Cooking Fuel "Stacking" Implications for Willingness to Switch to Clean Fuels in Peri-urban Kathmandu Valley, Nepal

by

Bridget Rogers

Duke Global Health Institute
Duke University

Date: ______________________
Approved:

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Marc Jeuland, Advisor

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Lawrence Park

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Ipsita Das

Thesis submitted in partial fulfillment of
the requirements for the degree of
Master of Science in the Duke Global Health Institute
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ABSTRACT

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Abstract

Cooking fuel "stacking," or the use of multiple types of fuels, can be problematic in interventions when households are using both clean and dirty fuels at the same time. Dirty fuels such as firewood contribute to indoor air pollution, cause detrimental health effects, and are inefficient forms of energy. In this study, cooking fuel preference data was collected from 360 households in peripheral-urban Kathmandu, Nepal during August 2019. Respondents provided fuel information and gave economic preferences for a contingent valuation experiment on their reported primary fuel type. We explored two aims through multiple regression analyses: the relationship between fuel stacking behavior and willingness to pay (WTP), and the household characteristics associated with fuel stacking behavior. The analyses showed that stacking does not affect WTP, and household expenses are a significant factor associated with WTP only among households using LPG as their primary fuel. The secondary aim found that the main household characteristics associated with fuel stacking are household size, firewood gathering behavior, and if the household was affected by the 2015 LPG blockade. The relationships of these characteristics are complex and depend on whether the household is using more LPG or more firewood when stacking. More research is needed to better understand fuel stacking, and why most people in peri-urban Kathmandu prefer LPG as their primary fuel.

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1. Introduction

Approximately 3 billion people around the world use "dirty" cooking fuels that cause detrimental health effects, generate particulate matter (PM) air pollution, and are inefficient forms of energy ("Goal 7: Sustainable Development Knowledge Platform," n.d.). Dirty cooking fuels that cause incomplete combustion and emit smoke consist of biomass like firewood or dung, charcoal, or kerosene. Clean cooking fuels produce comparatively much less PM/smoke when burned, and include liquified petroleum gas (LPG), electricity, and biogas. While clean fuel sources are promoted and sometimes subsidized by governments, the progress of transitioning to these fuels is typically gradual. It is estimated that approximately 2.3 billion people will continue to use dirty cooking fuels in 2030 (Schunder & Bagchi-Sen, 2019).

The concept of an "energy ladder" is often used to describe the energy transition in low- and middle-income countries (LMICs) from undesirable/dirty fuels to clean energy. Among low resource populations, biomass fuel may be the only option either due to availability or low cost. The bottom of the energy ladder is represented by the use of dirty biomass fuels, and movement up the ladder corresponds to the use of transitional fuels like kerosene or transitional stoves like efficient/improved biomass technology, followed finally by the use of clean fuels like LPG and electricity at the top of the ladder (Schunder & Bagchi-Sen, 2019). While it is expected that regions will move up the energy ladder as cleaner fuels become available and affordable, this is not always the case. The metaphorical ladder was previously thought to be linked to the economic standing of any household, meaning that income was the main determinant of fuel choice, and a household would switch as income permitted. Yet recent studies have shown that the energy transition is more nuanced, as socioeconomic changes along with societal preferences and other factors may come into play in determining which fuels, or combination of fuels, a household chooses (Hiemstra-van der Horst & Hovorka, 2008).

Attempts to modernize forms of energy and cooking fuel in LMICs can be successful, but interventions can also lead to only partial switches, where households use clean fuels but also continue to use dirty fuels. The use of multiple types of stoves or cooking fuels is referred to as "stacking" and can result from an "accumulation of energy options" in which traditional dirty fuels are still used alongside transitionary or clean fuels (Hiemstra-van der Horst & Hovorka, 2008; Brooks et al., 2016). Fuel stacking goes against the logic of the energy ladder model and contributes to the lack of health and environmental improvements that are the goals of clean cooking interventions (Jeuland et al., 2015). However, stacking also provides a benefit for the households who engage in it, as stacking persists in many areas of the world.

The decision to stack fuels may not always be affected by income or financial concerns. A 2008 study on energy preferences conducted in Maun, Botswana found that households preferred to use fuelwood as an energy source despite having the income to afford switching to clean alternatives. Fuelwood was used by 86% of respondents overall, and 89% of households used two or three types of energy sources. The study results showed that respondents used energy in a complex way and tended to prefer fuel stacking and traditional fuelwood despite access to clean alternatives (Hiemstra-van der Horst & Hovorka, 2008). This study is just one example, but stacking behavior is common worldwide.

Another study in rural China found that fuel stacking has increased in the past several decades, as the number of rural households using only one type of fuel decreased from 28% to 11% from 1992 to 2012. The study found that the use of both biomass and gas fuels led to excess energy use, at an estimated 40% increased rate from cooking and 20% increased rate from heating. In areas like rural China, stacking behavior and differential energy transition rates mean that the actual transition to clean fuels is quite complex (Zhu et al., 2019).

It has been well documented that household air pollution (HAP) released through the incomplete combustion of solid fuels can lead to detrimental health effects, such as lung disease, respiratory illness, cataracts, and cardiovascular disease risks (Shupler et al., 2019). Globally, four million annual deaths can be attributed to household air pollution. In southeast Asia, the burden of disease from HAP is high. In

India, approximately 770 million people (70% of the population in 2017) use solid fuels as their primary cooking fuel. Exposure to HAP accounts for almost one million premature deaths each year and is the third highest source of disability-adjusted life years (DALYs) (Pillarisetti, Jamison, & Smith, 2017). Improvements to health outcomes based on HAP exposure are often found when a household ceases the use of dirty biomass fuels and fuel stacking behavior, since any exposure to PM can lead to health effects. Understanding this stacking behavior and its benefits to households is important to making progress towards completely clean and sustainable energy transitions.

In order to best interpret the results of this study, it is important to understand the determinants and implications of cooking fuel stacking behavior. Among rural Indian households, it has been noted that the approach of trying to replace traditional stoves that are often "demonized as wasteful, unhealthy, dirty and obsolete" is likely not the best approach to encourage lasting change to cleaner cooking fuels (Khandelwal et al., 2017). A slower shift may be necessary in order for communities to move towards clean fuels, therefore embracing the idea of cooking fuel stacking as a transitionary step may be helpful (Khandelwal et al., 2017). Other recent interventions encourage cooking fuel stacking, instead of pushing for households to fully switch to clean fuels immediately (Hiemstra-van der Horst & Hovorka, 2008). Even in interventions that promote new technology, continued use of traditional stoves is typically observed (Pattanayak et al., 2019).

The rationale for cooking fuel stacking can be viewed from multiple angles. The first step is accepting that the relevance of income and household characteristics, while important, may be exaggerated in some contexts, and the financial-only view of cooking transitions "oversimplifies the complex dynamic interactions among technology, habits, cultural norms, preferences, and behavior involved in the transitions" (Ruiz-Mercado & Masera, 2015).

The adoption of clean cooking fuels can be affected by seasonal changes that affect household incomes and actual access to fuel sources (such as biomass from crops or dung being more available during certain seasons). Clean fuels may also not be constantly accessible or reliable because of market availability or price changes (Ruiz-Mercado & Masera, 2015). Therefore, fuel stacking can be beneficial to households facing variability in that using multiple fuel types provides more resilience and flexibility (Ruiz-Mercado & Masera, 2015). It is also noted that biomass fires provide versatility; they may be used for cooking but also for heating or as a family gathering time all at once (Ruiz-Mercado & Masera, 2015). This could potentially be true in Nepal, where firewood is the main biomass fuel.

In light of the complicated nature of fuel stacking behavior, this study aims to analyze the trends in cooking fuel stacking observed in peripheral areas of Kathmandu Valley in Nepal, as well as how fuel stacking affects the economic fuel preferences for these households. This study will determine factors associated with fuel stacking, so that we can better understand the incentives and preferences that may be hindering a complete transition to clean cooking fuels in this region.

2. Context

2.1 Demographics and Energy in Nepal

The most recent country-wide census in Nepal was conducted in 2011 and gathered demographics for a population of 26.5 million people ("CensusInfo Nepal 2011," n.d.). The main type of cooking fuel used country-wide in 2001 was firewood at 64%, with 21% LPG use, 10% dung biomass, and the rest other sources. The use of LPG had increased the most since the last census in 2001, when only 5% of the population reported LPG as the main cooking fuel. The use of kerosene also decreased from almost 9% in 2001 to 1% in 2011, and the use of firewood decreased slightly from 70% in 2001 to 64% in 2011. Among urban areas specifically, 68% of households reported LPG as the main cooking fuel in 2011, with 26% using firewood ("CensusInfo Nepal 2011," n.d.). The prevalence of LPG in urban areas has likely increased since then. Throughout both censuses, the prevalent cooking fuels are firewood, LPG, dung, and possibly biogas. Also note that the census asked for one type of fuel used, so respondents could be stacking fuels as well.

Additionally, the other demographics collected in the census may be helpful to compare to the demographic information collected amongst our sample of peri-urban households in Kathmandu Valley. The 2001 census reported a 66% literacy rate overall and stated most Nepali had finished only primary education. The predominant religion in Nepal is Hinduism at 82%, with 9% of people reporting Buddhism, and the rest other religions. The average household size is 4.88 people. The main source of drinking water is piped tap water (48%) followed by tubewell/handpump (35%), then well (7%) or other sources. For sanitation, 41% of people own a flush (modern) toilet, while 38% report not owning any toilet ("CensusInfo Nepal 2011," n.d.).

There has not been much research on the demographic aspects of cooking fuel preferences within Kathmandu Valley specifically. The Kathmandu area of Nepal has the largest demand for modern, clean fuels (like LPG) while rural areas of Nepal tend to use biomass fuel (Bhandari & Pandit, 2018). Demand for LPG increased quite rapidly from about 2014 through 2018, and it is used by almost 26% of Nepali households (Bhandari & Pandit, 2018). LPG is also the most prevalent cooking fuel in urban areas of Nepal, including Kathmandu, and was estimated to be used by almost 60% of households as of 2018 (Bhandari & Pandit, 2018). The percentage of households using LPG may be higher today. Traditional fuels of firewood and dung are readily available within Nepal, though transitional and clean fuels must be imported. Because of this and since 90% of rural Nepali households rely on traditional biomass fuels for some cooking fuel and other energy, firewood is nonetheless projected to remain the dominant fuel source in Nepal (overall) in the coming years (Joshi & Bohara, 2017).

2.2 Fuel Blockade and Crisis of 2015

In September 2015, Nepal ratified a new Constitution that caused India to retaliate by blockading all points of the border between India and Nepal. The unofficial blockade restricted access to many imported goods and created a crisis during its duration. It remained in effect for six months, until early 2016, and occurred only shortly after the devastating earthquake hit Nepal in April 2015. The blockade affected the distribution of medicines and heath provisions, along with energy and gas availability (Lamichhane, 2015). Since all LPG and gas products in Nepal are imported from India, LPG was not available at that time, except on the black market at a very high price, causing a fuel crisis. Therefore, most households that previously used LPG were forced to switch to electricity or firewood for cooking fuel during this period.

2.3 Energy and Electrification in Nepal

Nepal does not produce petroleum products and is reliant on the importation of all oil products from India, which is why the blockade of 2015 caused a fuel crisis. The country's annual demand for oil products is approximately 1 million tons of oil equivalent (Mtoe) and is predicted to increase over the coming years. About 84% of energy consumption was residential as of 2014, with very little commercial or industrial use (8% total) and 7% for transportation. As Nepal continues to develop, its energy demand is expected to increase only modestly at 1.9% annually through 2035 (Asian Development Bank, 2017).

Part of the Sustainable Development Goals (SDG) from the United Nations (UN) include goal 7 to achieve "affordable, reliable, sustainable, and modern energy for all" ("Goal 7: Sustainable Development Knowledge Platform," n.d.). As of 2017, Nepal is on track to meet the electrification goal of 100% access for all citizens by 2030. As of 2014, 84.9% of Nepal was connected to electricity, with 97.7% of urban households connected and 81.7% of rural households connected. This represents a nearly 20% increase in electrification for rural Nepal households since 2010 ("Universal access to electricity," 2017). The high rate of access to electricity means that this fuel is theoretically possible to use as a main source for cooking and other activities, but few Nepali households are using electricity for cooking today ("CensusInfo Nepal 2011," n.d.). Poor reliability of electricity supplies may be a hindrance to its viability as a fuel source in parts of the country. The government of Nepal may be interested in motivating citizens to switch to electricity, since it could be produced locally with hydropower. Nepal's greatest energy resource is hydropower with 83,000 megawatts of energy potential, though less than two percent of that power is currently being harnessed ("Energy Efficiency," n.d.; Asian Development Bank, 2017).

3. Methods

3.1 Sampling Plan

A research team from Duke collaborated with local firm the Foundation for Development Management (FDM) in Kathmandu to conduct this research, which was funded by the Clean Cooking Alliance (CCA). I was present at the firm from July to August 2019 to help coordinate and start the study. Data collection consisted of a multi-part quantitative questionnaire that was administered to 360 households in peripheral-urban Kathmandu Valley in Nepal. Sampling followed a probability proportional to size (PPS) distribution within the three districts of Kathmandu Valley: Kathmandu (which contains the city center), Bhaktapur (to the east of the main city), and Lalitpur (to the south of the main city).

Within each of the three districts, two municipalities were randomly selected. From the six randomly chosen municipalities, peripheral wards were first selected and then randomly chosen from the selection, to ensure sampling would occur in peripheral-urban areas. This purposive selection of wards was done to locate areas in which residents were most likely to be utilizing a mix of cooking fuels, as most of the urban parts of Kathmandu use only LPG. The number of households to sample for each ward were determined by PPS based on the population. See *Figure 1* for a map of the districts of Kathmandu Valley, with the sampled municipalities added in colors (modified from "Figure 1b," 2016). Refer to the final sampling distribution in *Table 1* below.

Figure 1: Map of Kathmandu Valley districts and sampled municipalities

Table 1. Final sampling distribution via PPS methodology

Final Sampling Distribution				
Municipality	**Proportional households to sample**	**Selected ward numbers**	**Proportion of households in wards**	**Number of households to sample**
Lalitpur				
Godawari	58	Nos. 2 / 3 / 4	29% / 50% / 22%	17 / 29 /13
Mahalaxmi	49	Nos. 8 / 9 / 10	57% / 36% / 7%	28 / 17 / 3
Bhaktapur				
Changunarayan	40	Nos. 4 / 8	47% / 53%	19 / 21
Suryabinayak	60	Nos. 7 / 8 / 10	26% / 47% / 26%	16 / 29 / 16
Kathmandu				
Budhanilkantha	86	Nos. 1 / 5 / 11 / 13	21% / 24% / 38% / 16%	18 / 21 / 33 / 14
Tarakeshwor	67	Nos. 2 / 3 / 5	28% / 30% / 42%	19 / 20 / 28
Total	**360**			**360**

3.2 Procedures

Once the wards were chosen, areas to sample focused on peripheral clusters within each ward, to again try to ensure that we would see a mix of primary cooking fuels. Within peripheral areas in each ward, the field supervisor selected households at random using a counting method. At all randomly selected households, a Screening Questionnaire (APPENDIX A) was completed verbally with a household member and recorded by an enumerator. The screening questionnaire asked about willingness to participate in the complete survey, if the main cooking-related decision maker was available, and the type of the household's primary and secondary cooking fuels.

The screening process served to determine the primary cooking fuel mix within each ward, as the study specifically aimed for a ratio of 60% LPG primary fuel users to

40% other primary fuel users. This ratio was selected in order to give the final collected data enough statistical power to draw conclusions about each of the different primary cooking fuels. The field supervisor kept a Household Screening Summary Sheet that documented the ratio of households with each primary fuel type: LPG, firewood, or electricity. If the ratio of LPG/other fuel use was not under the desired 60/40 ratio after randomly sampling households in the ward, the enumerators would go back to the households that were originally skipped (not randomly selected) and follow a new random household selection pattern until a ratio of 60/40 was found. After the field supervisor determined which households to sample from the screening process, enumerators were sent back to each household to complete the full survey. Each enumerator completed surveys in Nepali on tablets provided by FDM. The field enumerators and supervisor were sub-contracted by FDM from a separate company, and they had previous experience completing surveys and with using the tablets.

Before data collection began in the field, we conducted several days of survey training with the enumerators (conducted in Nepali by FDM associates), as well as two days of piloting to ensure that data collection would proceed well. Detailed enumerator training occurred on July 28 and July 29, 2019. FDM hired a specialist to set up the survey in Open Data Kit (ODK), an online software compatible with the tablets. The questionnaire was finalized in English and then translated to Nepali by FDM staff. The

Nepali version was tested by enumerators and during piloting, and any revisions to language were made as necessary. The survey took approximately an hour to complete with respondents. The main day of survey piloting occurred on July 30, 2019, with another day of piloting that included the screening process occurring on August 8, 2019. Piloting of the survey was conducted within wards that were not selected for actual data collection. All survey data was collected and completed in August 2019.

3.3 Questionnaire Content

The survey questionnaire used for this study was modified from a similar survey used by the Duke research team previously in Kenya, with changes made to fit it to the Nepali context. Finalized data was cleaned by FDM staff, with personal and identifying information removed before being sent to the Duke team securely. The questionnaire consisted of 10 subsections which are summarized in APPENDIX B. This study on the association between cook stove stacking and willingness to pay is part of a larger overall study conducted by Dr. Marc Jeuland's team. Therefore, only portions of the data collected from the survey will be used for analysis. [BR1]

3.4 Contingent Valuation/Willingness to Pay

The contingent valuation portion of the survey asked about willingness to pay (WTP) for cooking fuels. Households were posed hypothetical questions based on their primary cooking fuel (as previously gathered in the survey). Respondents were asked if they would continue using their primary fuel if the price of that fuel were to increase by a randomly generated amount (25, 50, 100, or 200% increases), or if they would switch to an alternative fuel. This contingent valuation was double-bounded, meaning that the WTP amount was found through an initial and then a follow-up question of a random price increase to the household's primary fuel. The double-bound means that households were given follow-up questions based on their response to the initial random price increase. If the household refused the initial increase and switched to a different fuel, they would be offered half their original increase. If the household accepted the initial price increase and stayed with their primary fuel, they would be offered double their original increase. For this study, only the household's response to the initial/first WTP question was considered. The following table has the market price and percentage increase prices for LPG and firewood fuels:

Table 2. Contingent valuation price options for the two primary cooking fuels

Percentage	LPG Price (per 14.2 kg tank refill)	Firewood Price (per 25 kg bundle)
Market Cost	1400 NRS	500 NRS
25% increase	1750 NRS	625 NRS
50% increase	2100 NRS	750 NRS
100% increase	2800 NRS	1000 NRS
200% increase	4200 NRS	1500 NRS

3.5 Specific Aims

This study utilized quantitative research methods to answer two specific aims concerning fuel stacking among participating households in Kathmandu Valley.

3.5.1 Aim 1: What is the relationship between fuel stacking and willingness to pay?

The first aim will explore the relationship between fuel stacking and willingness to pay (WTP) for clean fuel (LPG) and for firewood, respectively. Fuel stacking behavior will be explored as both a binary and continuous (percent usage) variable, and WTP will be considered a binary variable as whether or not the respondent agreed to the first price increase randomly offered. While there could be an effect of WTP on stacking, such as income limitations that lead a household to have multiple types of fuel instead of a preferred/more expensive fuel, this analysis will focus on the effect of stove stacking (independent variable) on the WTP response (dependent variable).

This aim will be analyzed through logistical models and is reflected through this equation:

$$Y_1 = \beta_0 + \beta_1 P + \beta_2 S + \beta X + \varepsilon$$

where Y_1 is the binary answer of whether (1) or not (0) the household was willing to pay for the first randomly allocated WTP price increase, P is the price variable of the randomized increase (categorical), S is the binary fuel stacking variable, X is all other variables chosen for the model, and ε is the error.

The X variables included in the regression include: a price*stacking interaction term, household size, head of household gender, age, and education level, and average monthly expenses. The null hypothesis is that there is no association between fuel stacking and WTP amount; the alternative hypothesis is that there is an association between fuel stacking and WTP amount.

Based on the literature published on fuel stacking, I predict that the WTP response will be associated with expenses and with fuel stacking. If households have both a biomass stove (to burn firewood) and an LPG stove, they are likely to switch to the cheaper source of cooking fuel (firewood) if the price of the LPG were to increase. I think this effect will be seen amongst those who reported LPG as their primary cooking fuel, as those who use firewood as their primary fuel may not be constrained by price, since firewood is free for those who gather it or relatively cheap to buy in comparison to the price of LPG.

The results of this regression analysis will show whether each household answered yes to the first WTP question offered to them in the survey, and we are controlling for fuel stacking and the price offered to each household, which varied based on the random percentage increase given.

3.5.2 Aim 2: What are the household characteristics associated with fuel stacking behavior?

The second aim will explore correlations between household characteristic variables and stove stacking behavior, as both a binary and continuous variable. This aim will be analyzed through logistical models and is reflected in this equation:

$$Y_2 = \beta_0 + \beta Z + \varepsilon$$

where Y_2 is the binary answer of whether households stack fuels (1) or not (0), Z is all other variables chosen for the model, and ε is the error. For the binary outcome of fuel stacking, a household that does stack reports using two or more types of cooking fuel (any types), and a non-stacking household reports only using one type of cooking fuel. The continuous variable of stacking is separated for LPG and firewood and reflects the percentage of use of each over the total household's energy use of LPG, firewood, and electricity in a proportion from 0 to 1.

This model will include variables that are predicted to impact stacking behavior, including: household size, age of head of household in categorical ranges, education level of head of household, gender of head of household, monthly household expenses, if the household experienced a crisis within the past six years, if the household pays for firewood (versus gathering it), if firewood is gathered by an adult (versus a child), a wealth index of assets owned, if the women of the household are in a self-help group (SHG), and if the household was affected by the LPG blockade of 2015. The null hypothesis is that each variable is not associated with stacking; the alternative hypothesis is that each variable is associated with stacking.

Based on the literature about stacking behavior, I predict that income and expenses will be correlated with stacking, and those with less wealth will be more likely to stack. I also predict that stacking will be associated with household size, with larger households more likely to stack in order to provide more food to a larger group of people. I am interested to see if stacking is also associated with a certain gender or age of the household head of cooking, as traditional views of cooking may influence a household's decision to stack.

3.5.3 Generated Variables

In order to run all of the regressions to fulfill the aims of the study, a number of variables were generated from collected data. As mentioned, stacking variables were generated for the binary definition of fuel stacking and for the two continuous percentage fuel definitions of fuel stacking, for LPG and firewood. For the binary variable, only households that reported using more than one fuel type were added as "stackers" to the variable. When generating the continuous variables, the reported use in kilograms (kg) of each fuel was used to convert to total energy usage of each fuel, with efficiency of each fuel type considered. The fuel efficiency of LPG used was 53%, with an energy conversion of 48.325 MJ/kg. The fuel efficiency of firewood used was 18.8% (assuming traditional stove use) with an energy conversion of 16 MJ/kg. Since electricity was reported as a secondary fuel among 24 households and 23 households reported using electric rice cookers as their form of electric stove, the MJ/kg of electricity was generated from the hours of use of the rice cooker each day. A search of common rice cookers in Nepal found that the average rice cooker is about 500 W, so this value was used along with an average efficiency of 40% to calculate the MJ/kg of electricity used (Das et al., 2006). Since rice cookers are very fuel efficient, these MJ/kg values were quite low in comparison to the LPG and firewood numbers. Then, the continuous variables were generated by taking LPG or FW over the sum of all the fuels (electricity included), so that the proportion of stacking was created for each fuel on a scale of 0 (that fuel is not used) through 0.5 (household is stacking 50% the primary fuel, 50% other fuels) to 1.0 (household does not stack and uses 100% their primary fuel).

A polychoric principal component analysis (PCA) was conducted on household variables reported that could contribute to wealth. Assets included were the number of rooms in the home, the number of electric fans, number of televisions, number of mobile phones, bicycles, and the total value of the household's jewelry, among other assets. This polychoric PCA generated a wealth index that was they entered into the regressions.

Additionally, a variable of household expenses was use in place of household income in all regressions, as income was reported individually in the survey. Since there was a wide range of expenses and the value was in 1 Nepali rupee increments, the expenses were divided into 1,000 NRS increments, to facilitate the interpretation of otherwise very small regression coefficients and odds ratios. Monthly household income was generated and found to be mostly correlated with expenses. Given this correlation, expenses were used in the regressions because they appeared to be a better reflection of a household's budget and ability to pay for the hypothetical price increases, as revealed in initial regression analyses.

Other binary variables were also generated from survey questions, including whether the household was affected by the 2015 blockade, if an adult over 18 collects firewood in a firewood household (versus a child under 18), and if a household pays for firewood (versus gathering it for free). These variables were included in the regressions and will be explored further in the analysis. All regression analyses were run through the statistical program Stata.

4. Results

4.1 Descriptive Statistics

A total of 360 households (HH) were surveyed and all 360 were used for the analyses. First, demographic characteristics were compiled for the households.

Table 3. Descriptive statistics for demographic characteristics.

Demographic Statistics				
	Overall	**Kathmandu**	**Lalitpur**	**Bhaktapur**
Sample size (N)	360	153	107	100
Household Size	4.008	3.928	3.748	4.410
Head of HH Age	47.591	44.634	47.980	51.696
Monthly HH Expenses (NRS)	30,410	44,680	16,164	23,819
Rooms in House	3.989	3.824	3.336	4.940
Female Head of HH	18.33%	19.61%	14.95%	20.00%
Women in SHG	57.50%	34.64%	70.09%	79.00%
HH Connected to Electricity	98.89%	100.00%	97.20%	99.00%
Affected by 2015 LPG Blockade	39.17%	46.41%	31.78%	36.00%
HH Crisis in Past 6 Years	58.89%	51.63%	83.18%	44.00%
Religion: Hindu	77.78%	75.82%	70.09%	89.00%
Buddhist	16.67%	16.99%	24.30%	8.00%
Other	5.56%	7.19%	5.61%	3.00%
Education: None	31.39%	34.64%	29.91%	28.00%
Primary	28.06%	16.34%	39.25%	34.00%
Secondary/ Postsecondary	35.28%	45.75%	18.69%	37.00%
Informal training	5.28%	3.27%	12.15%	1.00%

Household pays for FW	5.56%	10.46%	1.87%	2.00%
Adult collects FW	21.94%	13.07%	27.10%	30.00%

The above table shows the overall sample's demographics (reported as mean values or total percentages) along with the specific respondents within each of the three districts in Kathmandu Valley. The monthly household expenses are highest among those living in Kathmandu district; it appears that more households there were also affected by the 2015 fuel blockade, which is likely because more households in that district use LPG. The monthly household expenses were substantially lower among those living in Lalitpur and Bhaktapur, which reflect that living closer to the city is more expensive.

The mean household size was about four people, and the mean age of the head of household was almost 48 years old. Almost 99% of the total sample report access to electricity. Notably, less than 6% of the total population are paying for firewood (only 17 out of 141 (12%) of primary firewood users pay); the rest gather/collect firewood for free. This is important and informs our results among primary firewood users. Other religions reported include Muslim, Christian, and no religion.

Since this study is looking at cooking fuel and stacking under multiple lenses, we have specified the primary fuels used, all fuels used by a household, and the type of fuel stacking. First, a tabulation of fuel types showed that no households reported using charcoal, kerosene, ethanol, or solar energy as a primary (or secondary) fuel for cooking. The following primary fuel types were reported:

Table 4. Primary fuel reported by households

Primary Fuel Used		
Fuel Type	**Number of households**	**Percent**
LPG	218	60.6%
Firewood	141	39.2%
Biogas	1	0.2%

The following is a tabulation of all reported fuel types, not just primary, and includes overlap for the households using more than one type of fuel/stacking:

Table 5. Overall cooking fuel types reported by households, including overlap.

All Reported Fuel Types		
Type	**Number of households**	**Percent**
LPG	299	83.1%
Firewood	198	55.0%
Electricity	24	6.7%
Biogas	3	<1%

A binary variable of any combination of fuel stacking was generated and found 141 households (39.2%) are stacking and using more than one fuel type. Cooking fuel types were isolated in Stata to find the number of households engaging in each possible fuel stacking combination. The results of this show that all stacking households are using LPG, with the following breakdown by type:

Table 6. Fuel stacking combinations observed among households.

Fuel Stacking by Combination		
Fuel Type	**Number of Households**	**Percent of total HH**
LPG + FW	114	31.7%
LPG + ELEC	11	3.1%
LPG + BG	1	0.3%
LPG + FW + ELEC	13	3.6%
LPG + FW + BG	2	0.6%
Total	**141**	**39.2% of 360**

There is a notable discrepancy between the type of stoves reported by households and the type of cooking fuels reported. According to the stove types, only 43 households could be stacking (based on the reported ownership of stoves that burn more than one fuel type- see *Table 6* below). However, reported *fuel* use shows that 141 households are actually engaging in fuel stacking. The definition of binary fuel stacking throughout this study refers to the fuel combinations listed in the table above. The discrepancy in the stove versus fuel data could be due to confusion from the enumerators about asking respondents to specify other types of cookstoves that they may have owned.

Table 7. Reported stove type combinations owned by each household.

Stove Type	N of HH	Percent
ONE STOVE ONLY		
Multiple burner LPG stove ONLY	149	41.4%
Portable firewood stove ONLY	2	0.6%
Mixed LPG-electricity stove ONLY	1	0.3%
Fixed biomass stove ONLY	59	16.4%
TWO STOVES		

Biogas stove + Multi burner LPG	1	0.3%
Multi burner LPG + portable firewood	14	3.9%
Multi burner LPG + electric rice cooker	9	2.5%
Portable firewood + fixed biomass	105	29.2%
Single LPG + multi LPG	1	0.3%
Fixed biomass + Single LPG	1	0.3%
THREE OR MORE STOVES		
Mixed LPG-elec + Biogas + Fixed biomass	2	0.6%
Multi LPG + Electric rice + Electric induction	1	0.3%
Multi LPG + Fixed biomass + Electric rice	12	3.4%
Fixed biomass + Multi LPG + Single LPG	1	0.3%
Fixed biomass + Multi LPG + Electric coil	1	0.3%
Fixed biomass + Portable FW + Multi LPG + Elec rice	1	0.3%
Total	360	

4.2 Aim 1: Regression of binary stove stacking on binary WTP

To complete Aim 1, two sets of four regressions were analyzed: for each primary fuel type reported in the WTP section (LPG and firewood), two models were run with the binary definition of stacking (with and without interaction terms) and two models were run with the continuous definition of stacking (with and without interaction terms). Both the uninteracted and interacted model specifications [BR2](of the stacking and fuel price increase variables) are shown for comparison, to see what results would hold across different models. Note that separate variables were generated for LPG stacking percentages and firewood stacking percentages, and only the applicable variable was added to the model. [MJ3]The purpose of the interaction terms is to compare whether respondents' answers to the randomized WTP prices differed as a function of the degree of stacking. This serves to gauge whether there is an association between stacking and respondents' relative fuel price sensitivity, and therefore WTP (the outcome).

4.2.1 Aim 1: LPG

The results of all four regressions among primary LPG users are below. Odds ratios are reported; significant odds ratios over 1.0 mean a variable is more likely to be associated with answering yes to the WTP. P-values under 0.1 were considered significant.

Table 8. Results (odds ratios) of Aim 1 regressions among LPG primary users.

Aim 1: LPG				
	No interaction variables		**Interaction variables**	
VARIABLES	Binary stacking	LPG continuous percentage stacking	Binary stacking	LPG continuous percentage stacking
WTP LPG fuel prices	1.000	1.000	1.000	0.999
	(0.000)	(0.000)	(0.000)	(0.001)
Binary stacking fuel	**0.423****		0.572	
	(0.171)		(0.708)	
Household size	0.845	**0.786***	0.848	0.805
	(0.124)	(0.108)	(0.126)	(0.114)
Age of household head	1.000	0.996	1.000	0.996
	(0.015)	(0.015)	(0.015)	(0.014)
Household monthly expenses/1000	**1.042****	**1.044****	**1.043*****	**1.044*****
	(0.017)	(0.019)	(0.017)	(0.017)
Education of HH head = Primary	1.085	0.996	1.079	0.981
	(0.485)	(0.443)	(0.479)	(0.428)
Edu. Of HH head = Secondary/Post-Secondary	1.612	1.355	1.608	1.390
	(0.804)	(0.669)	(0.796)	(0.666)
Edu. of HH head = Informal training	0.790	0.773	0.821	0.956
	(0.746)	(0.714)	(0.792)	(0.927)

Female household head	1.753	1.662	1.726	1.569
	(0.732)	(0.674)	(0.722)	(0.633)
Wealth asset index	1.138	1.172	1.138	1.163
	(0.147)	(0.149)	(0.147)	(0.146)
LPG continuous stacking		2.287		0.198[BR4][MJ5]
		(1.470)		(0.417)
Binary stacking* WTP price interaction			1.000	
			(0.000)	
LPG continuous stacking* WTP price interaction				1.001
				(0.001)
Constant	2.327	1.461	2.151	10.967
	(2.427)	(1.903)	(2.344)	(22.964)
Observations	218	218	218	218
r2_p	0.126	0.114	0.126	0.121

*** p<0.01, ** p<0.05, * p<0.1; Robust se eform in parentheses; Head of HH Edu base = no education

For LPG primary users, the binary fuel stacking variable (column 1) was found to be significant with a P value under 0.05 and an odds ratio of 0.4, meaning this stacking indicator decreased the likelihood of answering yes to the WTP fuel increase by more than half. Those who do not stack and were LPG primary users were more likely to say yes to the price increase. The other definitions of stacking (columns 2-4) were not found to be significantly associated with WTP, although the significance of the continuous measure of stacking (column 2) on its own is sensitive to inclusion of different covariates (specifically, this variable becomes significant when controlling for income instead of consumption, and categorical measures of age rather than the continuous measure).

Across models, the interactions are never close to significant, however, suggesting that stackers are no more or less sensitive to fuel price increases than non-stackers.

For both the binary stacking and continuous stacking variables of primary LPG users, the P-value of monthly household expenses was significant at the <0.01 level. Based on the low odds ratios (all about 1.04), households were slightly more likely to stack if they had higher monthly expenses. Expenses are correlated with income; therefore, finances were a significant factor found to be associated with the answer to the WTP question among LPG primary users.

Additionally, household size was found to be significant in one model, the continuous stacking variable without interaction terms, with an odds ratio of about 0.8. This means that households with more members were less likely to answer yes to the WTP price offered than smaller households, but this finding did not hold across the other models of binary stacking and those with interaction terms included.

The education levels of the head of household and the interaction terms were not found to be significant among LPG primary users. Interestingly, the different prices offered in the WTP were also not found to be significant, meaning that the range of different price increases were not associated with the respondents' WTP.

4.2.2 Aim 1: Firewood

The results of the four regressions among primary firewood users are below. Again, odds ratios are reported and P-values under 0.1 were considered significant.

Table 9. Results (odds ratios) of Aim 1 among firewood primary users.

Aim 1: Firewood				
	No interaction variables		Interaction variables	
VARIABLES	Binary stacking	FW continuous stacking	Binary stacking	FW continuous stacking
WTP Firewood prices	1.001	1.001	1.001	1.001
	(0.001)	(0.001)	(0.001)	(0.002)
Binary stacking fuel	0.976		1.163	
	(0.449)		(1.497)	
Household pays for firewood	**6.535***	**7.100***	**6.561***	**7.127***
	(7.322)	(7.997)	(7.359)	(8.047)
Household size	0.921	0.932	0.920	0.932
	(0.153)	(0.152)	(0.152)	(0.153)
Age of household head	1.005	1.005	1.005	1.005
	(0.018)	(0.018)	(0.018)	(0.018)
Household monthly expenses/1000	1.006	1.004	1.006	1.004
	(0.008)	(0.006)	(0.008)	(0.006)
Education of HH head = Primary	**0.428***	0.436	0.434	0.431
	(0.219)	(0.230)	(0.222)	(0.234)
Edu of HH head = Secondary/Post-Secondary	1.669	1.503	1.676	1.489
	(1.109)	(1.016)	(1.109)	(1.006)
Edu of HH head = Informal training	0.552	0.560	0.555	0.556
	(0.425)	(0.412)	(0.427)	(0.409)
Female household head	1.121	1.103	1.122	1.095
	(0.643)	(0.621)	(0.642)	(0.618)
Wealth asset index	0.962	0.965	0.966	0.965
	(0.178)	(0.177)	(0.178)	(0.178)
FW continuous percentage stacking		3.293		3.980
		(2.403)		(9.191)
Binary stacking* FW WTP price interaction			1.000	
			(0.001)	

FW continuous stacking * WTP price interaction				1.000
				(0.002)
Constant	1.602	0.526	1.438	0.452
	(2.409)	(0.900)	(2.587)	(1.106)
Observations	141	141	141	141
r2_p	0.0829	0.0996	0.0830	0.0996
*** p<0.01, ** p<0.05, * p<0.1; Robust se eform in parentheses Education of HH head base= no education				

For primary firewood users, neither the binary nor continuous definition of stacking were found to be significant; fuel stacking was not associated with the WTP response. Among all models, whether the household paid for firewood or not was statistically significant with P values under 0.1 and high odds ratios of 6.5-7.1. This means that households who paid for firewood were 6.5 to 7 times more likely to accept the offered price increase in the WTP than households who did not pay for firewood and gathered/collected it.

Among the noninteraction binary stacking model, primary school education level of the head of household was found to be significantly associated with the WTP answer with an odds ratio of about 0.4. This means that household heads with a primary education were less likely to answer yes to the WTP price than those with no education. This did not hold for the other models, or for other levels of education. This finding may be statistically but not practically significant.

None of the other tested variables, including the WTP price increase offered to respondents, were statistically significant in any of the firewood models. It is interesting that the varying price increases did not affect WTP responses, though it might be logical for those who were randomly allocated a lower increase to be more willing to pay than those who had an increase that doubled or tripled the current market price (refer to *Table 2* in Methods for the price increase amounts that were randomly allocated). Even the average monthly household costs were not statistically significant in these models; this means that money was not a significant factor in determining whether households would pay a higher price for firewood or not. Perhaps other factors that we did not measure affect whether households would pay more to continue to use firewood as a primary cooking fuel.

None of these stacking variables are associated with a household's answer to the WTP question, which reflects that the WTP may be reflective only of costs and the household's economic ability to pay that price. Their responses to the WTP could also be based on other factors we did not capture within the study.

4.2.3 Fuel Preferences from WTP

While fuel stacking was found to be consistently significantly associated with WTP responses in one of the LPG regression models, stacking was not associated with WTP in any of the firewood models. To further understand respondents' motives for using each fuel type, I referred to the questions we asked households about why they prefer their primary fuel at current prices.

Table 10. Fuel preference responses by primary fuel type

Primary Fuel Preference Reasons		
Why do you prefer this fuel at current prices?	**LPG Primary Users**	**Firewood Primary Users**
It is clean, so the price is worth it	69 (31.7%)	2 (1.4%)
It is most affordable	17 (7.8%)	110 (78.0%)
It is most convenient and easy to use	129 (59.2%)	17 (12.1%)
It is safest for me and my family	3 (1.4%)	12 (8.5%)
Total households	**218**	**141**

The most commonly reported preference reason for LPG users was convenience (almost 60%) followed by that it is a clean fuel (32%). The overwhelming preference reason for firewood users was affordability (78%). Interestingly, more households reported safety as a main preference for firewood (9%) than LPG users (1%); this indicates that there could be some misinformation about the health effects of particulate matter/smoke generated by burning firewood. There could also be safety concerns among those who use LPG canisters.

Table 11. Fuels respondents would switch to from WTP section.

Fuel switched to in WTP				
	LPG	**Firewood**	**Electricity**	**Total**
Primary LPG	148	50	20	218
Primary Firewood	36	103	2	141
Total	184	153	22	359

While all analyses considered the respondent's WTP answer as a binary yes or no, the question also asked respondents to specify which fuel type they would switch to if they chose to switch. The above table shows the results of this question among each of the primary fuel types. Those who said yes to the higher price in the WTP are listed under the same fuel column, and those who said no to the higher price are listed under the type of fuel they chose. Of the 218 households who used LPG as a primary fuel, 70 (32.1%) households refused the higher price in the WTP; 50 (71.4%) of those households switched to firewood, and the remaining 20 (28.6%) switched to electricity. Of the 141 households who used firewood as a primary fuel, 38 households refused the higher price offered; almost all of those households would switch to LPG (94.7%), with only 2 households (5.3%) switching to electricity. Note that the WTP section was completed by 359 (not 360) households, as one household reported biogas as a primary fuel and was excluded.

It is interesting that less than a third of those who would switch from LPG chose the only other clean fuel option: electricity. Additionally, households switching from firewood, likely because they were offered a large price increase in the hypothetical WTP survey, chose LPG, an expensive fuel option. There was a lower preference for electricity among primary fuel types, though the preference for electricity among primary LPG users was notably higher. This may be because households that are stacking LPG and firewood (about 90% of stacking households) can easily switch from one of those fuels to the other, or it could be because these two fuels are more popular, convenient, or reliable in the Kathmandu Valley area.

4.3 Aim 2: Regression of household characteristics on fuel stacking

For Aim 2, five regression models were run to compare different versions of the fuel stacking variables with multiple household characteristics to identify what is associated with stacking behavior. For this aim, the continuous variable of the head of household's age was transformed to categorical age ranges. The results of the binary model are reported as odds ratios, and the results of the other four models are reported as coefficients. P-values were significant under 0.1.

Table 12. Aim 2 regression results reported in odds ratios (binary variable; far left column) and coefficients (continuous variables; right four columns).

Aim 2					
VARIABLES	Logit	Continuous stacking among all HH		Continuous stacking among primary fuel HH	
	Binary stacking	LPG cont. stacking	FW cont. stacking	LPG cont. stacking	FW cont. stacking
Household size	**1.536*** **	**-0.053*** **	**0.052*** **	-0.010	-0.000
	(0.166)	(0.015)	(0.015)	(0.014)	(0.018)
Age of HH head: 41-50	**2.794*** **	**-0.155*** **	**0.153*** **	**-0.074***	0.019
	(0.997)	(0.047)	(0.047)	(0.043)	(0.064)
Age of HH head: 51-60	**3.018** **	**-0.117** **	**0.116***	-0.078	-0.008
	(1.399)	(0.059)	(0.059)	(0.068)	(0.076)
Age of HH head: 61+	**4.201*** **	**-0.172*** **	**0.171*** **	**-0.125***	-0.008
	(1.716)	(0.054)	(0.054)	(0.069)	(0.056)

Household monthly expenses/1000 (in NRS)	0.995	**-0.001*****	**0.001*****	-0.000	0.000
	(0.006)	(0.000)	(0.000)	(0.000)	(0.000)
Female household head	1.380	-0.073	0.073	-0.029	0.048
	(0.475)	(0.048)	(0.048)	(0.054)	(0.073)
Women in HH in SHG	**2.700*****	0.042	-0.041	-0.039	**-0.113****
	(0.869)	(0.040)	(0.040)	(0.031)	(0.051)
HH had crisis in last 6 yrs.	1.130	**-0.068***	**0.069****	-0.039	-0.064
	(0.324)	(0.035)	(0.035)	(0.032)	(0.040)
Wealth asset index	0.958	0.023*	-0.023	0.004	0.012
	(0.107)	(0.014)	(0.014)	(0.011)	(0.020)
HH affected by 2015 LPG blockade	**0.501****	**0.396*****	**-0.398*****	**0.090****	-0.288
	(0.147)	(0.040)	(0.040)	(0.038)	(0.204)
Household pays for FW	2.060	**-0.162****	**0.163****	-0.254	-0.107
	(1.316)	(0.078)	(0.078)	(0.232)	(0.077)
Adult collects firewood	**8.413*****	**-0.272*****	**0.272*****	**-0.377*****	0.007
	(2.989)	(0.044)	(0.044)	(0.059)	(0.049)
Edu. of HH head= Primary	**2.180****	-0.032	0.030	-0.063	-0.003
	(0.828)	(0.052)	(0.052)	(0.051)	(0.069)
Edu. of HH head= Secondary/Post-Second.	**2.161***	-0.002	0.001	-0.057	0.067
	(0.854)	(0.049)	(0.049)	(0.046)	(0.061)
Educ. of HH head= Informal training	1.989	-0.114	0.113	0.036	0.015
	(1.209)	(0.083)	(0.083)	(0.063)	(0.092)
Constant	**0.012*****	**0.868*****	0.135	**1.037*****	**0.934*****
	(0.008)	(0.091)	(0.091)	(0.075)	(0.121)
Observations	360	360	360	218	141
R-squared		0.454	0.454	0.363	0.133
r2_p	0.269	.	.	.	.

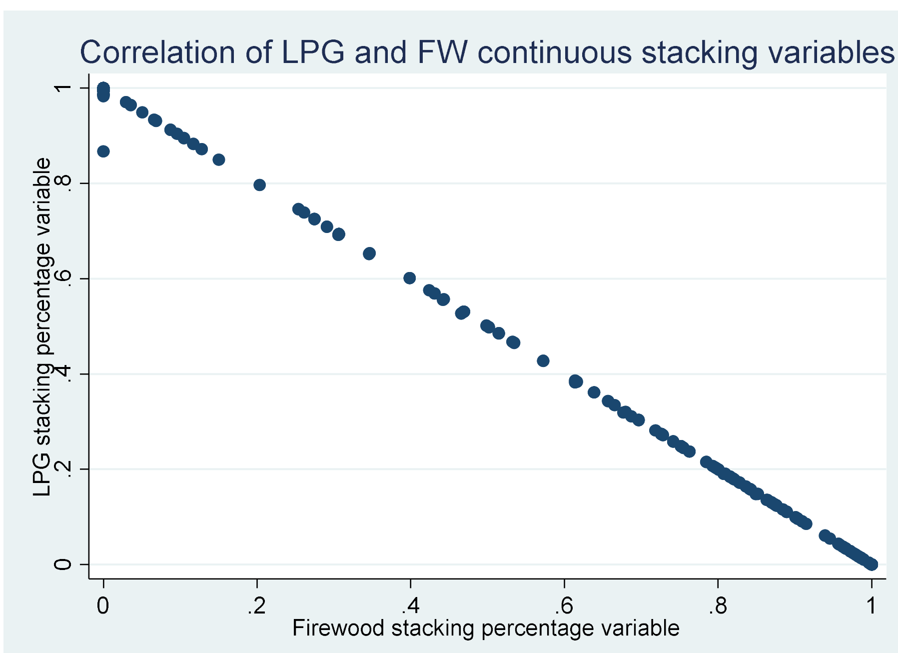
*** p<0.01, ** p<0.05, * p<0.1; Robust se eform in parentheses
Education of HH head base= no education; Age of HH head base= 40 and under

4.3.1 LPG and FW percentage stacking variables

Before interpreting the results of these regression models, it should be noted that the LPG and FW continuous variables that were generated are strongly correlated.

While these two variables reflect the amount of usage of each fuel among stacking households on a continuous scale, they yielded extremely similar coefficient and P-value results in the regressions. Below the two fuel percentage stacking variables are compared, to show the level of correlation between them (*Figure 2*). This correlation may be because 129 of the 141 stacking households (refer back to *Table 5*), or 91.5% of stacking households, are stacking with LPG and firewood. Since electricity users are only secondary (taking up a smaller percentage of energy) and biogas users were dropped from the continuous variables, it is logical that LPG and firewood would be colinear, as households using more LPG are using less firewood, and vice versa.

Figure 2. Correlation of LPG and FW continuous percentage stacking variables.



4.3.2 Aim 2: Binary variable

The following variables were significantly associated with binary fuel stacking: household size, all age ranges of head of household, if an adult in the household collects firewood, if women in the household are part of a SHG, and the household being affected by the LPG blockage of 2015.

Whether an adult collects firewood had a very high odds ratio over 8, meaning that households where adults collect firewood were more than 8 time more likely to stack than households who had a child under 18 years old collect firewood. This may be because adults' time could be considered more valuable, as they likely have work or other tasks to do also. A benefit of stove stacking is likely time savings, since you can choose which fuel is more readily available, and LPG at least is very efficient and quick to use as a cooking method.

Household size was significant with an odds ratio of about 1.5, meaning a household is 1.5 times more likely to stack with every additional household member. Older heads of household were much more likely to stack in comparison to heads of household that were 40 and under. Each older age group had a progressively higher odds ratio and were 2.8, 3.0, and 4.2 times more likely to stack, respectively. Education of the head of household was also identified as significant with odds ratios of about 2.2

for both primary level and secondary/post-secondary level education, versus no education.

The regression of the binary stacking variable also identified whether women in the household were in a self-help group (SHG) as associated with stacking. It is interesting that this regression found this significant, while three of the other ordinary least squares (OLS) regressions did not. According to the significant odds ratio, households with these women are 2.7 times more likely to stack than households with women not in SHGs.

Average monthly expenses were not associated with the binary variable of fuel stacking, which is interesting, as expenses are significant among two of the other stacking variables. Gender of the head of household and ownership of wealth assets were not statistically significant within this model.

4.3.2 Aim 2: LPG and FW continuous stacking variables among all households

An OLS regression was run among all 360 households using the LPG percentage stacking variable as the dependent variable and a separate regression was run using the FW percentage variable for stacking. Due to the correlated results of these variables, all coefficients are very similar if not identical, but are associated with stacking in different directions. Note that columns 2 and 3 in the table above have very similar coefficients of opposite signs. Among these continuous variables in the total population, significant variables included: household size, all age ranges of the head of household, average household monthly expenses, if the household was affected by a crisis in the past six years, if the household was affected by the 2015 blockade, if the household pays for firewood, and if the firewood is gathered by an adult.

Household size was significant, with larger households about 5% less likely to stack with LPG and 5% more likely to stack with firewood. Age of the head of household was significant for all age ranges, with a decreasing likelihood to stack with LPG as the head of household was older (15 to 17% less likely) and an increasing likelihood to stack with firewood as the head of household was older (15 to 17% more likely). This is logical, since older persons may be more knowledgeable about and interested in preserving traditional firewood methods of cooking.

Household monthly expenses were significantly associated with fuel stacking, with higher expenses (thereby assuming wealthier households) slightly less likely to stack with LPG and slightly more likely to stack with firewood, which is counterintuitive to what might be expected. The coefficient of this relationship was still very low at less than 1%.

If a household was affected by a crisis in the last six years, they were almost 7% less likely to be stacking with LPG and 7% more likely to be stacking with firewood. This is the opposite direction of association as households affected by the 2015 LPG blockade; households were almost 40% more likely to be stacking with LPG and 40% less likely to be stacking with firewood if they were affected by the fuel blockade. This suggests that households who prefer LPG and were affected by the blockade are more likely to be stacking fuels.

I included the firewood collection variables in both the LPG and firewood use models to check and was surprised to see that these variables are significant among those who use more LPG, as well. However, the relationships between whether a household pays for firewood/has an adult gatherer and their association with fuel stacking are in opposite directions; the coefficient for LPG variable was -0.27 while it was positive 0.27 for the continuous firewood variable. This means that primary LPG users are about 27% less likely to stack with other fuels if households are collecting firewood and if the firewood gatherer is an adult (versus a child under 18 in the household). Primary firewood users are about 27% more likely to stack with other fuels if the household collects firewood and the gatherer is an adult.

Among the firewood continuous percentage use variable, the coefficients for paying for firewood and if an adult gathers firewood show that households are about 16% more likely to stack with firewood if they are paying for it and 27% more likely to stack if an adult gathers the firewood; these ideas seem to be counterintuitive. If a household is paying for firewood, they may also be purchasing LPG, but if a household has an adult doing the gathering (then they are not paying for firewood), it might be a drain on the valuable time of that adult, leading them to want a more efficient option, and LPG is a fast and efficient form of energy.

4.3.3 Aim 2: LPG and FW continuous stacking variables among primary fuel households only

To determine if the continuous stacking variables had greater effects among just the households that reported each as a primary fuel, separate models were run for those households. As previously noted, 218 households reported LPG as a primary fuel and 141 households reported firewood as a primary fuel.

The results of the LPG continuous stacking variable among LPG only households somewhat strengthen the results seen from the LPG continuous stacking variable among all households but are not completely consistent (compare columns 2 and 4 of Table 12). The significant variables in this model include: two age ranges of the head of household, if the household was affected by the 2015 LPG blockade, and if an adult collects firewood. If the age of the household head was in the range 41-50, households were about 7% less likely to stack with LPG, and households with a head over 61 were almost 13% less likely to stack. The middle age range was not found to be significant. Households were 9% more likely to stack with LPG if they were affected by the 2015 LPG blockade, compared to almost 40% more likely in the LPG variable among all households. Finally, LPG primary households were almost 40% less likely to stack with LPG if an adult collected firewood.

The results of the firewood continuous stacking variable among only primary firewood users were not at all consistent with the results of the firewood continuous stacking variable among all households (compare columns 3 and 5 of *Table 12*). The only significant variable was if women were in a self-help group, with a coefficient reflecting that households were 11% less likely to stack with firewood if any women were a member of a SHG. This variable was not found to be significant among any of the other continuous variable models and does not logically align with the significance of women in self-help groups found in the binary variable's output. No other variables in this model were statistically significant.

5. Discussion

The results of Aim 1 showed that WTP was associated with stacking for LPG primary users in one model's results; therefore, we did find a relationship between fuel stacking and being less willing to accept the hypothetical price offered in the WTP. This supports our hypothesis that households using multiple fuel sources possess a broader set of alternatives that they deem acceptable and that may help mitigate against having to pay higher prices for their primary fuel. This relationship was less clearly a function of the extent of stacking in the LPG primary models of Aim 1, and there was no differential in this effect across prices. Amongst firewood users, stacking was not associated with the WTP response in any model specification. Firewood users were more likely to accept the hypothetical price increase offered if they already paid for firewood. LPG primary users' responses for the WTP were associated with household expenses across all models, showing that budgeting and finances played a role when households determined if they would pay more for a fuel.

The results of Aim 2 showed some inconsistencies among the different models and suggested a more complex relationship between household characteristics and how they are associated with fuel stacking. Across most of the five models, the age of the head of household, if the household was affected by the 2015 blockade, if an adult collects firewood, and household size were associated with stacking. Expenses were not as relevant to the decision to stack as expected. While I hypothesized that household size would be associated with stacking, I did not expect circumstantial and behavioral characteristics such as firewood collection habits and exposure to a crisis or blockade event to be relevant. Results showed that older household heads were more likely to stack, and more likely to stack with firewood specifically. This makes sense due to cultural and traditional methods of cooking on firewood stoves. It is interesting that income and expenses seem to be less important to households when deciding whether to stack fuels, while other circumstances seem to be more important. These results imply that convenience, time, fuel security, or other preferences may be more relevant factors in whether a household chooses to stack fuels.

The goal of this study was to better understand what factors are associated with cooking fuel stacking and how that affects households' willingness to pay for different cooking fuels. This information provides a better understanding of the fuel preferences of Nepali consumers and also why they may not be as willing to switch from firewood to clean cooking fuels. Though LPG is clean, it can be expensive, and yet the results of our study showed that it is a dominant form of cooking fuel in the Kathmandu Valley. Though almost 99% of households reported access to electricity, very few households are using electricity even as a secondary fuel source, and even then, only in the form of rice cookers. As seen in recent studies, the tendency to stack makes movement up the energy ladder more nuanced and not straightforward, and more research needs to be conducted to understand why the people of Kathmandu Valley prefer a more expensive, harder to get fuel (LPG) or a biomass fuel that causes air pollution (firewood) over electricity.

5.1 Limitations of Study

The sampling structure of the study included purposive selection of certain areas of Kathmandu Valley, which impacts external validity and generalizability. The decision to focus on peripheral urban areas was made to find a mix of different cooking fuels among participating households, though it makes part of the selection process not randomized and not representative of Kathmandu Valley as a whole. Our results are representative of the peripheral areas of Kathmandu Valley only. We would likely not have had WTP results for as many primary firewood users if we had not selected areas of the districts that were peripheral, as households closer to the city used LPG as a primary fuel much more frequently. We also did not find any primary electricity users, which was surprising, but we cannot know if this was because the Kathmandu Valley does not have many electricity primary users, or if the peripheral areas we surveyed do not. Though almost all sampled households reported electricity connections (to the grid), only 84% of households report 24-hour access, and the rest report some outages (only 22-23 hours of electricity daily). If households are concerned about when there might be an outage, then may be less inclined to use electricity as a primary fuel.

The chosen definitions of fuel stacking influenced our results, and there could be other ways to consider stacking variables. The simple binary definition made sense to us as a starting point, and the percentage of fuel use seemed a more comprehensive view for the continuous stacking variables chosen. Stacking could also have been defined in other ways, such as based on number of meals cooked versus overall energy usage.

The answers to the WTP section among firewood users who do not pay for firewood but collect it may also be unreliable. Too many participants collected firewood for us to eliminate them and analyze results among only paying households. Yet this is a notable point that could skew results.

Assumptions were made throughout the analysis as well. Monthly household expenses were used as a proxy for income and were considered to be a more robust measure of households' finances and ability to pay, but this could be a flawed assumption. Also, we considered which variables and characteristics to include in each model, but the variables chosen do have large effects on the results seen.

Since enumerators were hired to complete all surveys with participants in Nepali, it cannot be certain that every section of the survey was perfectly explained to each household. There may have been some error within data recording as well. We can see from the answers to the stove types owned that households may not have been prompted to specify other types of stoves they owned; some confusion occurred over that section, as fuels used did not correspond to stoves owned. This study was also limited by time and resources; if more than 360 households had been surveyed, we may have seen a more diverse array of responses for fuel types and WTP responses.

5.2 Implications for Policy

There may be governmental interest in understanding the cooking fuel preferences of residents of the Kathmandu area, as electricity is cheaper and can be produced locally in Nepal. Yet our results are not truly representative of Kathmandu Valley as a whole, and there were no qualitative components asking about cooking fuel type preferences, so the results of the study are best interpreted only economically through the WTP responses and regression analyses. The fuel preferences stated in the WTP are useful in understanding the demand for LPG and firewood, respectively.

If the government of Nepal wanted to encourage switching households from LPG or firewood to electricity in the future, I would recommend two entirely different approaches, based on our results. We found that LPG users may be financially motivated, so it could be possible to incentive switching to electricity through electricity subsidies or discounted electric stoves. A promotional campaign focused on encouraging national pride and using local fuel (hydropower-produced electricity) could also be beneficial. Among firewood users, financial incentives are unlikely to be helpful. The majority of firewood users are collecting their own fuel for free already. The best approach to encouraging a switch from firewood to electricity would be to focus on the harmful health effects of household air pollution produced by burning firewood. Subsidies could also be beneficial to help lower costs, allowing households to be able to afford to switch to a different fuel.

5.3 Future Research

Qualitative data is needed to get a better understanding of why households persist in fuel stacking, and if it is a more of a concern of money, preference, or security. There are many logical theories concerning LPG stacking behavior in the Nepal context: households may be afraid of unreliable electricity (which has become more reliable recently but is not flawless), cooks may prefer the efficiency or taste of food cooked with LPG, or it could be because it is just the popular fuel. Similarly, we do not understand why firewood stacking behavior occurs, though it could be because people prefer the taste of food cooked over firewood, it is a traditional method that may be culturally important, or it could be considered a reliable and secure form of fuel in light of past electricity unreliability and the LPG blockade. One way to further clarify why people in the Kathmandu Valley area are stacking fuels would be to conduct more in-depth and focused qualitative studies to explore specific theories as well as households' beliefs

Then quantitative studies could gather data on these preferences more systematically among households, to better inform policy makers and help improve researchers' understanding of the cooking context in Nepal.

6. Conclusion

This study aimed to determine if and how fuel stacking affects WTP for clean cooking fuels among households in peri-urban Kathmandu Valley. It was hypothesized that fuel stacking behavior may complicate the answers to our contingent valuation, and results of the analysis showed that stacking [BR6][MJ7]was associated with WTP responses among LPG primary users in one model. This reflects our prediction that households will be less likely to pay a higher price for their primary fuel if they are stacking and have access to a secondary fuel. This finding did not hold for all of the LPG models, and no association was found between fuel stacking and WTP among primary firewood users. A secondary aim looked at the characteristics associated with fuel stacking and found complex associations, including household size, age of the household head, and circumstantial/behavioral factors, as more reflective of whether a household will stack cooking fuels than income, expenses, or wealth. It will be interesting to see how the people of Nepal continue to choose their cooking fuels and whether stacking will persist in the coming years. LPG remains the predominant form of cooking fuel among respondents from peripheral Kathmandu, and electricity, while cheap, is not popular. Fuel stacking appears to be a preference for many households in the Kathmandu Valley area, and while stacking with firewood leads to continued health risks through exposure to household air pollution, stacking may be a necessary step in the transition to clean fuels. Further research is needed to better understand the motivations behind fuel stacking and how best to encourage a complete switch to clean fuels over time.

Appendix A – Screening survey

Screening Questions

Municipality:_________________ Ward:___________ Household:______________

Introduction: Hello, I am ___ and I work for FDM Nepal in Kathmandu and Duke University in America. We are doing a research study on cooking fuels in collaboration with the Clean Cooking Alliance. Your household has been randomly selected to participate. We would like to ask a few preliminary questions now.

1. Are you willing to complete an interview and participate in the study?
   a. Yes → Proceed to 2
   b. No → Thank them for their time

2. Is the cooking-related main decision maker available (the person who manages cooking or is most knowledgeable about cooking practices in the household)?
   a. Yes → Ask questions 3-5 to them
   b. No → Is the head of the household available? If yes, ask them. If no, note it and ask whoever you are talking to

3. What is your household's main cooking fuel, that you use most often to cook? (select ONE)

   ____

4. What other, secondary cooking fuels does your household also use? (select ALL THAT APPLY)
   a. LPG
   b. Electricity
   c. Firewood
   d. Other: ______________

5. What share of cooking do you do with each fuel type? (help derive % from fractions, or if they say 2:1 for one type to another, enter 67% and 33%, etc)
   a. LPG: ________%
   b. Electricity: ________%
   c. Firewood: ________%
   d. Other: ________%
   e. Other: _______%

Close: Thank you for your willingness to participate and for answering these screening questions. We are making a list of households that we are looking for and will return today/tomorrow/X day if you are selected for the complete interview. Thank you for your time!

Appendix B – Questionnaire explanation by section

A. *Household Information*

This section assessed willingness to participate in the survey and whether the head of household and main cooking-related decision maker were available, as well as asking religion and recording location information. We aimed to have the household's main cooking-related decision maker, whoever made choices about cooking and fuels used, complete the survey.

B. *Family Roster and Socio-Demographics*

Next, we asked for the names, ages, occupations, and incomes of each member of the household. This section is useful to determine household trends based on education, occupation, or other demographics. Finalized data did not include the names and personal identifying information.

C. *Respiratory and Medical Information*

Illness information was gathered for each household member, including recent cough or cold symptoms as well as chronic and long-term medical information. The survey asked for symptoms, treatment costs, and time lost for education or work due to illness. This information is important since the use of dirty cooking fuels, such as firewood, is linked to respiratory and lung disease. Medical information will be useful for drawing correlations between illness, cooking fuel preferences, and stove stacking.

D. *Stove Characteristics and Use*

Households were asked detailed information about every type of cooking stove or heater used in the house as well as upfront and maintenance costs of each. The amount of time each device was used, and meals cooked on the stove, were recorded. When adapting the previous Kenya survey for use in Nepal, the Duke team spoke to FDM to compile a list of all stoves used in the Kathmandu Valley area, as well as the types of foods commonly cooked. Enumerators had laminated photographs of several different types of stoves to show respondents as a reference during this part of the survey (refer to ATTTACHMENT 3). This section will be used to determine stove stacking and stove usage.

E. *Cooking Fuels Used*

This section separately asked about cooking fuels used for all of the stove devices respondents listed in Section D. Information on fuel usage rates, costs of market fuels, and methods and time needed to acquire the fuel were collected. This section is important to know the rate at which the household uses fuel(s) for the stove stacking analysis.

F. Willingness to Pay (Contingent Valuation)

The contingent valuation portion of the survey asked about willingness to pay (WTP) for cooking technology. This section was the most important part of the survey, since one of the goals of the overall study is to complete a contingent valuation on the primary cooking fuels identified in the data. Households were posed hypothetical questions based on their primary cooking fuel (as previously gathered in section D). The ODK software generated random price increases of 25%, 50%, 100%, or 200% the market price for their primary fuel. Respondents were asked if they would continue using their primary fuel if the price of that fuel were to increase by the randomly generated amount, or if they would switch to an alternative fuel. If they agreed to pay the higher price, they were asked if that hypothetical new price would affect cooking amounts. This contingent evaluation was double-bounded, meaning that follow-up questions were asked to find the range of prices each household found acceptable. If they switched, they would be offered half their original increase, and if they stayed with their primary fuel at the higher price, they would be offered double their original increase. The market price for a standard 14.5-kilogram (kg) LPG container in August 2019 was 1400 Nepali rupees (NRS). Therefore, if a household had the 50% increase and had reported LPG as their primary fuel, their original question would ask if they would pay 2100 NRS (or 150% the market price) for this fuel. If the household agreed, they would then be asked if they would be willing to pay 2800 NRS (200% the market price, or a 100% increase). This section also asked why households would switch if they chose to and which clean cooking fuel each household would prefer if price was not a concern.

F.A. Response to Fuel Crisis of 2015

While training with the survey questionnaire in Nepal, the research team decided to add another section about how respondents were affected by the fuel blockade of 2015. If the household reported being affected by the fuel crisis, they were asked about their primary fuel before and then during that time period. This section will not be analyzed within this study.

G. Socioeconomic Characteristics

House size, house value, and electricity availability were asked within this section. We also asked about water and sanitation. These socioeconomic characteristics may be incorporated with Section B and C data to determine how different factors affect fuel preferences and stove stacking behavior.

H. Consumption and Assets

This section asked if households produced any of their own consumables and how much money was spent on cooking fuel, electricity, and other important expenses over the past month. Emergency expenses and large assets were also asked about here. This information may also be incorporated with other characteristics to determine how they affect study outcomes.

I. Income and Loan Information

Savings, loan, and credit information were asked within this section, as well as serious burdens or crises that affected the household financially within recent years. This information may be compared against study outcomes.

J. Enumerator Observations

The final survey section was for enumerators to record without asking respondents and included house materials judged via observation. The exact GPS location was also recorded for each surveyed household, and tablets were able to gather the GPS coordinate automatically.

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