0.80***	0.073	-0.85***	0.065
St. dev. – Smoke			0.58***	0.12	0.52***	0.12			0.39*	0.22	0.049	0.23
Number of pots	0.50***	0.033	0.89***	0.052	0.88***	0.051	0.261***	0.042	0.54***	0.064	0.56***	0.062
St. dev. – Pots			0.44**	0.19	0.44***	0.16			0.072	0.27	0.25	0.18
ASC – Traditional stove[d]	0.19***	0.062	-3.79***	0.34	-4.37***	0.38	1.340***	0.081	2.57***	0.23	1.72***	0.23
St. dev. – ASC			9.43***	0.52	9.62***	0.53			5.07***	0.24	5.39***	0.27
WTP for unit increase ($US)												
Fuel requirement	-$10.1		-$11.6		-$16.5		-$6.2		-$5.6		-$6.6	
Smoke emissions	-$21.4		-$24.0		-$34.3		-$15.1		-$11.0		-$14.0	
Number of pots	$22.2		$22.3		$31.6		$10.4		$7.4		$9.1	
Traditional stove	$8.6		-$95.1		-$157.1		$53.5		$35.3		$28.1	
Observations	25329		25329		25329		21459		21459		21459	
Pseudo R^2	0.056						0.1734					
Likelihood ratio (χ^2)			4897.8		4915.0				3458.6		3567.1	

Notes: [a] ***Significant at 1% level **Significant at 5% level *Significant at 10% level
[b] Model excludes respondents who answered any one of four comprehension questions incorrectly prior to the first choice task.
[c] Price coefficient was rescaled for lognormal model to have a positive coefficient (price in Rs. was divided by -500).
[d] Traditional stove = 1 if it was the traditional stove, 0 if improved.

Table 5. Results for mixed logit sub-sample analyses[a]

Variable	**A.** Female respondent		**B.** Female hh head		**C.** State		**D.** Improved stove		**E.** Aware of clean stoves		**F.** Patient		**G.** Risk-taking	
	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.	Coef.	St.Err.
Price (Rs)	-0.0014***	0.0001	-0.0015***	0.0001	-0.0017***	0.0001	-0.0015***	0.0001	-0.0009***	0.0001	-0.0016***	0.0001	-0.0015***	0.0001
Price x female	-0.0002	0.0002												
Price x female hh			0.0003	0.0002										
Price x UK					0.0006***	0.0001								
Price x improved stove							0.0003*	0.0002						
Price x aware									-0.0012***	0.0002				
Price x patient											0.0007***	0.0001		
Price x risk-taking													0.00033**	0.00016
Fuel requirement	-0.50***	0.048	-0.45***	0.033	-0.62***	0.042	-0.42***	0.034	-0.34***	0.035	-0.47***	0.037	-0.44***	0.033
Fuel x female	0.13**	0.062												
Fuel x female hh			0.20***	0.076										
Fuel x UK					0.45***	0.060								
Fuel x improved stove							0.063	0.067						
Fuel x aware									-0.14**	0.06				
Fuel x patient											0.17**	0.069		
Fuel x risk-taking													0.098	0.08
Smoke emissions	-0.89***	0.11	-0.89***	0.072	-1.16***	0.095	-0.94***	0.075	-0.66***	0.08	-0.75***	0.097	-0.91***	0.077
Smoke x female	0.17	0.14												
Smoke x female hh			0.39**	0.17										
Smoke x UK					0.91***	0.15								
Smoke x improved stove							0.39***	0.15						
Smoke x aware									-0.42***	0.14				
Smoke x patient											0.13	0.17		
Smoke x risk-taking													0.67***	0.2
Number of pots	0.73***	0.10	0.60***	0.071	0.69***	0.086	0.53***	0.073	0.42***	0.078	0.60***	0.077	0.57***	0.072
Pots x female	-0.28**	0.13												
Pots x female hh			-0.32*	0.17										
Pots x UK					-0.26**	0.13								
Pots x improved stove							-0.034	0.15						
Pots x aware									0.27**	0.13				
Pots x patient											-0.12	0.15		
Pots x risk-taking													-0.093	0.17
ASC – Type of stove[b]	2.19***	0.30	2.64***	0.22	2.64***	0.265	2.73***	0.23	2.35***	0.23	2.31***	0.23	2.30***	0.21
ASC x female	0.44	0.43												
ASC x female hh			-0.62	0.45										
ASC x UK					-0.19	0.37								
ASC x improved stove							-1.12***	0.42						
ASC x aware									0.80**	0.4				
ASC x patient											1.37***	0.47		
ASC x risk-taking													0.79	0.59
Observations	20844		20877		21459		20991		21459		21102		20991	
Likelihood ratio (χ^2)	3369.3		3365.7		3512.2		3359.5		3474.5		3408.6		3369.2	

Notes: [a] ***Significant at 1% level **Significant at 5% level *Significant at 10% level; Model excludes respondents who answered any one of four comprehension questions incorrectly prior to the first choice task.
[b] Type of stove ASC = 1 if it was the traditional stove, 0 if improved.

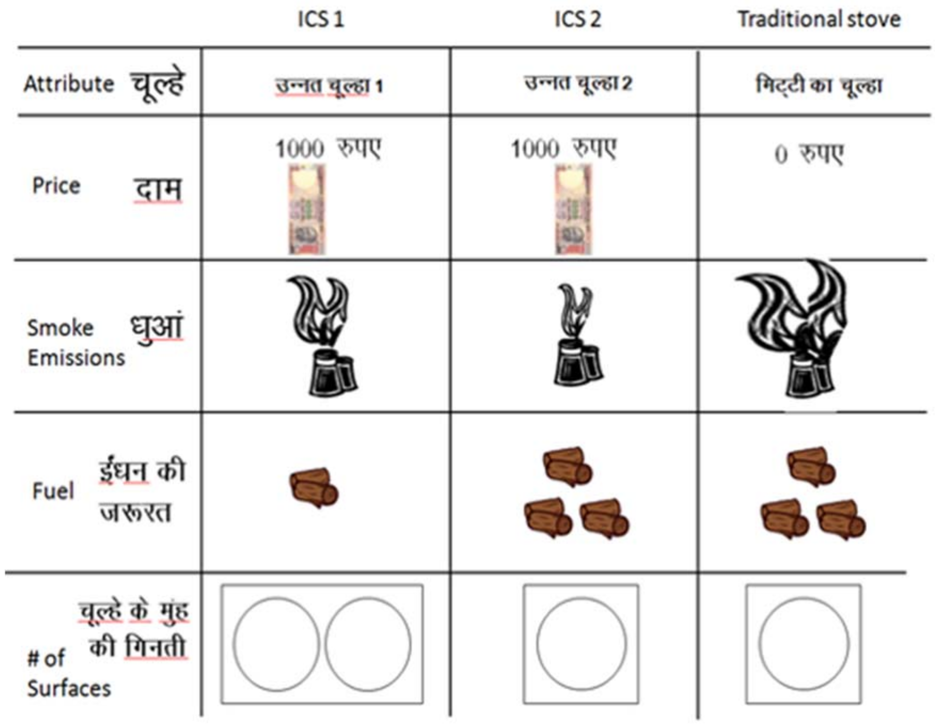

Figure 1. An example choice task in the stove decision exercise

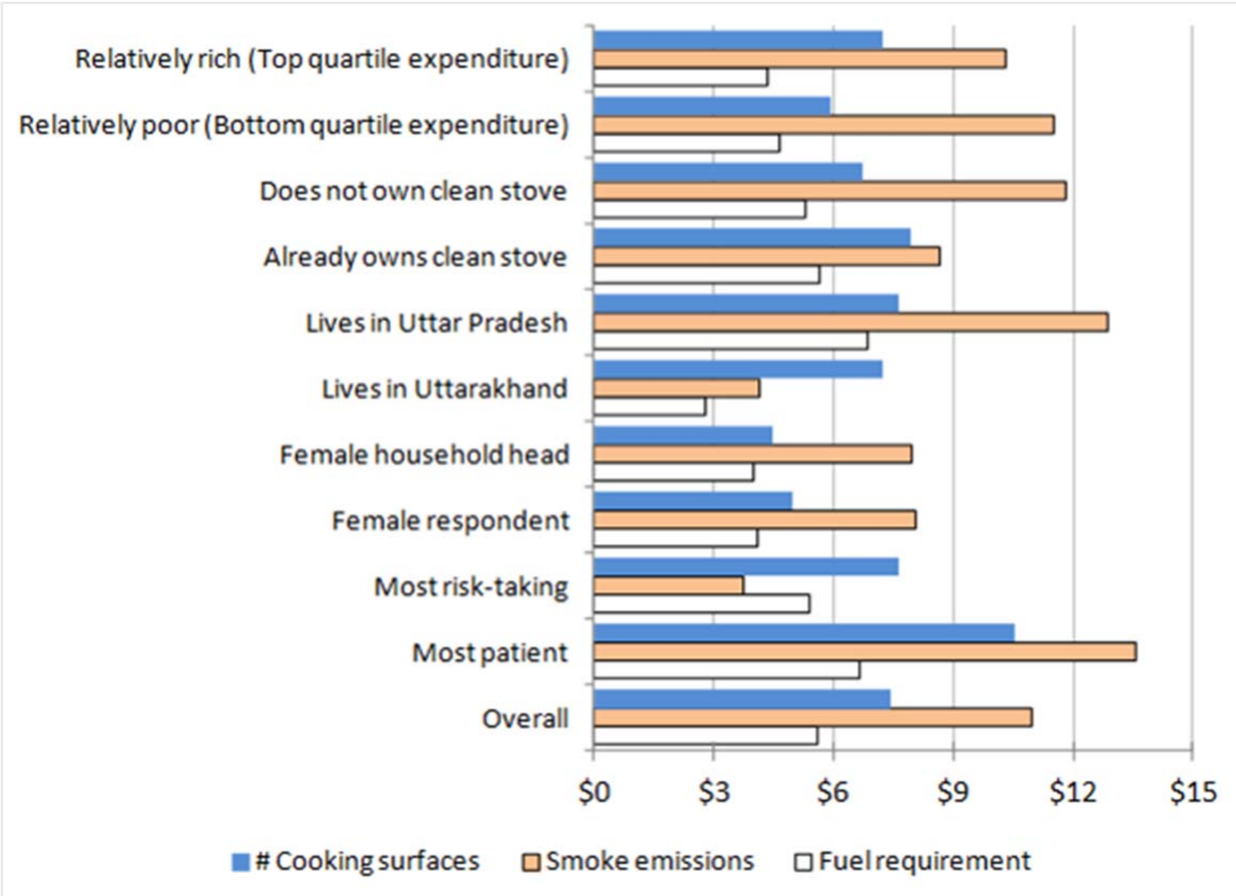

Figure 2. Willingness to pay for 1-unit changes in stove attribute levels among different sample sub-groups (Notes: 1 unit corresponds to a 33% decrease for smoke emissions and fuel requirement, and 1 additional cooking surface)