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Evaluating the relative strength of product-specific factors in fuel switching and stove choice decisions in Ethiopia. A discrete choice model of household preferences for clean cooking alternatives

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ABSTRACT

Switching from conventional stoves to modern clean, safe, and efficient stoves will improve health and social welfare for the 2.7 billion people worldwide that lack reliable access to modern energy services. In this paper, we critically review some key theoretical dimensions of household consumer behaviour in switching from traditional biomass cooking stoves to modern efficient stoves and fuels. We then describe the results of empirical research investigating the determinants of stove choice, focusing on the relative strength of product-specific factors across three wealth groups. A stated preference survey and discrete choice model were developed to understand household decision-making associated with cooking stove choice in Addis Ababa, Ethiopia. The study found that, with the exception of price and usage cost factors for the high wealth group, the product-specific factors that were investigated significantly affect stove and fuel choices. The relative strength of factors was assessed in terms of Marginal Willingness to Pay and provides some evidence that consumer preference for higher quality fuels and stoves tends to increase with increasing wealth.

1. Introduction

The switch from traditional biomass to modern energy sources and efficient stoves is one of the major sustainability challenges facing developing countries. The International Energy Agency's World Energy Outlook has estimated that 2.7 billion people rely on traditional biomass fuels–including fuelwood, charcoal, animal dung and agricultural residues–as their main source of household energy; the highest dependence is in sub-Saharan Africa, where 80% rely on traditional biomass for cooking (IEA, 2010). The inefficient burning of biomass for cooking is the main source of indoor air pollution, exposure to which is linked to a range of health issues, resulting in approximately 2 million annual premature deaths in developing countries (Smith and Mehta, 2003). Gender inequality, women's drudgery and labour productivity are also closely linked to the use of biomass fuels (Cecelski and Unit, 2000; Dutta, 1997). In addition to the adverse welfare implications, biomass use also has serious environmental impacts, particularly deforestation and greenhouse gas emissions (Grieshop et al., 2011; Odihi, 2003; Smith and Mehta, 2003). Switching from biomass fuels to modern, energy efficient sources and/or to improved stoves can help to alleviate these problems.

Despite the numerous apparent benefits of fuel switching, the transition to modern fuels has been slower than expected. Indeed, the number of households relying on traditional biomass in sub-Saharan Africa is expected to increase in absolute terms by 14% by 2015 although the share will decline slightly to 77% (IEA, 2010). The promotion of energy efficiency measures and mitigation of the adverse economic, environmental and health impacts associated with the use of traditional biomass is an important policy issue in Ethiopia. Fuelwood is the main cooking fuel in rural areas of Ethiopia, whereas kerosene dominates in major urban areas such as Addis Ababa, where it accounts for over 40% of household cooking (Takama et al., 2011). The rising price of kerosene and concerns over its health and safety impacts contributed to a decrease in recent years in kerosene use in

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favour of fuelwood in Addis Ababa, where it has also been observed that poor households spend a larger share of disposable income on energy (16%) compared to 4% for wealthy households (Kassa, 2009). The alternative of cooking with a modern renewable fuel such as ethanol has therefore attracted increasing interest. It is within this specific context that this study seeks to understand the cooking energy switching pattern in general and determinants of the stove choice decision in particular.

Previous research on stove and fuel choices has tended to focus on socioeconomic variables such as income, education and household size. This research emphasises a rather different set of variables, namely the attributes or characteristics of the cooking stoves (and the associated fuel or fuels) themselves; we refer to such attributes as "product-specific" in the sense that they differ for each fuel/stove choice being considered. The research described in this paper was aimed at estimating the relative strength of product-specific factors in determining fuel/stove choice at the household level in Addis Ababa across different wealth or income groups. A choice experiment using a stated preference survey was designed and applied for the selected study group in Addis Ababa and a discrete choice model was developed and estimated. Stated preference methods provide a structured technique for elucidating respondents' valuation of certain attributes; unlike surveys of observed or revealed preferences, a stated preference survey can better accommodate alternatives that are unfamiliar to the respondents or are not yet available on the market. Indeed, a number of major initiatives around the world are specifically aimed at bringing new stove designs to the market (GACC, 2009; Venkataraman et al., 2010). Only stated rather than observed preference approaches can enable simultaneous comparison or evaluation of existing stoves with stoves that do not yet exist, i.e. by representing the new stove designs as a bundle of attributes or characteristics.

The following section provides background on the fuel/stove choice issue and a review of the relevant literature with respect to the research objectives. The logic behind the expanded focus on product-specific factors is explained in relation to the knowledge gaps that were identified and the relevance for policies and programme design. Section 3 gives the design of the research methodology and the approach that was adopted in investigating the determinants of fuel/stove choice in Addis Ababa. Section 4 provides a description of the results, including the estimation of model parameters using BIOGEME software. Section 5 discusses the significance of the model results in relation to previous research and the expected behaviour of household decision-makers, and also considers the deviations in fuel/stove choices across wealth groups and the limitations of the model in addressing the basic research questions. The final section offers some general conclusions as to how the model answered the research questions and the implications for future efforts aimed at understanding the structure of fuel/stove choices at the household level in developing countries.

2. Factors influencing cooking energy choice

As improved energy alternatives become available and affordable for households in developing countries, they may switch from traditional biomass to modern fuels such as LPG, kerosene, or electricity; this pattern of fuel-switching is often referred to as the "energy ladder" in which the steps of the ladder represent upgrades in the quality of energy services (Leach, 1992). A number of studies have been conducted to understand the factors that affect cooking stove choices and fuel consumption patterns. Many studies have pointed to income or wealth as a key factor, which is consistent with the energy ladder perspective (Barnes et al., 2010; Briscoe, 1979; Davis, 1998; Hosier and Dowd, 1987; Pachauri and Jiang, 2008). Other research has suggested a "fuel stacking" model in which households use multiple fuels and do not necessarily switch to options that are more efficient or of higher quality (Masera et al., 2000). The observed diversity in fuel-switching patterns is due to the presence of various non-cost factors such as local food habits and cooking frequency (Ouedraogo, 2006), ethnicity (Heltberg, 2005), local traditions and institutions (Hiemstra-van der Horst and Hovorka, 2008) and food taste preferences (Karekezi and Majoro, 2002; Leach, 1988). Research in Ethiopia has also suggested such a range of underlying factors (Kebede et al., 2002) and has illustrated the significant environmental impacts associated with fuelwood dependence (Zenebe, 2009).

The energy ladder model had a significant effect on the direction of earlier research and some work has therefore been aimed specifically at testing the validity of that model (Hiemstra-van der Horst and Hovorka, 2008; Hosier and Dowd, 1987). However, our concern in this research is not with the legitimacy of the energy ladder model or the fuel stacking model, but rather with the underlying determinants of cooking stove choice themselves and in particular whether some types of factors affecting fuel/stove choices are under-represented in the research. The research record does suggest the influence of a wide range of factors; a detailed review found that some 50 distinct factors have been identified in the scientific literature as the determinants of cooking fuel and/or stove choice (Tsephel, 2008). The factors can be broadly classified into socioeconomic and product-specific factors: socioeconomic factors are those characteristics related to the individuals or households making the choices, whereas product-specific factors are attributes of the particular stoves and fuels that are potentially available to the households faced with such choices (Takama et al., 2011).

Socioeconomic factors other than income have also received considerable attention in the literature, influenced to some extent by the energy ladder perspective, and including factors such as education, household size, age of household head, type of shelter and its ownership status, house location and distance from forest (Gupta and Köhlin, 2006; Heltberg, 2005; Hosier, 1985; Ouedraogo, 2006; Rehfuess et al., 2010). Since the issue of household energy in developing countries is closely linked with women's drudgery, factors associated with gender and women's position in the household were also found to be significant (Heltberg, 2004; Gupta and Köhlin, 2006; Rehfuess et al., 2010). Other socioeconomic factors identified are related to market availability or access, including electricity used for lighting, social status, reliability concerns and distribution constraints (Arnold et al., 2006; Campbell et al., 2003; Davis, 1998; Gupta and Köhlin, 2006; Hosier, 1985; Karekezi and Majoro, 2002; Kebede et al., 2002; Odihi, 2003; Rehfuess et al., 2010).

Factors related to affordability have also been evaluated, including fuel prices, availability and price of alternative fuels, appliance or stove price, availability of cash income, household expenditure level, and upfront capital cost (Allen and Barnes, 1985; Brouwer and Falcao, 2004; Davis, 1998; Dewees, 1989; Fisher, 2004; Gupta and Köhlin, 2006; Heltberg, 2004, 2005; Karekezi and Majoro, 2002; Kebede et al., 2002; Leach, 1992; Soussan et al., 1990). The research has suggested that affordability at the household level is a key driver of fuel and/or stove choice. However, we find that "affordability" includes a mix of socioeconomic factors (e.g. cash income, household expenditure level) and product-specific factors (e.g. stove price, fuel prices). Those attributes that are product-specific can be reasonably expected to exert some influence across a range of socioeconomic characteristics (e.g. a cheaper stove that performs just as well should be preferred) whereas socioeconomic characteristics are often associated with barriers or biases (e.g. upfront capital cost for low-income households, cultural preference for a traditional stove rather than an electrical stove). A better understanding of the influence of product-specific factors across income or wealth groups could support improvements in the design of programmes and policies in the traditional biomass sector, since such programmes often involve the targeting of products with particular characteristics and market segmentation on key socioeconomic factors (Johnson and Lambe, 2009).

One of the limitations in using socioeconomic factors to explain stove choice is that these factors change slowly over time and only product-specific characteristics can be easily modified in a relatively short period of time to develop an appropriate stove design with a high probability of acceptance in a target market. Consequently, analyses based on socioeconomic factors alone may not provide valuable knowledge for the practical design of programmes or policies to promote cooking alternatives that have public benefits such as improving energy access or reducing climate impacts. Although socioeconomic factors may help to identify the target market and consumer profile, the scope for intervention is greatly narrowed since these factors are not easily changed. For example, the research on 'factors determining fuel choice in Guatemala' (Heltberg, 2005) found that per capita expenditures, electricity connection, lifestyle, household size, and education were key determinants of fuel/stove choice. The inclusion of product-specific factors in such analyses would complement the socioeconomic factors and help to identify market barriers, desirable product characteristics, and determine the scope for improving market availability of clean cooking alternatives (Goldemberg et al., 2004; Schlag and Zuzarte, 2008). Socioeconomic factors are fixed in the short-term for most individuals, whereas product-specific factors vary based on the availability of new products and on individuals' changing understanding of the alternatives available.

Another shortcoming of previous research on cooking stoves is a lack of understanding of the relative strength or trade-off among the factors affecting stove and fuel choices at the household level (Odihi, 2003; Pundo and Fraser, 2006). Although many factors have been identified and evaluated, the relative strength of key factors (e.g. stove price, fuel price) in influencing fuel/stove choices remains poorly understood. A better sense of how household decision-makers weigh such key factors against each other in their fuel/stove choices would inform the policy process and help to improve the design of cooking stove projects and programmes. Lack of knowledge of these trade-offs has been cited as a key reason for the failure of many clean-cooking stove projects (Barnes et al., 1993; Manibog, 1984) and in other public health/environmental policies (Goodman et al., 2007). For example, if smokiness, safety and usage cost are thought to be important product attributes, then we would like to know how preferences change across the factors. If a marginally higher priced improved cooking stove provides a range of additional benefits, such as reduced smoke, will its price still present a purchasing constraint? If yes, to what extent? What are the overall trade-offs among these factors in relation to stove choice?

From economic theory, the trade-off or relative strength of the factors affecting stove choice can be described as 'part-worth' utility. Lancaster (1966) argued that "utility is derived not from goods per se but from the attributes/characteristics of the goods." In this case, we can say that consumers derive their utilities not from a cooking stove as such, but from its characteristics, such as price, heat energy delivered, cost, smoke, safety, convenience and so on. Hence, the strength of the factors affecting the choice of stove is the weight of the utility that an individual derives from each attribute of a stove.

The relative weight of each attribute or the value of the part-worth utility can be estimated by designing a choice experiment. Choice experiments are an advanced behaviour modelling technique used in the field of transportation, market research, experimental sociology, and more recently in environmental research, to identify factor strength and trade-offs (Do and Bennett, 2008; Provencher and Moore, 2006; Rigby et al., 2009; Takama and Preston, 2008). Alternatives to conducting a choice experiment include ranking and rating-based approaches. However, such approaches carry the risk of people listing every positive attribute such as safety, convenience of use and cleanliness as highly preferred, while negative attributes, such as smoke, price and operating cost, will be listed as the least preferred. It can be difficult to check and/or control for such biases, which can result in the generation of a potentially unrealistic 'wish list' that bears little resemblance to an actual fuel/stove design that could be brought to the market.

Unlike ranking, the choice experiment forces consumers to express their preferences in terms of trade-offs between the attributes. Discrete choice modelling can further help to establish preference orders for different alternatives represented by a set of attributes. Given the limited empirical evidence on the relative strength of factors influencing fuel/stove choice and the successful application of choice experiments in related fields, this research therefore aims to augment the methodological foundations in the area of cooking stove choice as well as providing a specific case study application in a country (Ethiopia) where there is special interest in these issues at the policy level. The next section on methodology explains the approach in detail. As the adopted approach has not been used before for the analysis of fuel and cooking stove choice decisions, the design is described in some detail.

3. Methodology and approach

In order to estimate the relative strength of product-specific factors, we adopted a choice modelling (CM) technique, namely a choice experiment (CE) based on a stated preference survey. In CE-based modelling, a product is described as a collection of attributes. Respondents in a CE are presented with a series of product choices that are differentiated across particular attributes, and are asked to choose the most preferred option (Atkinson and Halvorsen, 1990). The foundation of CE lies in the work of Lancaster (1966), who argued that consumer utility is obtained not from the product itself but from the attributes or characteristics of the product. In this application, consumer utility therefore arises not from the cooking fuel or stove itself, but from key attributes such as heat, price, usage cost, smoke, safety, convenience and so on. By estimating the value of the chosen attributes with a CE, our approach is aimed at discerning the relative strength of these attributes in influencing fuels and/or stove choice preferences.

We use discrete choice modelling (DCM) in order to establish the stove choice preference order. DCM posits that the probability that an alternative chosen is defined as the probability that the given alternative has the highest utility among the available options. In order to estimate the coefficient of the choice attributes, we used a multinomial logit model (MNL). MNL is commonly used for situations when a consumer has to choose a particular (discrete) option from among a set of alternatives that serve a common purpose or provide similar services. The model is based on the work of McFadden (1973) and has been used in the economic evaluation of cooking stove choice (Heltberg, 2004; Narasimha and Reddy, 2007; Ouedraogo, 2006; Pundo and Fraser, 2006). BIOGEME software (Bierlaire, 2003) was used for the parameter estimation.

Designing CE is a critical and challenging part of any stated preference-based choice modelling approach because the results are highly sensitive to the experiment design (Hensher et al., 2005). Furthermore, experimental research and the application of stated preference approaches can be complicated in developing countries, due to factors such as low literacy rates, differences in cultural norms and communication problems. Additional uncertainties are created by the fact that this was the first known application of CE-based research to cooking stove choice analysis. Consequently, this methodology section is concerned mainly with the CE itself, followed by a brief discussion on the survey sample and the discrete choice model. CE design involves the following steps (1) generation of choice options, (2) refinement of choice sets, (3) generation of attributes, (4) attributes label and level allocation and (5) choice sets construction. Our CE design for fuel/stove choice analysis in Ethiopia is discussed below for these five steps.

3.1. Generation of choice options

The first step in choice experiment design involves defining a universal choice set of options. The universal choice set was generated from the baseline data collected in 2005, which revealed that 32 different types of cooking stoves were in use in Addis Ababa (Kassa, 2009). As the 32 stove options are too large for designing CE, the stove options were refined by categorising stoves on the basis of the type of fuel used (e.g. kerosene, wood, charcoal, LPG). Such categorisation does not exclude any option, and thus it does not deviate from the statistical rule of independent and identically distributed rules (Louviere et al., 2000, p. 148). Based on the fuel classification, the universal choice set was regrouped into a choice set of 9 options.

3.2. Refinement of choice sets

The revised universal choice set with 9 options was still too large a choice set for designing the CE, and the list was further refined by eliminating irrelevant options. It is a common practice to remove insignificant or irrelevant options based on the study objectives (Hensher et al., 2005, p. 105). For this research, the relevance of options was evaluated based on four criteria: (1) number of users; (2) distribution across different wealth groups; (3) usage level; and (4) relevance to the study objectives. On the basis of the baseline data analysis in the light of the above criteria, charcoal, kerosene and wood were selected as the three most significant existing options. However, later during informal interviews, local energy experts suggested that charcoal is not an inter-substitutable option as essentially every household uses it for the traditional Ethiopian 'coffee ceremony'. Indeed, most Ethiopian households own a few different stoves, partly for such reasons (Kassa, 2009). Therefore, charcoal as an option was excluded from the choice set, as it is recommended to exclude the non-inter-substitutable dominant option in choice experiment design; the higher the dominance of an option, the less information is extracted from the specific choice set, since most people are unlikely to select other options (Alpizar et al., 2003). Lastly, in order to better understand the switching pattern from traditional to newer modern (and renewable) fuels, an ethanol option was added. Ethanol was also chosen because of its policy-relevance in Ethiopia, as it is being considered as a cleaner cooking alternative that can take advantage of domestic fuel production capacity. Hence the three selected stove/fuel options are wood, kerosene and ethanol.

3.3. Generation of attributes

The next step in CE design is to generate attributes that potentially affect the choice of the identified options. Hensher et al. (2005) suggest three criteria for selection of attributes — it should: (1) affect the choice; (2) be common across other options; (3) be relevant to research questions. As described previously, there are a large number of attributes reported to affect the stove choice decision; however, from a practical CE design perspective, the number of attributes has to be restricted in order for the experiment to be feasible. A compromise in the number of attributes is required to reduce experiment complexity, and is typical in CE designs (Hensher et al., 2005). Hence, in light of the above three criteria and on the basis of a literature review, the detailed analysis of baseline data and a pilot test in some households, four stove attributes were chosen for the CE model; stove price, monthly usage costs, indoor smoke emission level, and safety (Takama et al., 2011). Initially, it was expected that the type of fuel would be considered as an attribute of a stove. However, the baseline data indicated that stoves almost always burn just one type of fuel, and hence the fuel types were assigned as the labels for the stoves.

3.4. Allocation of attribute levels and labels

Levels are defined as constituting a measurement scale assigned to a given attribute as a part of the experimental design. For example, price is one attribute of a stove and its levels are the different prices of stoves. Each allocated level is assigned a name or narrative so that respondents can comprehend the meanings of different allocated levels. A summary of the allocated labels and levels for the three selected fuel/stove options is provided in Table 1.

Price and usage cost label and level allocation were straightforward except that some caution had to be exercised to minimise incentives for strategic behaviour by ensuring that the allocated levels are not too low or high. Three levels were assigned to price and usage cost attributes in each option, as presented in Table 2: the levels correspond to the maximum, minimum and average market prices for each option. Therefore, overall, 9 levels of prices and usage costs were tested in the CE, ranging from ETB 20–500 and ETB 40–320, respectively. The ranges of levels were estimated based on market information gathered from the baseline market data (Kassa, 2009) and the pilot study conducted (Takama et al., 2011). As the label 'price' itself is self-explanatory, there was no need for any new label allocation. However, in the case of usage cost, the label allocation was somewhat more complicated as the term "usage cost" encompasses various sub-attributes such as fuel price and fuel/stove efficiency. During the survey design, local experts noted that a typical household in Addis Ababa has five members. The label usage cost was therefore narrated as "cost incurred per month by a household with five members when the proposed stove/fuel is used for cooking." Such a common narrative helps to minimise subjective and context-specific scale differences. In general the variation with household size in energy consumption and usage cost of a given stove only becomes significant for small households of 1–3 persons (Pachauri et al., 2004), which are quite unusual in Addis Ababa. The survey in our study showed that the average household size was 3.84 and that more than 60% of households had between 3 and 5 members; for such household sizes, the cooking requirements would in fact be quite similar.

The level and label allocation processes for both the smoke and safety attributes were rather complicated due to definition and measurement problems. For example, the level of indoor smoke depends not only on the smoke emitted by the stove but also on the kitchen size, shape/layout, the kitchen's window size, other ventilation factors and the duration of cooking (Heltberg, 2004). Furthermore, a given quantity of smoke as such has no definite meaning as the same quantity of smoke may have a varying composition of many gases and particulates (Naumoff, 2005). Finally, the term "smoke" and any levels assigned to the term are highly subjective, and will differ across respondents. Similar to the smoke attribute, the attribute "safety" also has definition and measurement problems. For example, the term safety and the associated risk level is highly subjective, resulting in varying interpretations for the same risk level or label across the respondents. Furthermore, even for a single respondent, there was a measurement problem; for example, the perception of safety risk depends on the type of measurement and against whom the risks are weighed or applied (e.g. property, individuals, children, whole family, an entire community).

Table 1
Allocation of levels and labels for the four attributes.

	Ethanol	Kerosene	Wood
Stove price (ETB)	{500, 250, 100}	{150, 70, 30}	{120, 50, 20}
Usage cost (ETB)	{60, 120, 160, 320}	{50, 100, 150, 300}	{40, 80, 140, 250}
Indoor smoke	{No smoke, very little smoke}	{Very little smoke, moderately smoky}	{Very little smoke, highly smoky}
Safety risk	{Little unsafe, highly safe}	{Highly unsafe, little unsafe}	{Moderately unsafe, highly safe}

Note: ETB = Ethiopian Birr; the average exchange rate in July 2008 was 9.5 ETB/USD.

Table 2
Descriptive statistics for the ownership of stoves.

Stratum	Sub-stratum	Stove numbers
Type of stove	Kerosene	182
	Charcoal	177
	Electricity	103
	LPG	55
	Biomass	44
	Others	71
No. of stoves owned by a household	1	9
	2	44
	3	93
	4	44
	5	10
	6	5

Given that both attributes–smoke and safety–have measurement problems, it was decided to treat both attributes as pseudo-categorical variables, which assumes a linear distance between each categorical response. Thus, no smoke = 0, very little smoke = 1, moderately smoky = 2, and highly smoky = 3. For the safety attribute, no risk or highly safe = 0, little unsafe = 1, moderately unsafe = 2, and highly unsafe = 3. In order to minimise scale measurement errors, which may arise from subjective differences, Alpizar et al. (2003) and Hensher et al. (2005) have suggested that levels be linked to real life situations through approaches such as case description. Therefore, before conducting the experiment, each of the pseudo-categorical variables was defined as a case description for the respondents. For example, the label "moderately smoky" was defined as a situation when the smoke level inside the kitchen is so high that it causes some discomfort to the eyes and irritation to the throat. Likewise, the label 'highly smoky' was defined as a situation when smoke inside the kitchen is so great that the respondent cannot stay inside the kitchen without opening the windows or doors.

For the safety risk attribute, an analogous case description or narrative was developed: i) Highly safe: zero risk of burn and explosion; ii) Little unsafe: no risk of explosion but risk of burn; iii) Moderately unsafe: risk of both burn and explosion; iv); Highly unsafe: high risk of burn and explosion (specified as one burn and a minor explosion every 2 months). These specifications were used after pilot studies indicated that people had difficulty differentiating between minor risk and high risk. Some effort was also placed in pilot studies and in the survey design narratives to address historical safety experiences that might bias the respondents. In particular, there were perceptions of ethanol as unsafe due to a local company that had marketed a poorly designed and low quality blend of kerosene and ethanol in 2005, known as K-50, which was prone to explosion (Kassa, 2009). Consequently, the safety attribute narrative for the ethanol alternative was adjusted to explain that 100% ethanol would not entail such an explosion risk.

At the end of the experiment, the respondent's understanding of the labels and levels for smoke and safety attributes was tested by asking them to match the above-defined labels and levels of safety and smoke attributes with some of the commonly used stoves having similar features. The test was done for all labels (and thus the associated levels) of safety and smoke attributes. Lastly, the labelling and the allocation of associated levels of safety and smoke attributes were applied in such a way that they could be converted into categorical variables of "smoke" or "no smoke", "risk" or "no risk" with some amount of error. For this reason as well as to optimise the orthogonal design, only two levels were necessary for each smoke and risk attribute option.

Finally, we note that various other "soft" attributes (e.g. comfort, user convenience, associated status or brand, fuel availability, startup time, habits, aesthetic features) also play an important role in choice but are difficult to objectively assess and quantify. Furthermore as discussed previously, the CE design constraint required limiting the number of attributes to the four most significant attributes. Hence, a 'labelled experiment' was used for each fuel/stove option and an 'alternative specific constant' (ASC) was included to capture the cumulative strength of other factors effect on fuel/stove choice (Louviere et al., 2000, p. 220; Hensher et al., 2005, p. 113).

3.5. Choice set construction

In this step, the identified attributes and its levels are manipulated systematically by using statistical design theory. In CE design, given the above defined options, attributes and levels, it is possible to design 110,592 different types of choices, each corresponding to some specific bundle of attribute levels for a given fuel/stove. Hence, although it may generate some biases (Louviere, 2006), it is a common practice to use fractional design to reduce the number of choices to a manageable size by ignoring the interaction effects (Hensher et al., 2005, p. 110). Using orthogonal design technique with the help of SPSS software, the number of choices was reduced to 32 choice sets. However, the 32 choice sets were considered too large for each respondent to handle; hence, 4 blocks were introduced and the number of choice sets was reduced to 8 choices. In order to reduce cognitive burden, three options were introduced in pairs. One experiment was randomly repeated for each respondent in order to verify consistency. When the two-step-pair-wise data was entered into BIOGEME, this experiment was treated as one-step-three-option choice. More generally, the orthogonal design as applied to the choice sets was aimed at providing an appealing survey approach that could be easily understood by respondents.

3.6. Survey and sampling frame

For a statistically sound representation of respondents with mutually non-exclusive socioeconomic stratum (e.g. age, wealth, education and gender), a stratified cluster random sampling technique was adopted. Further, for a given socioeconomic stratum, the sub-stratum was selected in a manner such that it was mutually exclusive and collectively exhaustive. The sample size for the household survey was 200 households and for each stratum a minimum of 30 samples was ensured. The choice experiment design thus involved eight treatments per respondent plus the one repeated experiment, resulting in a total sample size for the choice experiment of 1800. The choice experiment therefore included nine experiments for each respondent, in which there were three different fuel/stove options. A structured household questionnaire was also carried out to collect socioeconomic information and the respondent's observed preference for cooking energy choice; however, we describe in this paper only the stated preference CE and the associated analyses.

Pilot testing of the questionnaire and choice experiment was carried out in two stages in Addis Ababa, Ethiopia. The first and second pre-tests were conducted by the staff of Gaia Association, Ethiopia during June–July, 2008. The main survey was then executed during July 2008. For designing the choice experiment, initial data analysis was carried out on the baseline data collected in 2005. Prior to the field work, a focus group discussion had been conducted in Stockholm in May 2008 with four energy experts, two of which were from Ethiopia and had long experience in household energy issues. Upon the completion of the household survey, one more focus group discussion was held in Addis Ababa with 18 cooking fuel consumers, representing different socioeconomic groups and different geographical areas of Addis Ababa city. This latter meeting was used to gather valuable background (mainly qualitative) information about cooking stove and fuel choices in Addis Ababa.

3.7. Discrete choice model

In order to explicitly analyse the tradeoffs across the selected attributes, we designed and applied a discrete choice model based on the standard multinomial logit framework (McFadden, 1973). The utility is expressed as the sum of the unobserved (non-stochastic) utility

V and the error term ε, i.e. U = V + ε: The model is designed to ascertain the probability of choosing one of the three fuel/stove alternatives, i.e. wood, kerosene or ethanol. The logistic form of the fitted model for choosing a given fuel/stove will have the same structure in each case; for the Ethanol stove, the model is:

$$P(\text{Ethanol}) = \frac{\exp\left(V_i^E\right)}{\exp(V_i^E) + \exp(V_i^K) + \exp(V_i^W)}.$$

P(Ethanol) is the probability of choosing an ethanol stove in a given situation. The specific form of the model chosen was based on testing the different combinations and comparing the results to the underlying theoretical basis for the choice sets and the inherent limitations in the data set. The next section describes the models that were tested and provides the results for the model that was chosen.

4. Results

In this section, we provide the results of the choice experiment and model development, including a summary of the survey statistics and a detailed description of the logit model. Of special interest in this research is the relative strength of the product-specific factors in influencing fuel/stove choices. The estimated parameters for the model are thus presented and discussed in terms of their explanatory value with respect to fuel/stove choice. The inclusion of wealth as an endogenous variable alongside the product-specific factors is evaluated and differences across wealth groups are compared and discussed. The results are also compared with intuitive expectations resulting from the background research, detailed focus group discussions and pilot studies that were carried out.

4.1. Descriptive statistics

A total of 632 stoves are owned by the surveyed 200 households, and the typical household in this sample owned 3 cooking stoves (Table 2). The maximum number of stoves owned was 6, which is the case for 5 households and only 9 households owned one stove. Kerosene and charcoal-burning stoves are the two most popular stoves, owned by 182 and 177 households, respectively. A conventional or "traditional" stove that burns some type of biomass (e.g. fuel wood, charcoal, agricultural residues) was owned by approximately 90% of the sampled households, indicating the continued importance of traditional biomass even in an urban area, as is common in sub-Saharan Africa.

There are several explanatory factors for the ownership of multiple stoves and the popularity of biomass-burning stoves (in an urban area). First, charcoal is required for the traditional coffee ceremony in which essentially all households engage, and charcoal can be used in basically any biomass-burning stove. However, it is generally not used extensively for cooking food due to a combination of cost and convenience compared to other fuels. Second, for reasons of taste or tradition, fuelwood may be preferred for the preparation of injera, the bread that forms a staple food of the Ethiopian diet. Finally, multiple stoves allow economic flexibility in terms of switching fuels, which is seen as valuable due to recent historical experience with the fluctuating prices of kerosene and the increasing scarcity or inconvenience of fuelwood (Kassa, 2009; Kebede et al., 2002). Since the focus of this research is on fuel/stove switching, the primary cooking (and water heating) needs are the most relevant and thus we do not expect the ownership of multiple stoves to have a significant effect on the results. Since charcoal was specifically excluded for the above reasons, the experiment design facilitates a more direct comparison between the fuels that could compete as the primary fuel/stove in a given household, namely kerosene and fuelwood, along with the addition of ethanol as a potential new alternative.

The wealth status of each household was determined not by income or expenditures but by contextualised information gathered by surveyors including indicators such as assets ownership, type of household, occupation. The surveyors made final judgment if a household should be classified as having low, middle, or high wealth-level. In developing countries, it is difficult and often unfitting to characterise wealth only by salary, household income or expenditures; they often participate in informal markets and in-kind exchanges and their income may often come from various other sources, such as agricultural labour or support from other household members and relatives.

The surveyor's judgment reveals the correlation of wealth with other social characteristics such as occupation, education, gender, type of house, and total fuel expenditure. Table 3 shows that the high-wealth group tends to have high level of education compared with other wealth groups. The high and middle wealth groups have stable employment, but not daily wage labour. The majority of the high-wealth group has a new house. The majority of the middle-wealth group has an old house and only three households have a thatched house. Only one household in the low-wealth group has a new house and more than a third of households have a thatched house.

Moreover, the total household energy expenditures are significantly different between the three wealth groups. An average high, middle, and low wealth household spends 437.4 ETB, 162.6 ETB, and 80.56 ETB on energy, respectively (Fig. 1). Based on these descriptive statistics, we concluded that the surveyors' judgment on wealth categorisation is justifiable.

4.2. Experiment results and model estimation

In order to evaluate the four product-specific factors together with socio-economic factors, various model structures were tested. Given the importance of wealth as an explanatory variable in the scientific literature, an intuitive model structure is one that is based on wealth segmentation, in this case with three classes (low, medium, high). With this structure, the following utility functions can be specified for the three alternatives across the different socioeconomic strata, where V is the

Table 3
Descriptive statistics for household numbers.

Stratum	Sub-stratum	High-wealth	Middle-wealth	Low-wealth
Gender of household head	Male	35	35	41
	Female	31	23	33
Education	Illiterate	0	2	9
	Literate without formal schooling	1	1	2
	Literate below primary	1	1	2
	Primary	2	1	15
	Middle	3	5	9
	Secondary	16	11	20
	Diploma/certificate	14	23	10
	Graduate	14	14	5
	Post graduate	14	1	0
Occupation	Farmer	1	0	0
	Daily wage labour	0	0	12
	Government employee	18	21	16
	Private business employee	14	15	19
	Self-employed—non-agriculture	19	11	11
	Student	0	2	0
	Others	11	9	13
	None	2	1	3
Type of house	New	35	16	1
	Old	31	40	52
	Thatched	0	3	21

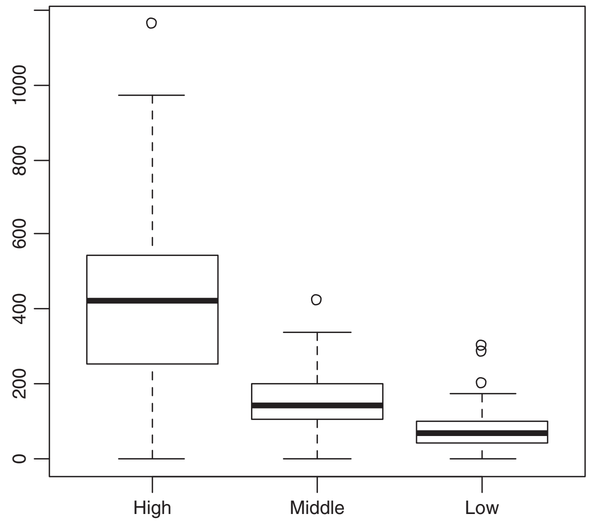

Fig. 1. Total energy expenditure of high, middle, and low wealth groups (ETB).

non-stochastic (unobserved) utility (i.e. $U = V + \varepsilon$) for each of the three fuel/stove options:

$$
\begin{aligned}
\text{Ethanol}: V_i^{E} = {}^{E} &+ \beta^{cost_H}(cost_e H) + \beta^{cost_M}(cost_e M) + \beta^{cost_L}(cost_e L) \\
&+ \beta^{price_H}(price_e H) + \beta^{price_M}(price_e M) + \beta^{price_L}(price_e L) \\
&+ \beta^{smoke_H}(smoke_e H) + \beta^{smoke_M}(smoke_e M) \\
&+ \beta^{smoke_L}(smoke_e L) + \beta^{safety_H}(safety_e H) \\
&+ \beta^{safety_M}(safety_e M) + \beta^{safety_L}(safety_e L) \\
\text{Kerosene}: V_i^{K} = \alpha^{K} &+ \beta^{cost_H}(cost_k H) + \beta^{cost_M}(cost_k M) + \beta^{cost_L}(cost_k L) \\
&+ \beta^{price_H}(price_k H) + \beta^{price_M}(price_k M) \\
&+ \beta^{price_L}(price_k L) + \beta^{smoke_H}(smoke_k H) \\
&+ \beta^{smoke_M}(smoke_k M) + \beta^{smoke_L}(smoke_k L) \\
&+ \beta^{safety_H}(safety_k H) + \beta^{safety_M}(safety_k M) \\
&+ \beta^{safety_L}(safety_k L) \\
\text{Wood}: V_i^{W} = \alpha^{W} &+ \beta^{cost_H}(cost_w H) + \beta^{cost_M}(cost_w M) + \beta^{cost_L}(cost_w L) \\
&+ \beta^{price_H}(price_w H) + \beta^{price_M}(price_w M) + \beta^{price_L}(price_w L) \\
&+ \beta^{smoke_H}(smoke_w H) + \beta^{smoke_M}(smoke_w M) \\
&+ \beta^{smoke_L}(smoke_w L) + \beta^{safety_b H}(safety_w b_H) \\
&+ \beta^{safety_b M}(safety_w b_M) + \beta^{safety_b L}(safety_w b_L).
\end{aligned}
$$

The variable and parameter names relate to relevant product-specific factors, as shown in Table 4 with the variables defined by pairing the four product-specific factors with the three wealth classes (L = low; M = medium; H = high). For example, cost_e_H is the cost variable for ethanol stoves and high wealth households. The α term represents a relevant alternative specific constant (ASC), with that of firewood fixed as zero. All fuel/stove alternatives use the same parameters except for the safety of firewood, which is expressed as $\beta^{safety\text{-}b\_I}$ (where b signifies burn risk only, and I = H, M, or L) since the safety issues are different between liquid and solid fuels, i.e. firewood does not have an explosion risk. The probability of choosing a given fuel/stove is defined as given in Section 3.7. This model was estimated using BIOGEME and the results are given in Table 4.

In addition to wealth, various models were tested with different combinations of socioeconomic attributes, including education, gender, and age. The only statistically significant and logically acceptable socioeconomic attribute was wealth level, and none of the models tested outperformed the wealth-segmented model given above. As shown in Table 3, wealth is correlated with other socioeconomic factors, and is well-established as the most important among these as an explanatory variable. For example, the effects of education and age factors are veiled by the wealth factors, e.g. the high wealth group tends to be highly educated and older. It is also difficult for gender to serve as an explanatory variable: although women do most of the cooking, the person who does the cooking and the person who decides on the stove purchase differ within wealth groups as well as across wealth groups. Low-wealth and middle-wealth households tend to cook themselves, whereas in high-wealth households, a cook or maid does the cooking. In order to account for such effects, the data would have to include who is making the decision, but there is no easy way to control for such a variable.

With the exception of usage cost and stove price for the high wealth group, the parameters were statistically significant at the 95% level, or the 90% level in the case of the ASCs. Wealth segmentation was used with all variables except the ASC variables, as the wealth-segmented ASC parameters proved to be statistically insignificant. The discussion sections below address this issue further, in terms of whether there is an a priori reason for a given option to be generally preferred and thus be reflected in the sign and strength of the ASCs. The meaning and importance of the estimated parameters is discussed further below, including the magnitude and sign of coefficients, the relative strength of attributes and some general aspects of the overall model design and subsequent representation of attributes.

4.3. Significance, sign and magnitude of coefficients

A total of 15 attributes were specified in the wealth-segmented model that was chosen as being the most intuitively appealing and empirically correct design. At the 90% level, 13 of the coefficients were significant; the stove price and usage cost attributes for the high-wealth group were insignificant. The strength of each attribute on fuel/stove choice is indicated by the magnitude of the respective attribute coefficient value, as presented in Table 4. The associated positive and negative signs show whether a particular coefficient increases or reduces utility. The sign of the coefficients conforms to expectations for the most part. The sign is negative for cost and price, indicating decreased utility, except for stove price in the case of high-wealth households. The sign is positive for the safety attribute in all cases and was also similar in magnitude. The sign was negative for smoke, with the exception of the low-wealth group, which had a positive sign for the smoke coefficient, a point that is discussed further in Section 4.5.

The usage cost and stove price coefficients were similar in magnitude for low and middle-wealth groups, indicating that they obtain comparable levels of utility at lower stove prices or usage costs. The usage cost and price coefficients for the high-wealth group were small in magnitude as well as being statistically insignificant. The results suggest that the high wealth group is generally indifferent or only mildly affected by stove price and usage cost. The results are not so surprising since energy costs form a rather small share of overall expenditures for high-wealth households (Kebede et al., 2002). Another result that stands out for the high-wealth group is their high aversion to smoke compared to the low-wealth and middle-wealth groups, as evidenced by the high negative coefficient for smoke. This high aversion to smoke in combination with the high-wealth group's near indifference to stove price suggests that some respondents may have had pre-conceived notions that more expensive stoves are always associated with less smoke.

The tendency to associate more expensive stoves with less smoke could also affect the estimation of the ASC parameters. The ASC (α) coefficient has the following preference order: the highest for ethanol (0.344), followed by wood (0.00) and lowest for the kerosene option (−0.350). This indicates that, other things being equal, ethanol is preferred to wood and kerosene stoves; furthermore, it also shows that people prefer wood to kerosene. There is also the possibility

Table 4
The general parameters derived from the BIOGEME model. Note: "*" indicates insignificance at 5% level and "**" indicates insignificance at 10% level.

Parameter name	Description	(Coefficient)		P-value		
α^{E}	Alternative specific constant ethanol	0	.344	0	.10	**
α^{K}	Alternative specific constant kerosene	−0	.350	0	.06	*
α^{W}	Alternative specific constant wood					
β^{cost_L}	Usage cost for low wealth group	−0	.003	0	.00	
β^{cost_M}	Usage cost for middle wealth group	−0	.003	0	.00	
β^{cost_H}	Usage cost for high wealth group	−0	.001	0	.13	**
β^{price_L}	Stove price for low wealth group	−0	.004	0	.00	
β^{price_M}	Stove price for middle wealth group	−0	.002	0	.00	
β^{price_H}	Stove price for high wealth group	0	.0003	0	.47	**
β^{smoke_L}	Indoor smoke emission level for low wealth group	0	.149	0	.03	
β^{smoke_M}	Indoor smoke emission level for middle wealth group	−0	.203	0	.01	
β^{smoke_H}	Indoor smoke emission level for high wealth group	−0	.522	0	.00	
β^{safety_L}	Safety level for low wealth group	0	.273	0	.00	
β^{safety_M}	Safety level for middle wealth group	0	.313	0	.00	
β^{safety_H}	Safety level for high wealth group	0	.342	0	.00	
$\beta^{safety\text{-}b\_L}$	Burn safety level for low wealth group	0	.196	0	.00	
$\beta^{safety\text{-}b\_M}$	Burn safety level for middle wealth group	0	.321	0	.00	
$\beta^{safety\text{-}b\_H}$	Burn safety level for high wealth group	0	.344	0	.00	

Summary statistics.
Number of observations: 1795.
$L(0) = -1972.009$.
$L(\beta) = 1682.503$.
$\rho^{2}(\beta) = 0.139$.

that the limitations of the choice experiment affected the estimation of the ASCs: due to a limited number of experiments and some faulty preconceptions about each option. For example, although ethanol stoves may be widely preferred, many may perceive ethanol stoves as dangerous, i.e. a faulty preconception from the explosion accidents of the previous kerosene–ethanol combined stoves (Kassa, 2009). This may have affected the significance of the ASC parameter for ethanol as well as for the other two alternatives.

4.4. Relative strength of attributes

The relative strength of attributes in a standard logit model of this type can be evaluated based on their ratio, as presented in Table 5; in this case, they are normalised to the stove price attribute. It can be also be interpreted as the Marginal Rate of Substitution (MRS), which is the rate at which one unit of an attribute is substituted for another, while maintaining the same level of utility. By normalising the MRS to stove price (given in ETB), the parameters can also be considered as the Marginal Willingness to Pay (MWTP), which is the value in terms of one stove price unit that a respondent would pay to receive one more or one less unit of another attribute specified in the model.

The sign of the MWTP value is negative in several cases. In the case of the safety attribute, the partial utility increases as the level increases, which is unlike the other attributes, i.e. a safety parameter with a positive sign is divided by a stove price parameter with a negative sign to calculate its MWTP value. The MWTP value for the smoke attribute for the low-wealth group is also negative as its parameter has a positive sign. A negative sign is interpreted, for example, as "a consumer is willing to pay a higher stove price to increase the safety level" since in this case it is an exchange between an attribute reducing one's utility (stove price) and another attribute increasing the utility (safety).

Table 5
Marginal Willingness to Pay (MWTP) relative to the stove price in Ethiopian ETB (ETB).

	Stove price	Usage cost	Safety for explosion	Safety for burning	Indoor air smoke
Low-wealth	1	0.832	−65.930	−47.260	−36.005
Middle-wealth	1	1.244	−137.200	−140.328	88.796

The MWTP calculation for the high-wealth group is not included in Table 5. The basis of the MWTP calculation includes the parameter for stove price, which is statistically insignificant at 10% level. Therefore the entire MWTP calculation is insignificant for the high-wealth group, i.e. the denominator of the calculation cannot be specified in statistical terms (Hensher et al., 2005, p. 354).

As the unit and scale used for the attributes differ for safety and smoke, a comparison of the relative strength of attributes based on coefficient value can only be directly assessed in economic terms for the stove price and usage cost attributes. The estimated MWTP value for the usage cost attribute is lower for the low-wealth group at 0.832 ETB, which is followed by 1.244 ETB for the middle-wealth group. For example, these numbers are interpreted as follows: in the case of the middle-wealth group, the corresponding stove price and usage cost coefficients were more than "1", and so the MWTPs indicate that usage cost is likely to be more important factors than stove price in purchase decisions made by households in the middle-wealth group.

In other words, The MWTP for stove price is simply the inverse of the MWTP for usage cost. For 1 ETB reduction in stove price the low and middle-wealth groups are willing to pay 1.244 ETB and 0.832 ETB respectively, indicating that with an increase in the level of wealth, the MWTP for increased stove price decreases significantly. The trade-off between stove price and usage cost is essentially the primary economic trade-off in the fuel/stove switching issue.

The value of MWTP for explosion safety shows that the low-wealth group is willing to pay 65.930 ETB, followed by 137.200 ETB for the middle wealth group, for an increase in the level of safety for explosion. Similarly, for a unit increase in the level of safety for burn, the low wealth group is willing to pay 47.260 ETB, followed by 140.328 ETB for the middle-wealth groups, respectively. The MWTP value for both safety factors thus increases with increase in wealth level, which is expected.

The MWTP value of the indoor smoke attribute shows that the middle-wealth group is willing to pay 88.796 ETB, respectively to lower the indoor smoke, while the low wealth group is willing to pay 36.005 ETB for an increase in the level of indoor smoke emission attribute.

4.5. Discussion of results

Most of the model parameter results conform to expectations in terms of the general patterns and the differences across wealth groups. The comparison between stove price and usage cost is the easiest to interpret in economic terms, since the other two attributes (safety and smoke) are categorical variables. The coefficient for stove price (β^{price}) was more than 80% higher (in absolute value) for the low-wealth group compared to the middle wealth group, showing the much greater sensitivity to stove price of low-wealth households (Table 4). The difference with the high-wealth group was even greater but since the coefficient (β^{price}) was positive and statistically insignificant we cannot compare the two values. Overall, the figures illustrate that with an increase in the level of wealth, the strength of the stove price attribute as a factor in fuel/stove choice decreases significantly.

The MWTP of the stove price for the low-wealth group with respect to usage cost was 0.832, meaning that they are willing to pay 0.832 ETB in stove price for a 1 ETB reduction in usage cost to get the same level of overall satisfaction (Table 5). The middle-wealth group had a MWTP of 1.25 so that they are willing to pay 1.25 ETB in stove price for a 1 ETB reduction in usage cost. Thus, the low-wealth group is willing to pay 50% less (relative to stove price) compared to middle-wealth group for the equivalent adjustment in usage cost. For example, since a 1 unit worth reduction in usage cost means a saving of 9.96 ETB a year for the low-wealth groups (usage costs were calculated or assumed on a monthly basis, i.e. 12 months times 0.832 ETB), it appears that the low-wealth group adopts a very high discount rate. The high wealth group appeared to be essentially indifferent to stove price, which suggests a low capital cost constraint and/or a low discount rate; the high-wealth households will tend to own many other appliances, and the stove is most likely one of the cheaper ones. Consequently, the results for the trade-off between stove price and usage cost seem to reflect the classic discount rate issue when it comes to paying upfront for improved performance or energy efficiency, even when the savings are significant (Brouwer and Falcao, 2004; Karekezi and Majoro, 2002; Kebede et al., 2002).

As discussed previously, the usage cost (β^{cost}) coefficients were negative and significant for the low and middle wealth groups, confirming the expectation of negative utility with higher usage cost, other things being equal (Table 4). The coefficient was 21% higher (in absolute value) than for the middle-wealth group and much higher (345%) than for the high-wealth group. Consequently, other things being equal, a given increase in the usage cost will have the most negative impact on the low-wealth group. Similarly, the estimated MWTP for a decrease in stove price was highest for the low-wealth group, as they are the most sensitive to upfront costs (Table 5). The two main factors that affect usage cost are stove efficiency and fuel price, and hence deductively we can infer (assuming fixed fuel price) that with an increase in wealth, people are willing to pay more for a more efficient stove. Since the MTWP is lowest for the low-wealth group, this would mean that a reduction in fuel price will have maximum welfare benefit on the low-wealth group.

Both safety coefficients–for explosion (β^{safety}) and burn ($\beta^{safety\text{-}b}$)–show, as expected, that all the three wealth groups prefer and are willing to pay for a safer option (Table 4). The MWTP values for explosion safety indicate that the middle-wealth group is willing to pay approximately twice more than the low-wealth group in terms of relative importance with the stove price (Table 5). For burn safety, the middle-wealth group is willing to pay approximately three times more than the low wealth group for a unit improvement. These results are generally consistent with the energy ladder theory in which modern energy sources that give improved performance (including safety) are preferred as wealth increases.

The comparison of the safety for burn and explosion MWTP values shows that the low-wealth group is willing to pay considerably more for an increase in explosion safety than burn safety (Table 5); this result seems logical since an explosion is potentially more dangerous and can impact the entire household whereas a burn is localised–and in the case of wood or charcoal–would be less serious and easier to treat. Furthermore, the low wealth group is much more familiar with biomass stoves and thus more able to prevent burns associated with them. The middle-wealth group is willing to pay considerably more than the low-wealth group for both types of increases in safety, and the difference in MWTP between the two types of safety is quite small, indicating that they view safety as highly important in a general sense, i.e. they do not differentiate among the two safety issues. Again, this result is somewhat consistent with the energy ladder theory regarding the adoption of modern energy sources with improved service and performance.

The indoor smoke (β^{smoke}) coefficient results illustrated that smoke is an important factor affecting the choice decision of all three wealth groups, as they were statistically significant and of a relatively high magnitude in all three groups (Table 4). As with the other attributes, the differences across wealth groups were significant. The MWTP for the middle-wealth group is 2.46 times greater than the low wealth group (Table 5). It is important to note that smokiness is a key factor among the softer (non-monetary) product attributes as it differentiates fairly clearly modern from conventional options, since it generally implies a switch from solid biomass to liquid or gaseous fuels, and thus the smoke attribute is important in evaluating fuel/stove switching patterns. Again, from a fuel/stove switching perspective, the results for the smoke attribute point to the energy ladder pattern with increasing level of wealth leading to greater aversion for indoor smoke emissions.

The positive sign and statistical significance of the smoke coefficient for the low-wealth group requires some special consideration (Table 4), since it leads to the conclusion that low-wealth households actually prefer more smoke! In fact, there are a number of underlying issues that can explain this somewhat counter-intuitive result. First, the magnitude of the coefficient is less than the magnitude for the middle-wealth group and much less than that of the high-wealth group, and thus their preference is not as strong. Second, there are actually some attributes of smoke that are valued: for example, smoke keeps away mosquitoes and other bugs. Third, the low-wealth group is more likely to cook outdoors and/or live in homes that are less airtight, whereas smoke is more bothersome and more difficult to deal with in modern high-rise apartments (Kassa, 2009). Similarly, the low-wealth group has extensive experience with biomass stoves and almost none with other stoves and thus they are accustomed to the smoke and are more likely to discount its impact. Finally, the observed “preference” for smoky stoves may veil some correlation due to the pre-conceived tendency to associate less smoke with higher stove price, as was the case with the high-wealth group.

It is important to note that safety and smoke are continuous in reality, whereas in this model they are pseudo-categorical variables represented as multi-level dummy variables. The variables were designed as ordinal categories (e.g. low, mid, high) and thus the transformation of the inputs into cardinal numbers assumed equal distances between levels. Unlike the tangible variables of cost and price, respondents are more likely to have differing perceptions of the same level of safety or smoke. An alternative could be to use binary variables to reduce such variation if the objective is mainly to ascertain the overall valuation of safety and smoke attributes. However, the three fuel/stove options presented have qualitatively different safety and smoke characteristics, especially when comparing solid and liquid fuels. Consequently, binary variables would be inappropriate. Since the choice experiment included narratives designed to convey the meaning of the multiple levels, we cannot test such a binary approach without running another choice experiment. Moreover, since these soft factors are difficult to measure and estimate, any approach would have to be tailored somewhat to the alternatives and the context, and other approaches could be tested in the future. For example, ordinal variables might be adopted, using a latent variable framework where the values are indicators of a latent variable (Provencher and Moore, 2006).

To analyse in more detail the effect of socioeconomic factors together with the product-specific factors (where we have placed greater emphasis) in a future study, larger sampling might be required. A future study with larger sampling may show significance for other socioeconomic factors, but the focus of this study has been on the product-specific factors with wealth categorisation or segmentation. The wealth characterisation was addressed with a stratified-cluster sampling design, which usually reduces sampling errors from a simple cluster sampling and reduce survey errors (Henry, 1990, p. 109). A stated preference survey and choice experiment in developing countries is complicated and could have large survey errors due to low literacy rates, the limited capacity of surveyors, etc., and thus it is necessary to design a stratified sampling to test other socioeconomic factors.

5. Conclusions

A switch from traditional biomass stoves to modern clean, safe and efficient stoves could enhance the welfare of the 2.7 billion people worldwide that lack energy access and help to reduce negative health and environmental impacts associated with traditional biomass use. In order to provide improved information for the design of cooking stove programmes and policies, this research empirically investigated the theoretical dimensions of factors determining fuel and stove choice at the household level. The study aimed to give particular attention to product-specific factors and thus the model design incorporated four such factors (usage cost, stove price, safety, and smokiness) along with three wealth classes. A choice experiment with 200 households in Addis Ababa using a stated preference survey was combined with a discrete choice model in order to evaluate the strength of the product-specific factors in influencing fuel/stove choice. The standard-form logit model that was estimated using BIOGEME included some 15 parameters, of which 13 were statistically significant at the 90% level. To the authors' knowledge, this is the first application of such a methodology to the fuel/stove choice problem.

The model results showed that low-wealth households were much more sensitive to stove price than middle and high-wealth households. The low-wealth group was also more sensitive to usage cost than the middle and high-wealth groups, but they were more willing to pay for reductions in usage cost than they were for reductions in stove price, suggesting the use of a high discount rate. The high and middle-wealth groups were also willing to pay considerably more than the low-wealth group for reductions in indoor smoke and increase in safety. The low-wealth group was willing to pay more for a reduction in explosion risk compared to burn risk, which is logical given the fact that low-wealth groups are much more familiar with burn risks as these are associated with solid biomass use, whereas explosion risks present an unknown hazard. Similarly, the low-wealth group showed a preference for smoky fuels/stoves, which, although counterintuitive in general terms, fits with their experiential knowledge of biomass stoves and the fact that they are more likely to cook outdoors and less likely to live in airtight apartments. The results were broadly consistent with the energy ladder theory in which consumers or households tend to choose more advanced stoves and fuels as their wealth increases.

The methodology introduced here, namely, combining a choice experiment with stated preference survey methods and discrete choice analysis, could be a promising way to explore more deeply the factors that affect fuel/stove choice in developing countries. As policy-makers seek to improve energy access and to reduce climate and health impacts of traditional biomass, a sharper set of analytical tools could better inform the design of new cooking stove programmes. This research also illustrates the value of incorporating product-specific factors such as usage cost, stove price, safety and smokiness along with socioeconomic variables. Other product-specific factors (e.g. food taste, convenience, start-up time, aesthetics) could be interesting to include in future research. Since cooking stove programmes are increasingly aimed at bringing new advanced stoves to the market, an approach such as this will be needed in order to consider the attributes of both existing and future cooking stoves within a unified and consistent analytical framework that facilitates the explicit evaluation of different attribute levels, trade-offs and household preferences.

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