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Preferences for improved cook stoves: Evidence from rural villages in north India

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ABSTRACT

Because emissions from solid fuel burning in traditional stoves impact global climate change, the regional environment, and household health, there is today real interest in improved cook stoves (ICS). Nonetheless, surprisingly little is known about what households like about these energy products. We report on preferences for biomass-burning ICS attributes in a large sample of 2120 rural households in north India, a global hotspot for biomass fuel use and the damages that such use entails. Households have a strong baseline reliance and preference for traditional stoves, a preference that outweighs the $10 and $5 willingness to pay (WTP) for realistic (33%) reductions in smoke emissions and fuel needs on average, respectively. Preferences for stove attributes are also highly varied, and correlated with a number of household characteristics (e.g. expenditures, gender of household head, patience and risk preferences). These results suggest that households exhibit cautious interest in some aspects of ICS, but that widespread adoption is unlikely because many households appear to prefer traditional stoves over ICS with similar characteristics. The policy community must therefore support a reinvigorated supply chain with complementary infrastructure investments, foster experimentation with products, encourage continued applied research and knowledge generation, and provide appropriate incentives to consumers, if ICS distribution is to be scaled up.

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). These fuels are often burned in cheap but highly polluting traditional stoves. Inefficient biomass fuel burning has been implicated in climate change, and also harms regional air quality, local forest environments, and household health (Bruce et al., 2006; Ezzati and Kammen, 2001; Martin et al., 2011; Ramanathan and Carmichael, 2008). These various ills have prompted great interest in, and a new push towards development and dissemination of more efficient and cleaner-burning improved cook stoves (ICS) (GACC, 2010; World Bank, 2013).[1]

Much 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 global climate change. Black carbon emissions from the use of traditional biomass cook stoves and diesel engines are considered to be the second largest contributor to global warming (Ramanathan and Carmichael, 2008). Research from villages in northern India located near our study sites has demonstrated that ambient black carbon concentrations increase during periods of

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[1] We use this term "improved cook stoves" (ICS) to refer to a broad set of more efficient technologies, which include stoves that rely on cleaner-burning fuels (e.g., gas or electricity), as well as more efficient biomass-burning options. When we wish to distinguish the biomass-burning class of ICS from technologies that rely on cleaner fuels, we use the term "biomass ICS".

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intensive traditional mud stove use (Praveen et al., 2012; Ramanathan and Balakrishnan, 2007). This research has also shown 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 interest in how traditional stoves contribute to global 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; Jagger and Shively, 2014). Household air pollution is thought to kill more than 4 million people each year, and is today the leading cause of death in South Asia (Lim et al., 2013). In addition, ICS dissemination is increasingly viewed as a potential mechanism for reducing problems of energy access (i.e., energy poverty) in poor countries (Birol, 2007; Pachauri and Spreng, 2011).

Yet despite the very large health risks associated with traditional stoves and previous distribution efforts, adoption of cleaner burning biomass stoves has been slow, and new technologies have not reached scale (Barnes et al., 1994). Beyond well-known problems of high costs and a weak supply chain, researchers and practitioners have claimed, without systematic evidence from rigorous field studies, that ICS prototypes have not been sufficiently adapted to local cooking requirements and user preferences (GACC, 2011; Lewis and Pattanayak, 2012; Shell Foundation, 2013; Singh and Pathy, 2012; Whittington et al., 2012). Meanwhile, more widely accepted technologies such as liquefied petroleum gas (LPG) and electric stoves remain costly for many households, and lack a robust and strong supply chain in rural areas. Such technologies are therefore more typically subject to stacking (alongside traditional stoves) rather than switching (Heltberg, 2004; Masera et al., 2000).

In response to these observations, field-based empirical research has begun to raise important questions about diffusion and dissemination strategies for ICS, and particularly for higher-efficiency biomass stoves. While there is some evidence of limited demand for such stoves (Larson and Rosen, 2002), recent and notable studies from East and West Africa reveal successful promotion under some conditions, at least in the short-term (Bensch and Peters, 2015; Levine et al., 2013). In fact, the debate over demand for ICS parallels a discussion in the broader literature on adoption of environmental health improvements. First, while demand is often low, it is driven by 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, the heterogeneity in tastes and constraints across communities and individuals translates into substantial variation in the real costs and benefits of ICS (Whittington et al., 2012; Jeuland and Pattanayak, 2012). 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 over technological performance, risk aversion and impatience all influence decisions about whether or not to adopt an unknown technology (Beltramo et al., 2015; Tarozzi et al., 2014). This and the other two reasons described above can explain the low rates of adoption and continued 'stacking', instead of switching to ICS. 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 hotspots for biomass burning in inefficient cook stoves (Smith, 2000). Progress in India has been particularly slow, even as global sales have sharply increased (GACC, 2012; Lewis et al., 2013).

This paper explores the demand for ICS using revealed and stated preference data collected from 2120 households located in two states – Uttar Pradesh and Uttarakhand. We analyze cross-sectional survey data that provides basic information on household socio-demographics and on perceptions, ownership and use of different stoves and fuels. This allows us to assess what types of households already use ICS, which in this sample are almost exclusively LPG stoves. We then use a discrete choice experiment (DCE) to consider how respondents value four different attributes of a hypothetical biomass-burning ICS: price, number of stove openings (i.e., burners), amount of smoke emissions, and amount of fuel required. All households selected their preferred stove options in a series of repeated discrete choice tasks; the analysis of these stated preference choices serves as the basis for assessing the heterogeneity in respondents' tastes for different ICS features (McFadden and Train, 2000). In particular, we consider whether and how various household characteristics, including ownership of LPG stoves, are correlated with variation in demand for these features of biomass ICS. Though we caution against ascribing a causal interpretation to the role of these observable characteristics in demand, and acknowledge that preferences for LPG versus biomass ICS may be systematically different, the comparison nonetheless allows us to assess the consistency of the patterns across the stated and revealed preference data.

Our paper makes several contributions. 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 north Indian households – are willing to pay for changes in specific biomass ICS attributes such as reductions in emissions, inconvenience, and fuel requirements. Existing studies on the demand for ICS have largely ignored the heterogeneity of user preferences and focused on average 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; Mobarak et al., 2012). An advantage of discrete choice preference elicitation is thus to allow consumers to explicitly consider the tradeoffs between stoves with different levels of ICS features.

Second, by analyzing how choice patterns vary across different subgroups of our sample, we are able to test whether preferences are related to observable household characteristics and contextual factors (van der Kroon et al., 2014). Similarly, our revealed preference regressions allow us to examine whether similar variables are correlated with patterns of ICS (LPG) stove ownership in the data. Such patterns provide clues on the penetration of existing alternatives to traditional stoves, and can inform more effective targeting of ICS promotion interventions since not all households will adopt and use such technologies. Alternatively, they may indicate which types of households already have and use alternative technologies and therefore do not need to be targeted. In particular, our analyses reveal substantial heterogeneity in preferences, which suggests that future ICS interventions should consider developing promotion messages and strategies that allow beneficiaries to understand the features of different products. Also, the extremely low levels of penetration of cleaner-burning stoves other than LPG stoves in our sample point to major supply-side challenges that impede widespread dissemination and diffusion of ICS. Collectively, our results call for policies that foster technological experimentation, support investment in infrastructure to support the ICS supply chain, encourage continued research and learning, and stimulate demand. Such a multi-faceted strategy is particularly relevant 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., 2013).

2. Methods

2.1. Research site and household sampling

In this study, we surveyed 2120 households living in 66 Census-delineated villages in two states of India – Uttar Pradesh and

Uttarakhand – between June and August 2012. These villages were selected to be stratified based on the presence or absence of micro-institutions that might affect ICS penetration; specifically, half of the villages had an active environmental NGO focused on clean energy or forest management, and half did not. Geographical and social differences between Uttar Pradesh and Uttarakhand led to somewhat different sampling strategies in the two states. In Uttar Pradesh, we worked in the main Gram Panchayat (GP) village (the lowest unit identified in the Indian Census), and also sampled in 1–3 randomly selected satellite villages located near the GP, depending on its size. Thirteen households were randomly selected in each of these 2–4 sub-villages using the right hand rule and selecting every nth household (n was obtained by dividing sub-cluster population by 13).

In Uttarakhand, sub-villages were more scattered and often contained only a handful of households. This created more variation in the number of sub-villages sampled from each GP. In small Census communities, 20 households were targeted; in medium ones 30; and in large ones 40. If a village was divided into distinct geographical 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 nth household 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 Uttar Pradesh, and July to early August in Uttarakhand.

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.[2] 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 Uttar Pradesh (5 villages) and Uttarakhand (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 simple 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.[3] 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; only those selecting this smaller (1500 Rs.) amount were classified as "most patient". In the risk module, respondents were presented with pairs of tradeoffs between a certain amount

[2] In total, 194 households were replaced in this way. Forty-one households refused to participate (33 in Uttarakhand and 8 in Uttar Pradesh), while an additional 153 (85 in Uttarakhand and 68 in Uttar Pradesh) could not be interviewed because they were not present during the day of the fieldwork.

[3] The exchange rate employed throughout this paper is US$1 = 52 Rs.

Table 1
Summary of discrete choice experiment (DCE) design.

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

Note: [a]$US ≈ 52 Rs.

(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. Those respondents selecting the option with a 50–50 change of obtaining 0 or 1000 Rs. were classified as risk-taking.

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). Based on systematic testing of various designs of the DCE during focus groups (Bhojvaid et al., 2013), attributes eliminated due to lack of clarity or salience to respondents included time savings, operation and maintenance requirements, 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 types) were described to respondents in detail, both orally and using pictures, and each attribute was explained by the enumerator using a specific script accompanied by pictorial representations. At the end of this description, respondents completed a 4-question comprehension test. If a respondent answered any question(s) 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 tasks completed during the survey, respondents were presented with two improved stove alternatives (both were the same "type") and a 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 Fig. 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, though based on hypothetical decisions, are widely used to estimate consumer preferences for multi-dimensional goods and services for which well-developed markets may not exist (Carson et al., 1994; Hanley et al., 2001; Louviere et al., 2000). 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), yet few studies have been conducted for ICS (Johnson and Takama, 2012; van der Kroon et al., 2014). Johnson

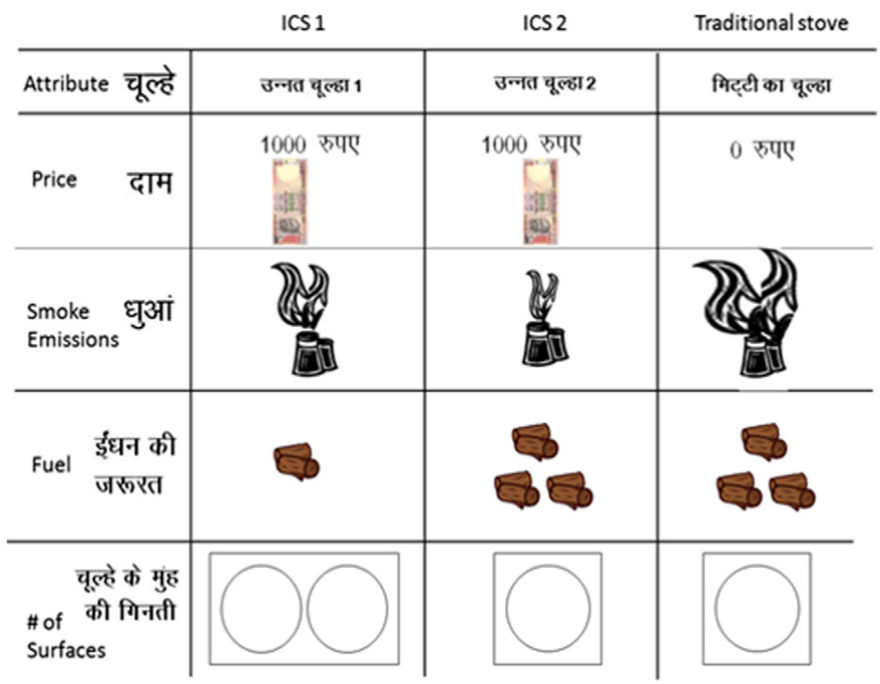

Fig. 1. An example choice task in the stove decision exercise, as presented to the respondent.

and Takama 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). Their analysis however does not indicate whether households care more about specific features of ICS technologies (e.g. smoke, convenience, fuel use), and how these preferences vary by household type. Van der Kroon et al. (2014) focus on ICS that use alternative fuels (wood, charcoal, and ethanol) and find evidence that demand varies considerably with contextual supply-side factors, particularly the extent of development of local consumer markets, which are related to fuel availability. We extend this line of work by focusing on the tradeoffs in attributes of the stove technology, that are receiving significant attention from manufacturers and air pollution researchers (Grieshop et al., 2011).

The basic framework for analysis of the discrete choice data is based in random utility theory.[4] We model household choices of alternatives having different combinations of 4 attributes – price, fuel requirement, smoke emissions, and number of stove openings – and two stove types (this is represented by a dummy variable indicating whether the alternative is a traditional stove). The random utility model assumes that the indirect utility for household i (U^i_{jt}) associated with alternative j in task t can be written as a function of its price (p_{jt}) and non-price (X_{jt}) attributes, plus a vector of household characteristics (Z^i):

$$U^i_{jt} = V^i\left(p_{jt}, \beta^i_0, X_{jt}, \beta^i, Z^i\right) + \varepsilon^i_{jt}, \tag{1}$$

where:

$V^i(\cdot)$ the non-stochastic portion of the utility function for household i;
β^i_0 a parameter which represents the marginal utility of money for household i;
β^i a vector of parameters which represents the marginal utility for household i associated with the different non-price attributes of the alternatives (including the alternative-specific constant, or ASC); and
ε^i_{jt} a stochastic disturbance term.

Within a given choice task, utility-maximizing household 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. Assuming a linear specification of utility 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). Using maximum likelihood methods, the values of the coefficient values are selected to maximize the likelihood that one would observe the choices observed in a given sample of respondents. The marginal willingness-to-pay (WTP) for each attribute then corresponds to the ratio of its coefficient to the coefficient for price.

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.[5] 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 coefficients and random parameters are estimated using simulated maximum likelihood, as discussed elsewhere (Jeuland et al., in press; Revelt and Train, 1998). Our analysis explores the implications of different distributional assumptions (normal and lognormal) for η.

[4] We present key details of the model here, but refer the reader to several other publications for additional details.

[5] 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.

Table 2
Sample descriptive statistics.

Variable	Overall			Uttar Pradesh			Uttarakhand		
	Mean (s.d.)		N	Mean (s.d.)		N	Mean (s.d.)		N
Below poverty line		64%	1917		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%	2118		8%	1057		85%	1062
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 weeks		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
Infrastructure/Electricity:									
Constant electricity		12%	2081		0.2%	1050		25%	1030
Intermittent electricity		58%	2081		45%	1050		71%	1030
If intermittent, hours/day supply	14.4	(7.6)	1443	6.7	(3.3)	469	18.1	(6.2)	974
Village has transport facilities		35%	2120		17%	1057		52%	1063
Took a loan in past year		14%	2120		13%	1057		15%	1063
In village with environmental NGO presence		0.5	2120		0.5	1057		50%	1063
Stove ownership									
Traditional stove[a]		97.5%	2120		97.6%	1057		97.5%	1063
LPG stove		20.0%			11.4%			28.5%	
Kerosene		0.8%			0.4%			1.2%	
Biogas		0.5%			0.0%			1.0%	
Average stove use time (hr/day)	3.8	(3.6)	2120	2.0	(3.4)	1057	5.6	(2.7)	1063
Median use among owners (hr/day)									
Traditional stove	3.3	(2.6)	2066	1.5	(1.6)	1032	5.0	(2.3)	1034
LPG stove	3.1	(4.9)	423	4.2	(7.9)	120	2.6	(2.8)	303
Kerosene	0.7	(0.7)	15		0.0	2	0.8	(0.7)	13
Biogas	1.6	(0.9)	11		–	0	1.6	(0.9)	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[c]		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 LPG cylinder (in 1000 Rs.)[b]	0.48	(0.1)	2120	0.5	(0.1)	1057	0.45	(0.06)	1063
Report high firewood price		55.0%			55.2%			54.9%	
Awareness of impacts of traditional stoves		71.5%			78.5%			64.4%	
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		51.8%	1057		31.0%	1063
Passed the comprehension test for the DCE		84.7%	2120		97.2%	1057		72.2%	1063

Notes: [a]traditional stoves include: mitti ka chulha (mud stove), angeethi (mud stove alcove), 3-stone fire, and sagarh (portable metal pan that burns charcoal or biomass).
[b]At the time of the baseline survey in 2012, US$1 = 52 Rs.
[c]Kerosene is primarily used as a lighter fluid by households since very few households owned kerosene stoves.

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 (as described in Section 2). The average household size at the time of the survey was 5.3 people. Most households in the sample (and all in Uttarakhand) are Hindu, and about 15% in Uttar Pradesh are Muslim.

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 Uttar Pradesh are in this category), and only 12% report having electricity all the time (0% in Uttar Pradesh). 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 (overall prevalence of respiratory illness was 9.4%; 11.5% in Uttar Pradesh vs. 7.3% in Uttarakhand).

At the time of the interviews, seventy percent of households had a single or multiple pot traditional mud stove (mitti ka chulha or angeethi); 51% of these stoves included a chimney or vent to the outside. Other stoves owned by significant numbers of households included the traditional 3-stone stove (24%), LPG stove (20%), and a portable metal pan (sagarh) (10%). The average number of stoves owned by each household was 1.2, and almost all LPG-owning households were stackers, i.e. used multiple stoves (only 7% of these did not also use their traditional stoves on a daily basis). In Uttarakhand, households reported total stove use time to be 5.6 h/day; in Uttar Pradesh this average was 2.0 h per day.[6] Respondents identified that the three best aspects of traditional stoves were 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 their smoke (75%) and heat (36%) emissions, the cleaning requirements (27%), and the amount of fuel required (20%). Among respondents, awareness of the negative health effects of traditional stoves was highest (68%), followed by local environment and forests (54%), and finally outdoor air pollution and/or climate change (38%). Only 33% of respondents believed their actions could have medium or large effects for mitigating these negative impacts.

The most commonly used fuels by households were firewood (97%), dung (39%; 78% in Uttar Pradesh), LPG (19%, 9.6% in Uttar Pradesh) and kerosene (15%; 22% in Uttar Pradesh), the latter primarily as a lighter fluid (i.e., to start fires) since very few households used kerosene stoves. Seven percent of households reported burning crop residues or twigs (14% in Uttar Pradesh), 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.

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

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.

We first present probit regressions that reveal the correlates of binary measures of ownership and use of non-traditional stoves (nearly all LPG) in our sample; 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. It is noteworthy that the analyses for the two ICS indicators are substantively identical, which suggests that households owning ICS in this sample also generally use them, though not exclusively. As shown in Table 3 (comparing Columns C and D to A and B), the estimates are also insensitive to the inclusion of households who were dropped from the DCE analysis because they failed the comprehension test for that exercise.[7]

Though we cannot claim causal relationships due to the observational 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, education of the head of the household and primary cook, and higher expenditures, though the latter are not statistically significant) and is higher in households who are aware that traditional stoves have negative effects 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. On the other hand, we find a negative association between ICS ownership and use and overall household size. We find a similarly negative association between these indicators and risk-taking preferences, and a positive relationship with investment in another technology – toilets – that reduces environmental risks, though the coefficients for the former are not statistically different from zero.

Turning to supply-side or contextual factors, we find that households reporting higher costs of firewood and lower LPG costs in their communities are more likely to have an ICS.[8] Households in communities with more reliable electricity and transport infrastructure are somewhat more likely to own a clean stove, perhaps reflecting the better rural connectivity with markets in those locations. Noting the difference in ownership patterns across the two states, we also estimated separate regressions by state (see Supplementary Table A2), and found the correlation patterns to be mostly consistent across states. The most notable exceptions were that a) households who were aware of the negative effects of traditional stoves were no less likely to have ICS in Uttar Pradesh; b) both patient and risk-taking households were less likely to own and use ICS in that state but not in Uttarakhand; and c) electricity supply was more strongly related to ownership and use of ICS in Uttar Pradesh, where it is also much more limited.

3.3. Preferences for ICS: results from analysis of discrete choice experiment

We next present the main effects from the stove decision exercise or DCE. Specifically, we consider that a respondent selected a biomass ICS if it was indicated as the preferred alternative in a choice task and the respondent also responded affirmatively to the 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?”[9] Uncertain responses to the latter question are conservatively treated as indicating a preference for the choice of opting out, to reduce threats of overestimating the true willingness to purchase an ICS due to hypothetical bias (Murphy et al., 2005). Furthermore, we exclude the roughly 15% respondents who failed to correctly answer any one of the four comprehension questions, and those with missing covariates from the previous probit analysis.[10] This yields a final sample of 18,120 choices, observed from a group of 1515 respondents.

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

[7] These estimates do not appear sensitive to the sample construction, but the 84% of households who passed this comprehension test were not surprisingly somewhat different from those who did not (see Table A1 in the supplementary materials for the results of this selection model). Such households appear to be positively selected; in particular, they had higher wealth and expenditures, more educated primary cooks and younger household heads, and were more likely to believe that ICS would have medium to high impacts on health and the environment.

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

[9] As described above, 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.”

[10] Results are not substantively different if we include the choices by respondents who had partial covariate information (see Tables A3 and A4, and Figure A5, in the supplementary materials).

Table 3
Clean stove ownership and use.

Variable	A. Own clean stove		B. Used clean stove (past week)		C. Own clean stove DCE sample only		D. Used clean stove (past week) DCE sample only	
	Probit		Probit		Probit		Probit	
	Coef.	St.err.	Coef.	St.err.	Coef.	St.err.	Coef.	St.err.
Relative wealth	0.51[a]	0.07	0.49[a]	0.06	0.50[a]	0.07	0.49[a]	0.07
log(Expenditures)	0.09	0.07	0.09	0.07	0.10	0.08	0.12	0.08
# Rooms	0.04[c]	0.02	0.02	0.02	0.02	0.02	−0.00	0.02
Head of hh education	0.05[a]	0.01	0.05[a]	0.01	0.04[a]	0.01	0.04[a]	0.01
Primary cook education	0.05[a]	0.01	0.04[a]	0.01	0.05[a]	0.01	0.05[a]	0.01
General caste	0.15	0.12	0.21[c]	0.12	0.13	0.13	0.19	0.13
hh size	−0.09[a]	0.02	−0.08[a]	0.03	−0.09[a]	0.03	−0.08[a]	0.03
# Children under 5	0.13[b]	0.06	0.13[b]	0.06	0.15[b]	0.07	0.17[b]	0.07
hh took loan in past year	−0.03	0.13	−0.09	0.14	0.00	0.15	−0.09	0.17
Female respondent only	0.11	0.09	0.05	0.09	0.05	0.10	0.00	0.10
Female-headed hh	0.36[a]	0.12	0.39[a]	0.12	0.34[b]	0.14	0.38[a]	0.14
Age of head of hh	0.01[a]	0.00	0.01[b]	0.00	0.01[b]	0.00	0.01[c]	0.00
Hindu	0.18	0.22	0.06	0.23	0.20	0.22	0.08	0.23
Aware of negative effects of traditional stoves	0.25[c]	0.13	0.22	0.14	0.31[b]	0.15	0.28[c]	0.15
Can have medium/high impact	0.10	0.09	0.06	0.09	0.07	0.10	0.02	0.10
hh uses/owns toilet	1.2[a]	0.16	1.2[a]	0.16	1.2[a]	0.16	1.3[a]	0.16
Most patient	0.04	0.10	0.00	0.10	0.06	0.11	0.04	0.11
Most risk-taking	−0.13	0.11	−0.08	0.10	−0.11	0.12	−0.09	0.11
Report high price of fuelwood	0.18[b]	0.09	0.20[b]	0.09	0.10	0.09	0.12	0.09
Price LPG	−3.3[a]	0.73	−3.3[a]	0.73	−3.2[a]	0.78	−3.2[a]	0.78
Electricity access (hours per day)	0.01[c]	0.00	0.02[b]	0.01	0.02[b]	0.01	0.02[b]	0.01
Transport facilities in village	0.24	0.15	0.25[c]	0.15	0.23	0.16	0.24	0.17
Environmental NGO in village	−0.04	0.13	−0.06	0.13	−0.04	0.14	−0.07	0.14
Uttarakhand (state dummy)	−1.0[a]	0.21	−0.93[a]	0.21	−1.0[a]	0.23	−0.95[a]	0.23
Constant	−2.8[a]	0.75	−2.8[a]	0.78	−2.9[a]	0.78	−2.9[a]	0.81
Observations	1792		1792		1515		1515	
Pseudo-R^2	0.357		0.357		0.373		0.377	

Notes: Standard errors are clustered at the hamlet level. 94% of clean stove owners and users have LPG. Columns A and B present the results for all households (n = 1792) with complete covariate and outcome information. Columns C and D pertain to the sub-sample of 1515 households who had complete covariate and outcome data, and who also answered the DCE comprehension test questions correctly, for which we present results in Tables 4 and 5.
[a] $p < 0.01$.
[b] $p < 0.05$.
[c] $p < 0.1$.

The coefficients for different specifications of the logit models used for analyzing 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 openings were more likely to be selected (Table 4). In addition, the standard deviations for all random parameters are highly significant, indicating that preferences are highly variable. The estimates reveal a strong predilection to opt out and select a traditional stove, as indicated by the large positive coefficient on the traditional stove ASC.

Derivation of the marginal WTP for a one-unit change in each attribute in all three specifications (Column A–C) reveals that a 33% (one-unit) reduction in smoke emissions is most valuable to households on average, followed by the addition of one extra cooking burner and finally a one-unit (33%) decrease in fuel requirements (as shown also in the last row of Fig. 2 for the mixed logit with a normally distributed price parameter). The large coefficient on the ASC for the traditional stove type indicates a strong average preference for traditional stoves, although this preference is considerably smaller in the lognormal specification. Households clearly have a strong default preference for the technology they already know and use; the implication is that many respondents would need to see large reductions in the attribute levels to see a net value in adopting an improved stove.

Given the substantial heterogeneity in preferences, we close by considering whether the demand for stove attributes or type is related to observable respondent characteristics, by interacting attribute levels and the traditional-stove ASC with dummy variables for a particular class of characteristics (Table 5). This analysis assumes that the coefficients on all attributes and interactions are normally distributed. The sub-group analysis shows that a variety of observable characteristics of households is significantly correlated with attribute preferences. As shown by the significance of the interaction terms in these estimations, sub-group differences are greater for the price, smoke and fuel use attributes, and somewhat less for the number of burners. Female headed households are relatively more price responsive than the others, while women respondents have lower demand for changes in the three ICS attributes (Columns A and B), implying lower marginal WTP for both groups (Fig. 2). Meanwhile, households already owning clean stoves are less price responsive and place reduced weight on traditional stoves (Column D), but also have 25% lower WTP for reduced smoke emissions (Fig. 2). Interestingly, households who are aware of the negative effects of traditional stoves are more price responsive than those who are unaware of these, but have lower preference for traditional stoves (Column E). Households in the lowest expenditure quartile of the sample do not have significantly different preferences for the ICS attributes (Fig. 2), but were significantly more likely – by 50% – to select the traditional stove (results not shown). Finally, less patient households were much more price sensitive than others, while risk-taking households placed lower value on improvements in each of the three attributes, especially smoke (Columns F and G), yielding lower marginal WTP for both of these types of households (Fig. 2).

In terms of variation with contextual variables, the analysis by geography (Table 5 Column C) indicates that Uttarakhand households have lower implied WTP for the ICS reductions in smoke emissions reductions and additional cooking surfaces than those in Uttar Pradesh (Fig. 2). Demand for the attributes of the biomass ICS was also lower among households reporting higher fuel prices, and was somewhat lower in locations with better transport

Table 4
Results for basic discrete choice models.

Variable	A. Willing to pay for stove[d]		B. Willing to pay for stove[d]		C. Willing to pay for stove[d]	
	Conditional logit		Mixed logit Normal st.errs.		Mixed logit Lognormal st.errs.	
	Coef.	St.err.	Coef.	St.err.	Coef.	St.err.
Coefficient estimates						
Price (Rs)[e]	−0.00049 [a]	0.000	−0.0014[a]	0.000	0.82[a]	0.11
St. dev. – Price			0.0013[a]	0.000	2.9 [a]	0.15
Fuel requirement	−0.17 [a]	0.020	−0.44[a]	0.033	−0.43[a]	0.033
St. dev. – Fuel			0.13	0.12	0.15	0.14
Smoke emissions	−0.38 [a]	0.047	−0.78[a]	0.078	−0.82[a]	0.072
St. dev. – Smoke			0.64 [a]	0.14	0.38[b]	0.19
Number of pots	0.28 [a]	0.046	0.57[a]	0.071	0.58[a]	0.069
St. dev. – Pots			0.39 [c]	0.20	0.36 [b]	0.17
ASC – Traditional stove[f]	1.4 [a]	0.089	2.5[a]	0.22	−0.62[a]	0.19
St. dev. – ASC			5.0[a]	0.25	2.4[a]	0.27
WTP for unit increase ($US)						
Fuel requirement	−$6.6		−$5.8		−$9.1	
Smoke emissions	−$14.8		−$10.2		−$17.3	
Number of pots	$10.7		$7.4		$12.3	
Traditional stove	$53.1		$33.3		$13.1	
Observations	18 120		18 120		18 120	
Pseudo R^2	0.181					
Likelihood ratio χ^2 (p-value)			2928.5 (0.000)		3038.0 (0.000)	

Notes: [a]significant at 1% level [b]significant at 5% level [c]significant at 10% level.
[d]Model excludes respondents who answered any one of four comprehension questions incorrectly prior to the first choice task. Also excludes respondents who were not included in the analysis shown in Table 3 due to missing data (see supplementary materials for results that do not exclude the latter).
[e]Price coefficient was rescaled for lognormal model to have a positive coefficient (price in Rs. was divided by −500).
[f]Traditional stove = 1 if it was the traditional stove, 0 if improved.

infrastructure and electricity supply, suggesting potential challenges in matching locations with both high demand and adequate supply infrastructure.

4. Discussion

The heterogeneity in perceptions, behaviors and ICS preferences presented in our analysis highlights a set of important demand-side factors and challenges that need to be considered by those seeking to promote household energy products such as ICS. The paper makes several contributions to the literature on this topic. First, we use both revealed and stated preference data to focus attention on the tremendous heterogeneity in demand and stove adoption outcomes. Then, we analyze the associations between these heterogeneous variables and a rich set of household and contextual characteristics. Prior quantitative analysis has rarely considered how supply- and demand-side factors in this domain are together related to cooking outcomes. We propose that consumer heterogeneity may be partly responsible for the wide range of findings articulated in recent studies of demand for biomass-burning ICS, as well as the benefits they deliver (Bensch and Peters, 2012; Bensch et al., 2015; Levine et al., 2013; Mobarak et al., 2012). At the same time, however, this heterogeneity is likely also correlated with important supply-side drivers, including market connectivity, fuel availability, and the presence and strength of technology-promoting micro-institutions.

We considered evidence of heterogeneity using approaches based on revealed and stated preferences. Our analysis of the revealed preference data – primarily for ownership and use of LPG stoves – contributes to a small body of evidence on a range of household characteristics and fuel or stove-related factors that are associated with adoption of non-traditional stoves (Lewis and Pattanayak, 2012). We find that adoption of alternative technologies is positively correlated with wealth, education and risk reducing behaviors, and negatively correlated with household size, perhaps because it is difficult to cook for many people on ICS or because household size is also a proxy for lower socio-economic status. LPG owners are also more likely to report awareness of the negative health or environmental effects of traditional cook stoves. Finally, female-headed households and households with young children are more likely to own and use LPG stoves. Also noteworthy is that we observe almost universal stacking of LPG stoves alongside other stoves,

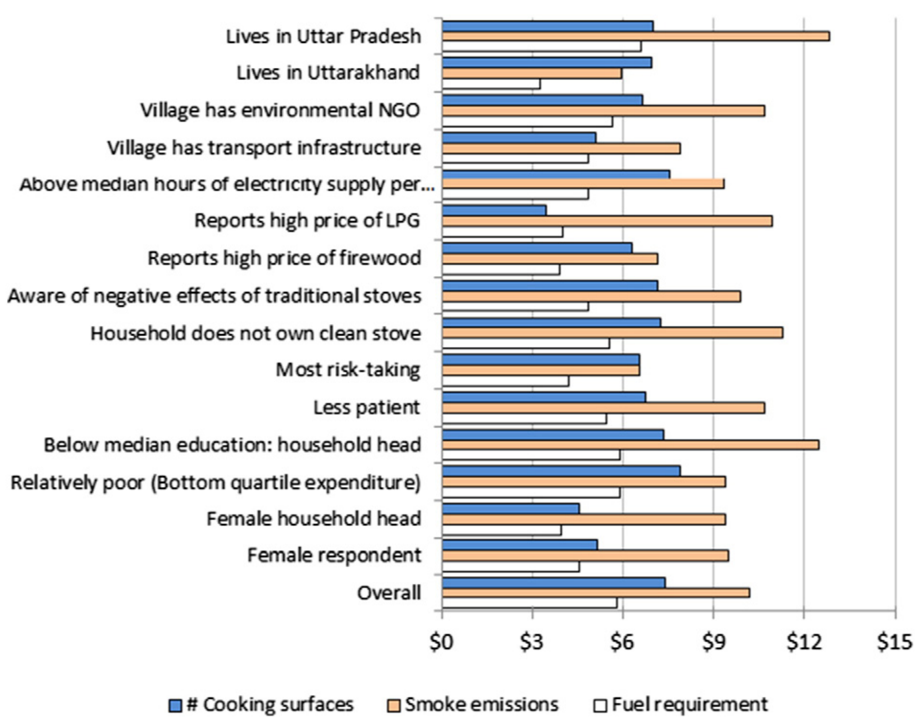

Fig. 2. Willingness to pay for 1-unit changes in stove attribute levels among different sample sub-groups (notes: 1 unit corresponds to a 33% decrease for smoke emissions and fuel requirement, and 1 additional burner).

Table 5
Results for mixed logit sub-sample analyses.

Variable	A. Female respondent		B. Female hh head		C. State		D. Improved stove		E. Aware of negative traditional stove impacts		F. Patient		G. Risk-taking	
	Coef.	SD	Coef.	SD	Coef.	SD	Coef.	SD	Coef.	SD	Coef.	SD	Coef.	SD
Price (Rs)	−0.0015[a]	0.0013[a]	−0.0015[a]	0.0013[a]	−0.0017[a]	0.0013[a]	−0.0015[a]	0.0012[a]	−0.00085[a]	0.00082[a]	−0.0017[a]	0.0013[a]	−0.0015[a]	0.0013[a]
Price x female	−0.0000	0.0002												
Price x female hh			−0.00037[b]	0.00043										
Price x Uttarakhand					0.0006[a]	0.0002								
Price x improved stove							0.0002[a]	0.0009[a]						
Price x aware									−0.00093[a]	0.0013[a]				
Price x patient											0.00073[a]	0.00026		
Price x risk-taking													0.00028[c]	0.00042[b]
Fuel requirement	−0.54[a]	0.13	−0.48[a]	0.17[b]	−0.63[a]	0.15	−0.45[a]	0.043	−0.38[a]	0.073	−0.49[a]	0.0.29	−0.45[a]	0.10
Fuel x female	0.18[a]	0.24[b]												
Fuel x female hh			0.24[a]	0.17										
Fuel x Uttarakhand					0.42[a]	0.16								
Fuel x improved stove							0.021	0.17						
Fuel x aware									−0.079	0.29[a]				
Fuel x patient											0.18[a]	0.27		
Fuel x risk-taking													0.18[a]	0.17
Smoke emissions	−0.94[a]	0.087	−0.88[a]	0.15	−1.2[a]	0.096	−0.90[a]	0.075	−0.57[a]	0.20	−0.95[a]	0.079	−0.97[a]	0.091
Smoke x female	0.18	0.15												
Smoke x female hh			0.31[c]	0.17										
Smoke x Uttarakhand					0.85[a]	0.32[c]								
Smoke x improved stove							0.28[c]	0.41[a]						
Smoke x aware									−0.37[b]	0.065				
Smoke x patient											0.36	0.32[a]		
Smoke x risk-taking													0.55[a]	0.038
Number of pots	0.77[a]	0.15	0.61[a]	0.11	0.67[a]	0.35 [c]	0.58[a]	0.24	0.22	0.23	0.60[a]	0.33	0.59[a]	0.16
Pots x female	−0.35[b]	0.004												
Pots x female hh			−0.33[c]	0.23										
Pots x Uttarakhand					−0.23	0.25								
Pots x improved stove							−0.087	1.0[a]						
Pots x aware									0.46[a]	0.14				
Pots x patient											−0.13	0.12		
Pots x risk-taking													−0.17	0.11
ASC[d] – Type of stove	2.8[a]	5.2[a]	2.9[a]	5.2[a]	2.9[a]	5.2[a]	3.0[a]	5.0[a]	3.4[a]	5.2[a]	2.9[a]	5.2[a]	2.6[a]	5.2[a]
ASC x female	−0.16	0.046												
ASC x female hh			−1.1 [b]	0.068										
ASC x Uttarakhand					−0.23	0.77 [a]								
ASC x improved stove							−1.5[a]	2.7[a]						
ASC x aware									−1.3 [a]	0.66 [a]				
ASC x patient											−0.45	0.49		
ASC x risk-taking													0.11	0.29
Observations	18120		18120		18120		18120		18120		18120		18120	
Likelihood ratio χ^2 (p-val)	2936 (0.000)		2940 (0.000)		2971 (0.000)		2907 (0.000)		2900 (0.000)		2920 (0.000)		2764 (0.000)	

Notes: Model excludes respondents who answered any one of four comprehension questions incorrectly prior to the first choice task. Also excludes respondents who were not included in the analysis shown in Table 3 due to missing data (see supplementary materials for results that do not exclude the latter).
[a]Significant at 1% level [b]significant at 5% level [c]significant at 10% level [d]type of stove ASC = 1 if it was the traditional stove, 0 if improved.

with a tiny minority of households making a complete switch to this technology. Overall, these findings provide support to a growing consensus that affordability and unfamiliarity with ICS are important barriers to adoption, and that existing ICS models may not be suitable for all households or all cooking tasks (Lewis and Pattanayak, 2012; Rehfuess et al., 2014).

Then, exploring the patterns in households' stated preferences for biomass-burning ICS, a very different technology than LPG, we observe that households on average have a strong preference for traditional stoves and have greater marginal WTP for smoke emissions reductions than for decreased fuel or increased convenience. This average however masks important heterogeneity. Sub-group analysis shows that female-headed households are more price responsive, and that women respondents have lower marginal WTP (MWTP) for ICS features. These results perhaps reflect greater financial constraints and/or the greater likelihood of female-headed households already owning clean stoves. Poorer (lower-expenditure) households have a stronger preference for traditional stoves, suggesting greater barriers to adoption among poor households. Households owning clean stoves place less weight (by about 20%) on additional reductions in smoke emissions, perhaps because they already possess a technology with lower emissions. Finally, risk-seeking and less patient respondents have very low MWTP for biomass ICS attributes; additional study of the role of such inherent but understudied preferences in constraining ICS adoption therefore seems warranted.

Our study is one of the first in the literature to consider how preference heterogeneity is correlated with contextual factors. Across states, we find higher rates of use of LPG among rural households interviewed in Uttarakhand (where 31% own ICS) than in surveyed areas of Uttar Pradesh (where 12% own ICS). Households in Uttarakhand also have lower MWTP for improvements in biomass ICS attributes. Meanwhile, those facing higher prices for both wood and LPG fuel, and households in communities with better transport and electricity infrastructure and electricity supply, also have lower MWTP for these benefits. Except for high LPG prices, the same factors are positively related to ownership of LPG stoves. These collective features suggest that there may be a possible misalignment of supply-side and demand-side drivers of biomass ICS adoption, and point to a need for better market segmentation and targeted marketing strategies that account for variation in household preferences (Shell Foundation, 2013; Singh and Pathy, 2012). Indeed, those pursuing efforts to scale up ICS interventions must acknowledge and strive to better understand and adapt to the range of incentives, constraints, and preferences facing specific communities and households (Pattanayak and Pfaff, 2009), as well as how they vary across locations (Lewis et al., 2015).

In terms of limitations, we note first that our results come from a single cross-section of data that only provides a snapshot of evidence. The preference patterns we describe should clearly not be considered causal, and thus do not provide sufficient information for identifying which ICS promotion strategies work. They also do not encompass all potentially important stove attributes; additional attention should be devoted to understanding features such as time savings, operation and maintenance, and ability to use multiple fuels. Rather, our findings on preferences provide evidence from a single point in time that demand for ICS is heterogeneous, and identify a need for systematic testing of the influence of this heterogeneity on stove and fuel use outcomes, and on the success of interventions developed to ameliorate these outcomes.

In addition, our findings were obtained from specific locations in two very large north Indian states, whose households have their own peculiar cooking behaviors and cultural norms. We also stratified our sampling according to the presence of environmental NGOs. This study design limits the generalizability of our findings, and also renders the final sample non-representative. Nonetheless, this sampling approach provides important advantages. First, the restricted range of the study meant that we were able to carefully prepare surveys that were most 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. Second, the generalizability of our findings, and the ability to consider important dimensions of contextual and preference heterogeneity, is enhanced by our deliberate sampling of households in two very distinct geographical zones – the foothills of the Himalaya and the Gangetic plains – who faced different fuel, cooking, and micro-institutional 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 for cooking in developing countries must be addressed, and biomass fuel use in inefficient stoves must be reduced. To consider the potential for such changes, this paper explored stated and revealed preferences for existing and potential ICS 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 (Smith, 2000). Analysis of the DCE data implies that households are willing to pay about $15 on average for realistic (one unit, or 33%) reductions in smoke and fuel consumption, which is equivalent to 50–75% of the market price of a cheaper biomass ICS. Despite this relatively high latent demand for the benefits of biomass-based ICS, households given a choice between the ICS and traditional stove types demonstrate a strong predilection towards the latter. At the same time, among all ICS types, only LPG stoves have achieved significant penetration in our survey locations, and only 7% of LPG stove owners (or 1.4% of our entire sample) use these ICS exclusively.

This paper also focuses attention on the heterogeneity in demand for the benefits of ICS. We find that ownership of LPG stoves and willingness to pay for improved features of a biomass-burning ICS are positively correlated with wealth and education variables, and are related to a variety of other household-level factors such as family size, gender, patience and risk aversion as well as contextual factors such as geography, fuel price, and market connectivity. Our analysis therefore provides a nuanced understanding of the potential for adoption of clean stoves in the survey communities, and suggests that widespread dissemination likely requires additional demand stimulation intervention through social marketing and the resulting focus on price, promotion, place and product (Lewis et al., 2015). Furthermore, evidence of heterogeneous tastes and constraints suggests a need for applying market segmentation and targeted marketing. For example, we observe that households that are poorer or headed by females ("constrained households") are interested in ICS but sensitive to price, while those who are wealthy but already use LPG ("stackers") have low demand for a biomass ICS. In addition, a group of "traditionalist" households tend to have lower education, face lower fuel costs, and are less aware of the negative impacts of traditional stoves. Meanwhile, the absence of widespread ICS use in our study communities implies that existing latent demand for cooking improvements has not proven sufficient to overcome significant supply-side challenges. Thus, high distribution and transaction costs may need to be reduced if the market for ICS is to take off.

In fact, improved cook stoves (ICS) are a quasi-public good (Jeuland et al., 2015). While some of their benefits are private (e.g., time and fuel savings, pollution reductions inside the home), many others are external to households (e.g., village-level or regional air quality, health, and forest preservation, and global climate change mitigation benefits). As such, there is likely to be underinvestment by private households, and therefore also investors, in ICS. It follows that there is a clear case for policy intervention in the market, and our findings have several important implications for policy design. First, the heterogeneity in household tastes suggests a need for policies that stimulate research and development of ICS technologies that are responsive to user preferences and to the importance of applying market segmentation and targeted social marketing. Policies should foster competition and diversity in the ICS market rather than being overly prescriptive about which specific technologies to use. This is a fine line: Innovation will clearly be impeded by burdensome regulation of new ICS, but there are obvious problems with support for technologies that do not meet standards for the delivery of benefits.

Second, because marginal WTP is lower among groups that may be important to reach (women and the poor), small changes in the price faced by such households can have a large effect on ICS purchases. Besides allowing a better alignment of adoption rates with optimal social benefits, subsidies and financing would thus lower the barriers to ICS adoption among the poor. In tandem with reductions in the cost of stoves, policy-makers should also consider options to stimulate demand through social marketing and other behavioral change approaches. Third, there are numerous supply-side challenges in remote rural areas that increase the costs of ICS, including low road and market connectivity, and barriers to commercialization (e.g., rules that prohibit NGOs from selling products such as ICS). Higher connectivity however appears negatively correlated with demand, suggesting that there may be misalignment of supply and demand drivers in many locations. Policies to reduce distribution and transaction costs in the market for ICS, and that support investment in complementary infrastructure, could therefore help to stimulate adoption. Finally, policy-makers and donors should continue to foster knowledge generation about the barriers to ICS promotion, leveraging learning from other environmental health domains (e.g., water and sanitation). Such knowledge and the research that produce it are a public good that is provided by academics, policy researchers and community development activists.

To conclude, 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. Part of the problem may be that previous promotion efforts have failed to sufficiently consider the role that preferences play in influencing adoption of new technologies, and households' predilection to use technologies with which they are familiar. To quickly scale up ICS, the policy community must stimulate demand and support the ICS supply chain and micro-institutions seeking to promote effective ICS models through three complementary strategies, for example. First, we must foster or subsidize small-scale experimentation that is sensitive to the diversity of preferences for product attributes such as price, emissions, and fuel needs. Second, we have to convince reticent households of the value of existing ICS through a full suite of social marketing, including emphasis on price subsidies, promotion and product modifications. Third, because characteristics such as education, experience, wealth and location suggested that households had varied tastes, we must segment the market based on these characteristics and target social marketing efforts. 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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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2015.11.010.

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