Analysis of households' modern energy deprivations beyond connections and access in the Northwest zone of Nigeria

Thesis Presented for the Degree of
DOCTOR OF PHILOSOPHY
in the School of Economics
Faculty of Commerce
UNIVERSITY OF CAPE TOWN
July, 2023

SOLOMON ABOAGYE

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I, **Solomon Aboagye**, declare that this thesis is my own unaided work, both in concept and execution, and that apart from the normal guidance from my supervisor, I have received no assistance except where appropriately acknowledged in the text. I further declare that neither the substance nor any part of this thesis has been in the past, or is being, or is to be submitted for a degree at this University, or any other university.

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Lois Amoah Aboagye

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Dad, finally I made it!!! I wish to express my heartfelt gratitude to the Almighty God for His abundant grace, giving me the knowledge, strength and protection for the successful completion of this thesis and PhD programme. There would not have been an end to this journey without Him.

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Notwithstanding support received from supervisors and colleagues, among others, I take full responsibility for the entire content of the thesis.

ABSTRACT

Access to modern energy is considered indispensable to the pursuit of economic growth and poverty alleviation. It also provides crucial support for the achievement of many sustainable development goals. Yet, Nigeria, the largest economy in Africa, has one of the lowest rates of net electricity generation per capita worldwide; with about 44% of its population lacking access to electricity. A remarkable 94% also lack access to any clean cooking technology despite the well-document benefits of modern cooking solutions. The condition is worse in the Northwest zone of the country, the study area, as it hosts a substantial share of the country's population without access to electricity and modern cooking solutions. The above situation raises, at least, three research problems. Firstly, how does the current state of access to electricity impact on the profits of households' non-farm enterprise beyond connections to the national grid? Secondly, to what extent does an improvement in the attributes of modern cooking solution influence households' health outcomes against the backdrop of widespread use of biomass for cooking? Thirdly, can subsidies and credit regimes be effectively deployed to stimulate large-scale uptake of improved cookstoves?

Consequently, chapter 2 evaluates the causal impact of access to electricity on the profits of households' non-farm enterprises as a latent poverty reduction pathway. Applying the generalized propensity score and inverse probability weighting of treatment methods of matching and estimation, the study found that on the basis of connections, access to electricity has limited positive causal effect on the profits of household's non-farm enterprises. However, moving beyond connections only and focusing on the attributes of electricity (i.e., the characteristics of the electricity services from the perspective of end-users which include electricity availability, reliability, affordability, quality as well as the capacity of the grid of electricity) among actual users of electricity the study established a strong positive causal impact of access to electricity on profits. Further analysis shows that in most instances, this impact however tends to be principally dependent on whether the enterprise is more profitable or otherwise.

Chapter 3 assesses the attribute dimension of cooking-health nexus. Utilizing the probit and Heckman models respectively to the cough and health expenditure per capita specifications it is

observed that when attributes such as exposure and safety of primary cookstove are improved, they tend to be important catalyst to reducing both cough incidence and total health expenditure per capita of the household. This important evidence could not have been learnt if the attribute dimension of the debate had not been evaluated. Ultimately, improvement in household's overall access to modern cooking solution is also associated with reduction in both cough incidence and total health expenditure per capita especially for households in higher tiers of access. Thus, a move towards clean cookstoves such as LPG/natural gas stoves, electric stoves while ensuring that households attain higher attribute tiers of modern cooking solutions could be expected to generate significant improvement in household's overall health.

Chapter 4 examines the effectiveness of one-off subsidy and credit regimes in driving households' willingness to pay (WTP) for improved cookstoves (ICS). Using a heteroscedastic-corrected probit models, the results show that allowing households to pay over time coupled with a one-off subsidy of no less than 34% significantly increases the mean WTP to the extent that households are willing to pay even more than the subsidized price. Given that the regime mean WTP values are higher than the effective price of subsidized ICS, both WTP incentives are not likely to damage future pricing when ICS are eventually circulated through pure market mechanisms. Furthermore, we observe the underlying mean WTP to decline after 12 months. This suggests that a 12-month payment instalment could be the maximum effective credit duration required to drive adoption. Additionally, we observe that income, access to grid electricity, access to credit, financial inclusion are critical stimulants of WTP towards ICS.

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LIST OF ACRONYMS/ABBREVIATIONS

AfDB	African Development Bank
ATEs	Average treatment effect
ATP	Ability to pay
ATTs/ ATET	Average treatment of the treated
CVM	Contingent valuation model/method.
EAs	Enumerated Areas
ESMAP	Energy sector management assistance programme
FAO	Food and Agricultural Organization
GACC	Global Alliance for clean cookstove
GDP	Gross domestic product
GPS	Generalized propensity scores
HAP	Household air pollution
HDI	Human Development Index
IAP	Indoor air pollution
ICEED	International centre for energy, environment & dev.
ICS	Improve cookstove(s)
IEA	International Energy Agency
IPTW	Inverse probability treatment weighting
LPG	Liquefied petroleum gas
MLE	Maximum likelihood estimation
MSMEs	Micro, small and medium scale enterprises
MTE	Multiple treatment effects
MTF	Multi-tier Framework
NBS	National Bureau of Statistics
NEP	Nigeria Electrification Project
POMs	Potential outcome means
QTE	Quantile treatment effects
ROSCAS	Rotating savings and credit association
SDG(s)	Sustainable Development Goal(s)
SDH	Social determinants of health

SMEs	Small and medium enterprises
SSA	Sub-Saharan Africa(n)
SUTVA	Stable unit treatment value assumption
TAM	Technology adoption/acceptance model
UNDP	United Nation Development Programme
WB	World Bank
WHO	World Health Organization
WTP	Willingness to Pay

I. THE PROLOGUE

CHAPTER ONE

1 Introduction

1.1 Introducing the Thesis

Nigeria is a West African country with a federation of 36 autonomous states which are often conveniently classified into six geopolitical zones. With an estimated population of over 210 million people in 2021, the country is the most populous in Africa and accounts for about 21% and 47% of the populations of the Sub-Saharan African (SSA) and West African sub regions respectively. The country is the biggest oil exporter and has the largest natural gas reserves in Africa and also considered the largest economy in the continent. Nevertheless, it is a lower-middle-income country with nominal GDP per capita standing at $2,430 in 2021 (World Bank, 2021). The country's growth relies extensively on its natural resource abundance making it vulnerable to commodity price volatility. For instance, the country's GDP grew at an average of 5.7% per year between 2006 and 2016, with growth standing as low as -1.5% in 2016. Growth picked up slightly but still quite below 2% even in 2021. Yet, poverty levels are still high – the National Bureau of Statistics (NBS) of the country reports more than 40% Nigerians living below the national poverty line based on the 2018/19 Nigerian Living Standards Survey (NBS, 2019a; World Bank, 2022). The NBS (2019a) further estimates that about 63% are multidimensionally poor and also cook with dung, wood or charcoal, rather than cleaner energy. In 2021, Nigeria had a Human Development Index (HDI) of 0.535 which was lower than the sub-region's average and saw the country ranked 163 out of 189 countries worldwide (United Nations Development Programme, 2021). Reconciling the country's poverty and growth profiles suggests that economic growth is thus too low to lift the bottom half of the population out of poverty and other forms of welfare deprivations (World Bank, 2021; Jaiyeola and Choga, 2020) and that much needs to be done to help lift millions of Nigerians out of poverty (World Bank, 2022).

Furthermore, with approximately 147 kilowatt hours, Nigeria has one of the lowest rates of net electricity generation per capita worldwide leaving many households to endure frequent load shedding, blackouts and a heavy reliance on private generators (IEA, 2016; 2021). According to the 2020 World Bank Doing Business report, Nigeria ranks 171 out of 190 countries in getting electricity to its citizens, business and has one of the largest grid electricity deficits in the world (World Bank, 2020). As of 2019, the overall electrification rate in Nigeria was 54%; urban – 84%, rural – 31%. While domestic electricity generation could be supplemented with imports, many of its neighbouring countries such as Benin, Niger, Ivory Coast who have less generation capacity even tend to import electricity from Nigeria. This makes electricity imports less realistic, cost ineffective and undesirable for national security issues. The African Development Bank's (AfDB) estimates suggest that there are over 80 million people in Nigeria lacking access to sustainable and affordable sources of electricity (AfDB, 2018). To achieve universal access to electricity by 2030 about 500,000 to 800,000 households ought to be connected each year. In line with this, the country, through the Nigerian Electrification Project (NEP) with support from the AfDB and other partners, seeks to extend clean, safe, reliable and affordable electricity through renewable power sources to unserved and underserved communities in the country including but not limited to households and small-to-medium-sized enterprises (MSMEs). Additionally, there is an overwhelming 94% of the country's population without access to any form of clean cooking technology, a situation that compels households to indulge in a widespread practice where biomass is fed into poorly designed and ill-ventilated traditional stoves for cooking purposes. This exposes a substantial proportion of the population to diseases related to indoor air pollution (IAP).

The *Northwest* geopolitical zone is the sample area of the thesis. The zone is constituted by seven states including Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto and Zamfara. With a population of approximately 49 million representing nearly 25% of the country's population, the zone is the most populous out of six geopolitical zones (World Bank, 2019). Yet, it is generally poor and has the least level of economic development relative to the other zones. Needless to say, with an unemployment rate of about 23% in 2020Q1 (NBS,2020), the zone has one of the highest levels of unemployment in the country as there are very limited economic opportunities. Importantly, the zone also hosts the largest share of the country's population without access to electricity and modern cooking technology (World Bank, 2019). Smallholder agriculture is the mainstay economic activity of the zone with many others of its inhabitants engaged in various forms of micro to small scale non-farm enterprises ranging from trading, cottage to basic manufacturing and other services such as hairdressing/barbering, phone charging, catering, among others (NBS,2020).

The foregoing discussion reveals at least three research problems that are considered in the thesis. The first relates to the current state of access to electricity and whether a shift of emphasis away from connection only to usage and attribute intensity[1] could exert positive causal impact on the profits of households' non-farm enterprise. A second problem concerns the extent to which improvements in the attributes of modern cooking solution affect households' health outcomes against the backdrop of widespread use of biomass for cooking. The third problem is a search for a mechanism to pragmatically reduce the level of household's modern cooking energy deprivation. The third problem focuses on the role of subsidies and credit regimes in easing liquidity constraints and consequently driving households' WTP towards ICS in ways capable of stimulating mass adoption and use.

1.1.1 Broad Objectives

Based on the three research problems highlighted in the preceding section the thesis is guided by three objectives which are stated below.

i. To estimate the impact of access to electricity on the profits of non-farm enterprises on the basis of intensity of electricity usage and attributes.
ii. To evaluate the effects of the various attributes of access to modern cooking solutions on household welfare (e.g., health).
iii. To determine household's WTP for improved cookstoves conditional on the availability of subsidy and credit regimes.

1.1.2 Relevance of the Thesis

The preceding section (i.e., section 1.1.) highlighted two major energy deprivations suffered by households in the country. One form of the energy deprivation relates to Nigeria's low rates of net

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[1] Attribute intensity (i.e., use intensity or extent of use) describes the different levels of electricity attributes – availability, reliability, quality, affordability, and capacity – enjoyed by the enterprises. The concept is discussed in detail in section 2.3.4.1.

electricity generation per capita and low overall electrification rate. This is worsened further by frequent load shedding and blackouts such that many households and enterprises have to rely heavily on private generators which have huge adverse financial and environmental implications. The second energy deprivation suffered by households is the overwhelming 94% of the country's population without access to any form of clean cooking technology. This situation compels households to indulge in a widespread practice where biomass is fed into poorly designed and ill-ventilated traditional stoves for cooking purposes. This has enormous health and environmental consequences. The section (i.e., section 1.1) also hints on some policy actions required to addressing some of these energy deprivations. For instance, through the Nigerian Electrification Project (NEP) with support from the AfDB and other partners, the country seeks to extend clean, safe, reliable and affordable electricity through renewable power sources to unserved and underserved communities in the country including but not limited to households and small-to-medium-sized enterprises (MSMEs). The relevance of the thesis is therefore profoundly rooted not only in the novel contributions it makes to the literature but also the insightful policy implications it reveals.

Foremost, as Nigeria is already undergoing notable power sector reforms including rural electrification (World Bank, 2019; AfDB, 2018), it is imperative that policy is provided with evidence on intensive electrification which places considerable emphasis on productive usage, availability, reliability, affordability and quality of electricity services rather than extensive electrification which concentrates mainly only on connectivity via extension of grid distribution lines. It is also useful to evaluate the extent to which electricity, as a major socio-economic infrastructure, is contributing to the fight against households' livelihood deprivations such as energy depravations, unemployment and poverty. The approach adopted by the thesis thus represents a paradigm shift of emphasis away from electricity connections only to usage/access intensity of electricity. It also establishes important evidence on whether or not access to electricity is favourable towards vulnerable non-farm enterprises. Although, research on the impact of electricity on profit is not recent, evidence from African countries is somewhat limited, and mixed, which could be due to data limitations. Moreover, bulk of the literature (e.g., Grimm et al. 2013; Peters et al., 2010; Vernet et al., 2019) focuses largely on electricity connection rather than the attributes of the underlying connection. Even studies that consider the attributes of electricity access (e.g., Arnold et al., 2008; Cissokho and Seck, 2013; Escribano et al., 2009; Burlando, 2010; Doe and Asamoah, 2014; Akpan et al., 2013) do not integrate them into a broader and wholistic framework of access to electricity. For instance, as discussed in the empirical literature review in section 2.2, even in the reliability literature (e.g., Cissokho and Seck, 2013; Escribano et al., 2009; Burlando, 2010), the focus tends to be on outages and the costs associated with those, rather than integrating reliability into a broader framework that considers electricity access in its various dimensions. The approach adopted by the study is an integration of several attributes of access to electricity (such as availability, reliability, capacity, quality, and affordability) into a comprehensive multi-tier framework of electricity access. This is one of the novel contributions of the study generally and in the context of Nigeria specifically.

The objective of evaluating the health effects of the attributes of modern cooking solution fits into the dimension of development economics which embraces some aspects of energy economics, welfare economics as well as health economics. In relation to that objective, the thesis, while providing evidence to addressing the health repercussions of the lack of access to clean cooking energy, makes further progresses from previous studies by analyzing several attributes of access to modern cooking solutions. This is because the study acknowledges the evidence that the effects of modern cooking solutions on health outcomes are extremely well studied in the literature such that there is already a vast body of literature on the effects of modern cooking solution on health. In general, there is a growing body of evidence in the literature on the adverse health effects of biomass and a parallel favourable health effects of modern cooking solution. For instance, Smith et al. (2012) found a statistically significant reduction in cough and pneumonia as well as an additional 50% reduction in personal child exposure to CO. Similarly, Faizan and Thakur (2019) observed about 17-60% higher incidence of asthma/chronic respiratory failure among individuals living in households where crop residue and coal/lignite are used as the primary cooking fuels relative to individuals living in households with no or little biomass cooking fuels. Also, Berkouwer and Dean (2022) examine, among other things, the effect of charcoal efficient cookstove adoption and found an annual emissions reduction of 3.5 tons of CO2 equivalent (CO2e) per household. Azorliade (2019) estimated a Tobit health expenditure model and found usage of charcoal and LPG for cooking to reduce the probability of spending on healthcare. Badamassi et al. (2017) also observed that residential sector combustion of fuel especially biomass fuel was significantly correlated with higher health expenditures. Moreover, Oluwole et al. (2013), Onyeneke et al. (2017), Onyeneke et al. (2019) among others have also analyzed the impact of an improved cookstove on several welfare and health indicators including cough and health spending. A major gap in the literature is that empirical analysis on the effects of the various attributes of modern cooking solutions on household health remains either sparse or almost completely unexamined. The approach adopted by this study is to contribute to addressing this gap by explicitly characterizing both the individual and the overall effects of these attributes on households' health outcomes. The main contribution of this study is therefore rooted in its focus of the attributes of the cooking solution rather than the cooking solution itself. Thus, in the first instance, the study analyses the effects of the individual attributes of modern cooking solution such as cooking exposure, cookstove efficiency, cooking convenience, safety of primary cookstove, affordability of the cooking solution and fuel availability. Clearly, this approach is novel relative to extant literature which often emphasizes the cooking technology/solution itself. Then, in the second instance, the health effects of a composite variable which encompasses all the attributes is also examined. This composite variable is termed as households' overall access to all the attributes. Thus, we analyze health effects of the attributes of modern cooking solutions, both individual and overall levels. This shows that the study further extends the assessment of access to modern cooking solution beyond the traditional binary (two-tier) measure dominant in the literature to an innovative multi-tier (six-tier) measure. The novelty of the approach is that it takes into account information from the several attributes of access to modern cooking solutions. This is expected to provide broader and comprehensive scope to the understanding of the notion of access to modern cooking solution. Along this line of relevance, access to modern cooking solution is consequently treated as a package that comprises not only fuel and stove but importantly also their underlying attributes (such as cooking exposure, cookstove efficiency, cooking convenience, safety of primary cookstove, as well as fuel affordability and availability) and the cooking activity itself. From a policy perspective, this sheds light on the mechanics to minimizing the health effects of energy deprivations faced by households.

Finally, the thesis examines the use of subsidy and credit regimes to easing households' liquidity constraints as a potential pathway to reducing households' modern energy deprivations. We acknowledge that issues related to liquidity constraints impeding adoption of improved technology are widely discussed in the literature. However, the literature has still not adequately examined how subsidy could be effectively combined simultaneously with credit regimes to stimulate mass uptake even though either has been shown to be an important catalyst. The empirical contribution of this study therefore is to analyze liquidity issues in ways that attempt to demonstrate the dynamics of the mean WTP for ICS overtime within the context of some subsidy-credit regime combinations. This is achieved by making unique behavioural assumption as it relates to households' time preferences in respect of credit facilities. Explicitly, it is assumed that households willing to pay within a short-term (such as Upfront) would be willing to pay within a long-term (such as 6 months, 12 months or 24 months) if they so desire (see section 4.3.3 for details of this assumption). Furthermore, it is important to mention that although RCTs have been implemented in some African countries such as Uganda (Betralmo et al., 2015), Senegal (Bensch and Peters, 2017), we are not aware of such RCT studies that have been implemented specifically for Nigeria and the Northwest zone. Thus, even though this study is not the outcome of an RCT, the approach utilized provides the first set of results that are concrete and context-dependent and could usefully help inform policymaking in Nigeria, particularly the Northwest zone. Thus, we contribute further to the limited study in these contexts. At the policy front, this could show how availing subsidy and credit concurrently impacts on WTP and thus assist in the formulation of effective pricing and subsidy design necessary to stimulate mass uptake of ICS. It could also serve as stepping stones and learning curves for the creation of self-sustaining ICS markets in the future.

1.2 Background

1.2.1 Multi-tier access to electricity

Access to modern energy is recognized by the United Nations as a key precondition to achieving many development goals and as a result established access to affordable, reliable, and sustainable modern energy for all by 2030 as Sustainable Development Goal (SDG) 7. In general, modern energy encompasses energy that is produced from sources that are mostly clean and environmentally-friendly. Thus, it may emanate from both renewable and non-renewable sources. Even though, not all modern energy sources are sustainable, it is expected that households would ultimately transition according to the energy ladder hypothesis so that non-renewable energy sources are phased out to conform to the SDG 7 of ensuring access to affordable, reliable, and sustainable modern energy for all by 2030. With this SDG, electricity is expected to play an important role as it is regarded as a major component of modern energy. Thus, enhancing access to electricity, undoubtedly, is a major step to promoting access to modern energy, particularly among households. Indeed, the recent past decades have witnessed many developing countries undertaking various energy-related initiatives, reforms and developments including electrification. Unfortunately, however, the focus of many electrification projects tends to be tilted primarily towards grid extensions with the overarching objective of increasing the number of communities, households, enterprises etc that have connections. While such projects are still commendable, the frequent incidence of power outages and fluctuations, coupled with electricity tariff hikes often disincentivize service users to the extent that the expected gains may not be maximized. For instance, even if households and their enterprises get connected to the grid through extensive electrification but electricity is scarcely available and there are frequent power cuts, the benefits of getting access to electricity are not maximized even though the electrification intervention may be considered successful, impactful and satisfactory simply on the evidence of the number households and their enterprises connected to the grid. It is against this backdrop that the thesis intends to progress beyond evaluating the impact of electrification projects on the basis of connection only to the analysis of intensity of use and the underlying attributes of the electricity services.

In Nigeria, even though access to electricity remained generally lower in the northern zones, its Northwest zone particularly hosts the largest share of the country’s population without access to electricity (World Bank, 2019). This is further exacerbated by the frequent power outages often witnessed by households and firms in the country in general and in the zone in particular. In addition, the zone is predominantly poorer compared to the other zones (World Bank, 2019). Consequently, given that electricity is a key socio-economic infrastructure, then improving both extensive and intensive electricity access in the zone could potentially trigger various income-generating economic activities even at the household level. This could enhance household productivity and contribute to accelerating economic development and poverty reduction. This is because enhanced access to electricity possibly will contribute to increased use of modern machinery and equipment which are mostly electricity-dependent. Moreover, there are household businesses such as frozen foods, processing and basic manufacturing, that can only be established and effectively run when there is better electricity access. Again, enterprises with improved electricity access could also enjoy extended business hours in the evenings due to better night lighting.

All these mechanisms are potential pathways for promoting job creation, economic development and poverty reductions. In this way, the thesis also examines whether calls for electrification especially in poverty-dominating settings could be justified further on the grounds that it enhances household productivity such as increasing the profits of household's non-farm enterprises. Moreover, on the basis of social equity and justice, expanding electricity access to the zone should be considered as an essential right which permits social integration and the accessibility to other equally essential services (Pereira et al., 2010). Hence, we argue again that electricity has productive uses and the associated benefits are maximized when it is available when needed, reliable, affordable and of good quality.

1.2.2 Modern cooking solution

Globally, there are about 2.5 billion people who do not have access to any form of modern cooking solutions (World Bank, 2019; IEA et al., 2020). Incidentally, these people are hosted largely in developing countries with SSA accounting for the greater majority. Approximately 700 million people are dependent on solid fuels (predominantly wood) for cooking in SSA (World Bank, 2019; IEA et al., 2020). This widespread cooking practice can have severe implications for health, climate change, gender equality, education and socio-economic development (Ekouevi and Tuntivate 2012; UNDP and WHO 2009). For instance, WHO (2012) ranked indoor air pollution (IAP) from solid fuels as the world's eighth largest health risk, causing 2.7% of global losses of healthy life. WHO further reported that 4.3 million premature deaths that occurred worldwide in 2012 was due to household air pollution (WHO, 2012).

Nigeria, the continent's most populous country and largest economy, still has about 94% of its population lacking access to clean cooking equipment (World Bank, 2019). Given the ratio of Nigeria's population to that of the continent, this implies that Nigeria alone accounts for nearly 15% of people without clean cook technology in Africa. This shows the extent of urgency that should be advanced in tackling the modern cooking energy deprivation suffered by households in Nigeria and its likely health effect. This situation might even be worse if the analysis is extended to investigate the repercussions of the underlying attributes of the widespread biomass-driven cooking technology in the country.

According to the World Bank (2019), on health grounds, the attributes of modern cooking solution are even more crucial as they reveal specific aspects of the cooking processes and the corresponding attendant health risk. In particular, World Bank (2019) emphasizes the following aspects of a typical cooking solution/technology as the attributes of modern cooking solution: Cooking Exposure, Cookstove Efficiency, Convenience, Safety of Primary Cookstove, Affordability, and Fuel Availability. These attributes are however often neglected in rigorous quantitative economic studies analyzing the effect of cook fuel or stove on households. Following the recent Multi-Tier Framework (MTF) method of measuring access to modern cooking solution by the Energy Sector Management Assistance Programme (ESMAP) in collaboration with the World Bank, analysis of the health impact of access to modern cooking solutions could therefore be bolstered.

1.2.3 Improved cookstoves

It is puzzling that there are still about 94% of the population lacking access to clean cooking equipment in Nigeria despite the well-documented associated benefits. In 2018, only 5% of the Nigerian population had access to any form of clean cooking solutions (IEA et al. 2018). The situation is even worse in the Northwest zone of the country as less than 3% of the households in the zone uses clean cooking fuels (NBS, 2019b; World Bank, 2019). This implies that most households are using traditional cooking fuels such as biomass which has just been highlighted to have adverse repercussions on health (WHO, 2012) and other important human and environmental outcomes such as climate change, gender equality, education and socio-economic development (Aboagye et al., 2020; Ekouevi and Tuntivate 2012; UNDP and WHO 2009).

Fortunately, there are several interventions aimed at ensuring access to affordable and modern cookstoves that promise greater fuel combustion and smoke emission efficiency and thereby possess the potential to cause substantial reduction in IAP and its concomitant effects. For instance, the Global alliance for clean cookstove (GACC) has since its inception in 2010 set out to empower 100 million households to adopt clean and efficient cookstoves by 2020 (Zhang et al. 2017) and a potential universal adoption of improved cookstoves (ICS) by 2030 (Simon et al. 2014). Particularly, between 2010 and 2015, GACC distributed about 53 million ICS in eight target developing countries which included Nigeria. Moreover, the government of Nigeria is persistently committed to maximizing the benefits of energy access for its people. For instance, the Nigeria Cookstove Program, established in 2014, is intended to promote the use of clean cooking solutions among households (World Bank, 2019). With these already existing vibrant ICS supply mechanisms, the natural question that arises relates to the ability of policy to induce mass uptake of ICS. Therefore, the high percentage of the population still lacking access to clean cook solutions raises various concerns regarding potential demand side constraints, user preferences and issues of willingness to pay (WTP).

One peculiar demand mechanism that has gained rekindled attention in many developing countries relates to the use of subsidies and credit payment facilities to stimulate development interventions (Barnes et al., 1994; 2012). This follows from a shift of emphasis away from aid-based distribution models to more market-oriented approaches by many international development donors/partners as a means to ensuring the sustainability of interventions (Barnes et al., 1994; 2012). The criticism against subsidies, for instance, is that they may not always yield sustainability of an intervention as subsidized interventions typically fail to ensure program cost recovery (Bailis et al., 2015). Nonetheless, subsidies could effectively enhance household's WTP and contribute to sustained use of ICS by not only reducing the cost burden on households but also providing a learning curve for the establishment of future markets. This potential gain could be improved further when complemented with flexible payment regimes that reduces even further how much of the subsidized price needs to be paid at regular periodic intervals. This is consistent with the evidence that credit regimes shift cost/payment to the future as they typically disperse one large payment across many periods (Berkouwer and Dean, 2022; Dertwinkel-Kalt et al., 2021; Gabaix and Laibson, 2017). Both subsidy and credit payment regimes are argued to be critical WTP incentives particularly when economic agents are generally poor, habitually short on cash, face persistent credit rigidities and/or are suffering from varied forms of chronic livelihood deprivations. For instance, Bensch and Peters (2017) found in Senegal that households who received a free stove six years back exhibit a higher WTP which suggests that one-time free distribution does not threaten future pricing and might even be a stepping stone for a future market. Similarly, Berkouwer and Dean (2022), observed in an experimental study of 1,000 households in Nairobi that, the availability of an interest-embedded loan increases the underlying mean WTP by more than 200%. This demonstrates the extent to which removing credit rigidities favourably affect adoption of privately optimal technologies. Again, Berkouwer and Dean (2022) argue that the loan facility is not likely to threaten future market-based distribution. Also, Betralmo et al. (2015) conducted a second-highest bid auction of a fuel-efficient cookstove through an RCT to examine how WTP for an ICS varies with time payment plans. The experiment revealed that marketing messages about the ICS had no systematic effect on household's WTP but time payment plan did. In particular, WTP was 40% higher with time payments than paying within a week. This shows the extent to which households generally prefer flexible payment plans even if short-termed.

Given the persistence of high poverty rates in Nigeria, government can deploy both subsidy and flexible payment schemes (i.e., credit regimes) as part of its development interventions. ICS is desirable for the perspective of public policy because its use has the potential of reducing household's energy deprivations, controlling environmental quality, improving health outcomes and contributing to many other important development goals. Relative to free distribution, subsidy (especially, one-off subsidy) and some credit regimes as WTP incentives are not likely to damage future pricing when ICS are eventually circulated through pure market mechanisms (Dupas, 2014; Bensch and Peters, 2017).

1.3 Methods

1.3.1 Multiple Treatments and Inverse Probability Treatment Weighting

Given the structural uniqueness of estimations required to respond adequately to the underlying research problems, different methods are used to address the different research objectives.

Consequently, in the next chapter (i.e., Chapter 2) where we evaluate the impact of access to electricity on the profits of households' non-farm enterprises, we employ methods of causal inferences. Conceptualizing the behaviour of households' non-farm enterprises within the standard theory of the firm, we argue that the most basic and important objective of the rational firm is to maximize profit (Jehle and Reny, 2011). Accordingly, higher profit implies greater household's income since households are owners of the enterprises. Since household members are consumers, the corresponding greater incomes subsequently contribute to a potential improvement in households' command over goods and services. Therefore, households are prepared to expend the required effort and resources to establish enterprises mainly as a means to economic livelihoods and/or to supplement existing income sources. In that regard, households are interested not only in having their non-farm enterprises connected to electricity but also and perhaps more importantly interested in how access to electricity contributes ultimately to profit. It is against this background that the thesis finds it conceptually compelling to examine the impact of electricity access and/or its usage on the profit of enterprises rather than other enterprise outcomes. The starting point is the following basic empirical model in (1.1)

$$\pi_i = \alpha + \tau W_i + \beta X_i + \varepsilon_i \text{ ------------ } (1.1)$$

Where π_i is the normalized profits of household's non-farm enterprises. X_i is a vector of relevant covariates. W_i is the treatment assignment variable while τ captures the estimands to be estimated. ε_i is the error term assumed to be independently and identically distributed.

The focus of the thesis in that chapter is to analyze access to electricity in ways that shift emphasis away from connection only to actual usage and attribute intensity of electricity. To achieve this, we recategorize access to electricity according to the level of usage and attribute intensity. This translates access to electricity into a multiple-level categorization. Hence, the causal impact is subsequently estimated using multiple treatment effects (MTE). The MTE allows for joint inferences across and between the multiple treatment levels (Cattaneo, 2010) and ensures potential efficiency gains in estimation. Within the MTE framework, the study also extends the analysis to generate quintile treatment effects (QTE) to ascertain whether access to electricity is favourable towards the less profitable enterprises. Matching and subsequent estimation of estimands for the MTE and QTE scenarios involve the application of inverse probability treatment weighting (IPTW) with generalized propensity scores (GPS) based on Imbens (2000). This procedure estimates pairwise average treatment effects/average treatment effects of the treated (ATEs/ATTs) as well as potential outcomes means (POMs) across enterprises attaining various distinct levels of multi-tier electricity access (Hott, Brunelle and Myers, 2012).

1.3.2 Probit and Heckman models

In chapter 3, we evaluate the effects of the attributes of modern cooking solution on households' health. Owing to issues of data availability, only two health outcomes are examined – incidence of cough and total healthcare expenditure (per capita). The methodology adopted is inspired by the World Bank's argument that access to modern cooking solutions is measured using six attributes. These attributes are cooking exposure, cookstove efficiency, cooking convenience, safety of primary cookstove, fuel/stove affordability and availability (World Bank, 2019). These attributes are utilized in two distinctive ways.

In the first instance, the effect of each of the six attributes of access to modern cooking solutions on the two household's health indicators are examined. These estimations are guided by the empirical model given by equation (1.2)

$$H_i = \alpha + \beta_i Attribute_i + \delta_i X_i^{'} + \varepsilon_i \text{ ------------------- (1.2)}$$

Where *H* measures household's health outcomes and *X* is a vector of covariates. *Attribute* is the main right-hand-side variable of interest which captures each of the six attributes of access to modern cooking solutions.

Then in the second instance, rather than focusing on the attributes themselves we use the attributes information utilized in the first instance (i.e., model 1.2) to generate another variable, (*HHAccess*), which captures each household's overall level (or tier) of access to modern cooking solutions. A household's overall level (or tier) of access to modern cooking solution is determined by the lowest tier value the household obtains among the six attributes (World Bank, 2019); where tier 5 represents having full access to modern cooking solution and 1 reflecting having the least access to modern cooking solution. Equation (1.3) is utilized to estimate the effect of household's overall access to modern cooking solution on the two household's health outcomes.

$$H_i = \alpha + \beta_i HHAccess_i + \delta_i X_i^{'} + \varepsilon_i \text{ ------------------- (1.3)}$$

Where *H* and *X* have the same meaning as in model (1.2). *HHAccess* is the main covariate of interest which captures households' overall tier or level of access to modern cooking solutions attained.

Originally, the incidence of cough is disaggregated across six gender-age compositions and this allows us to observe the gender-age dynamics. In the data, cough incidence is also discrete but productively transformed into binary since the study is only interested in its incidence rather than intensity. In the literature, the probit model is an acceptable way of estimating models with binary dependent variable. Hence, the probit model is applied to the cough incidence estimations. A more general formulation of the probability of the incidence of cough among members of a household is thus given by equation (1.4)

$$\Pr\left(\mathrm{y}_i = 1 \middle| \mathrm{x}_i\right) = F(\mathrm{x}_i\beta) \text{ --------------------- (1.4)}$$

where *F* is some function that returns values in the [0, 1] interval.

Household's health expenditure (per capita), the second outcome variable requires different estimation strategy as it is continuous rather than discrete. Often the OLS is a preferred estimator for linear models with continuous dependent variable. However, household health expenditure has many zero values which could be genuine, particularly, when households do not make any monetary spending on health. To avoid sample selection bias, the standard practice is that these genuine zero health expenditure observations are not excluded from the analysis (Jelani and Tan, 2012) but modelled together with the positive health expenditure observations. In the literature, the Heckman model is one of the workhorse models for handling regressions in which positive continuous outcome variable possesses genuine zero observations and thus, there is potential for sample selection bias. The notion of the Heckman model is closely related to censoring regression which observes the covariates of the censored observations. The model is particularly useful when the decision to spend on healthcare and the actual healthcare expenditure made are correlated. The Heckman model could have the following basic functional forms as given in (1.5) and (1.6) below.

$$y_{1i} = \mathrm{x}_i\beta + \varepsilon_{1i} \text{ ------------------------- (1.5)}$$

$$y_{2i} = \begin{cases} z_i\gamma + \varepsilon_{2i} \\ 1(z_i\gamma + \varepsilon_{2i} > 0) \end{cases} \text{------------------------ (1.6)}$$

Where y_{1i} (y_0, x) is observed if y_{2i} =1. Furthermore, $(\varepsilon_{1i},\ \varepsilon_{2i}) \sim N(0,\ 0,\ \sigma^2,\ 1,\ \rho)$. It is the correlation between ε_{1i} and ε_{2i} that generates the "sample selection bias". Given that ε_{1i} and ε_{2i} are bivariate normal, Heckman (1974) suggested that the $\boldsymbol{\beta}$ vector could be consistently estimated in a two-stage procedure. In the first stage the selection model given by equation (1.6) could be estimated consistently by a probit model. The estimated γ could then be used to form the inverse Mills ratio ($\hat{\lambda}$) which could then be added to the regression model in (1.5) as given in equation (1.7).

$$y_i = x_i\beta + \alpha\hat{\lambda} + \eta_i \text{----------------------- (1.7)}$$

Where the new error term η_i has mean zero. The statistical significance of $\hat{\lambda}$ is evidence of the presence of sample selection bias in the underlying data which then justifies the appropriateness of using the Heckman model to correct for the sample selection bias. Alternatively, equation (1.7) could also be estimated directly using Maximum Likelihood (ML). In the study, empirical estimation is therefore implemented with both techniques and a choice is made based on econometric soundness.

1.3.3 The Contingent Valuation Method

In chapter 4, the thesis examines the WTP for ICS based on data sourced from the MTF Global survey of the World Bank. In the datasets, households without ICS and/or any form of clean cookstove and for whom firewood is a primary fuel were asked about their WTP for various ICS. After a type of ICS is randomly chosen, its price was assigned based on one of the three percentages of the reference price: 33%, 66% or 100%. Households then revealed their WTP by simply declaring a "Yes" or "No". Following a typical dichotomous choice, households that declare a "No" for upfront payment are then given a 6-month instalment payment option and if they declare a "No", they are presented with a 12-month instalment payment option and finally a 24-month instalments payment. Thus, the underlying household choice is discrete in orientation.

To ensure that the responses reflect the household's stove preferences as well as WTP, the questions were presented to and answered by a household member who most frequently cooks for the household or the household member who decides to purchase the cookstove. In addition, the benefit of having ICS and the features of the assigned cookstove are described and explained extensively to the respondent. For instance, respondents are informed that the cookstove (i.e., ICS) can reduce the smoke and fuel consumption significantly while cooking time per meal will be shortened since firepower of the cookstove is stronger than the traditional cookstove. They are further reminded to keep in mind these benefits as well as the household's budget as they respond to the questions.

Conceptually, the WTP analysis is rooted in the consumer choice problem which posits that a consumer may be willing to pay for ICS provided this does not, at the least, lower utility beyond the base level. As the choice of any of these ICS solutions over their respective status quo stove is binary, it is convenient to cast the choice in a random utility setting which is then estimated using an appropriate discrete choice model. Given the structure of the WTP framework described above, the thesis therefore uses the probit model to estimate the underlying determinants of a household responding "Yes or No" for each ICS. According to Paap and Franses (2000), a more general formulation of the probability of responding "Yes or No" to a specific WTP Bid could be given by equation (1.7)

$$\Pr\,(\mathrm{y}_i = 1 | \mathrm{x}_i) = F(\mathrm{x}_i \beta) \text{------------ } (1.7)$$

Empirically, our model could therefore be of the form in equation (1.8)

$$y_i = \alpha + \delta Bid_i + X_i^{'} \beta + \varepsilon_i \text{--------- } (1.8)$$

Where ***y*** is the probability of responding "Yes or No" to a specific WTP bid which takes the value 1 if the respondent responds with a "Yes" and 0 otherwise. *Bid* is the randomized bid values (i.e., prices) of the underlying ICS while ***X`*** is a vector of covariates including but not limited to the household income. Once equation (1.8) is estimated the associated mean WTP are recovered using the following standard algorithm in equation (1.9)

$$MeanWTP = -\alpha / \delta \text{ ---------------- } (1.9).$$

Where α is the intercept of the WTP bid function in equation (1.8) and δ is the associated bid parameter.

1.4 Data

1.4.1 The MTF Global Survey

The thesis uses data entirely and exclusively from the Multi-Tier Framework (MTF) Global Survey conducted by the Energy Sector Management Assistance Program (ESMAP) in collaboration with the World Bank (WB) which was in response to a proposal made since 2015. They proposed a multi-tier approach as a new and better way to understanding access to modern energy through the MTF initiative. The MTF, *inter alia,* redefines the way access to electricity is measured, going beyond the traditional binary measure by collecting comprehensive set of data at the country level on multi-tier access to electricity. The MTF also redefines access to modern cooking solution that focuses on its attributes rather than the cook fuel or stove themselves. Since its inception, the approach has not been utilized to analyze the impact of multi-tier access to modern energy on household livelihood outcomes in the sample area.

The survey was carried out in 2018 in Nigeria, specifically Northwest Nigeria. The survey utilized a stratified sampling technique to draw a representative household sample of 3,668 out of which 3,240 have no clean cooking technology and 1,060 own various non-farm enterprises. The sample was spread across 264 enumeration areas (EAs) with equal distribution between urban and rural areas, which were treated as analytical domains. The sample was also distributed across the seven states of the zone according to their populations based on available data from the country's 2006 census.

The survey identified six measures of assessing access to electricity beyond connection to the grid. The enterprises targeted by the survey are not mainstream firms but household non-farm enterprises. About 99% of them are micro enterprises having less than five (5) employees. Almost all of these enterprises are not formally registered and thus it is not unreasonable to consider the sample as a set of informal micro-enterprises. The survey further highlighted six attributes of modern cooking solution which are utilized in evaluating the cooking-health nexus. The survey also, using a CVM characterized by a one-off subsidy and credit regimes, solicitated WTP responses for ICS among households without any form of clean cooking technology and for whom biomass is the primary cook fuel. The data contains a wide range of households' characteristics and enterprise-level variables that are deployed as covariates. Overall, the survey collected considerable data that allows for the estimation of the several models in the thesis. The data is publicly available and freely accessible on the website of the World Bank using the link below:https://datacatalog.worldbank.org/dataset/nigeria-multi-tier-framework-measuring-energy-access-2018

II. ANALYTICAL CHAPTERS

The thesis is organized into five broad chapters which include a prologue (chapter 1), three analytical chapters (chapters 2, 3 and 4) and an epilogue (chapter 5). The three analytical chapters address each of the three broad research objectives highlighted in the preceding chapter. Generally, each analytical chapter is independent of the other but they share several similarities and are also well synchronized into the overarching objective of analysing households' modern energy deprivations in Nigeria beyond connections and access. Particularly, Chapter 2 is concerned with "Evaluating the impact of access to electricity on the profits of households' non-farm enterprises beyond connections". The chapter also investigates whether electricity, as a key socio-economic infrastructure, is favourable towards less profitable enterprises. Chapter 3 on the other hand examines the "Health-cooking solution nexus – the attributes dimension of the evidence". Explicitly, the chapter seeks to identify, among other things, the attributes of modern cooking solution that can be targeted as policy tools capable of reducing the health repercussions associated with cooking. In Chapter 4, the study then evaluates "One-off subsidy, credit regimes and households' willingness to pay for improved cookstoves". Consequently, the chapter unveils potential pathways to stimulating mass uptake of clean cooking technology leading to the establishment of future self-sustaining markets for improved cookstoves.

These analytical chapters have been purposely arranged in this way to give structure and clarity to the arguments that have been espoused in the thesis in relation to modern energy deprivations in the country. Thus, as it can be seen, the first two analytical chapters focus on how the existing state of modern energy deprivation is affecting some aspects of households' livelihoods while the last analytical chapter examines the effectiveness of two policy instruments in reducing energy deprivations. The entire thesis and for that matter the three analytical chapters focus on the same households drawn from the Northwest zone of the country. In what follows, the thesis continues with the three analytical chapters before presenting its concluding remarks and implications for policy, literature and further research.

CHAPTER TWO

Evaluating the impact of access to electricity on the profits of households' non-farm enterprises beyond connections

Abstract

Access to electricity is considered a vital catalyst towards economic growth, poverty alleviation, and provides crucial support for the achievement of many sustainable development goals. Yet, Nigeria has one of the lowest rates of net electricity generation per capita worldwide, with about 44% of its population lacking access to electricity. The situation is worse in the North West zone of Nigeria, the study area, as more than 20% of the country's population without access to electricity are located in the zone. However, the recent decades have witnessed some electrification interventions in the country. There are also notable power sector reforms currently underway including major electrification projects. The extent to which access to electricity impact on profits beyond connection is scarcely examined. In attempt to investigate the potential causal effect of access to electricity on the profits of household's non-farm enterprises as a latent poverty reduction pathway, the study therefore shifts emphasis away from connections only to actual usage of electricity and its attributes which better capture the scope of electricity access. Utilizing the generalized propensity score and inverse probability weighting of treatment methods of matching and estimation, the study found that on the basis of connections only, access to electricity has limited positive causal effect on the profits of household's non-farm enterprises. However, moving beyond connections only and focusing on the attributes of electricity among actual users of electricity the study established a strong positive causal impact of access to electricity on profits even though in most instances, the impact tends to be principally dependent on where an enterprise lies along the profit distribution.

2 Impact of access to electricity beyond connections

2.1 Introduction

2.1.1 Background to the Study

Sustainable energy for all is becoming a very central global objective as the world continues to witness various forms of energy and welfare deprivations. The World Bank (2019) has noted, for instance, that without energy sustainability, promoting economic growth, overcoming poverty and supporting human development becomes challenging, if not impossible. The United Nations also considers modern energy in particular, as the golden thread that connects economic growth, facilitates increased social equity and provides an environment that allows the world to thrive (United Nations, 2012). This is mostly true as almost all sectors of the modern economy including the industry, agriculture, services, public and transport sectors rely heavily on energy for various economic activities such as production, distribution, service delivery among others.

At the household level specifically, energy is used for cooking, heating, lighting, entertainment and other socio-cultural activities. In addition, households, like other sectors of the economy, also use energy for similar economic activities. In performing these socio-cultural and economic activities there are various energy types and sources that are utilized by economic agents. At one end of the spectrum of the energy ladder are traditional energy sources such as biomass and fossil fuels which often constitute a significant share of household's energy portfolio in the country (IEA, 2016). These energy sources are not clean and invariably have adverse implications for environmental quality, human health and climate change (WHO, 2012; Ekouevi and Tuntivate 2012; UNDP and WHO 2009). At the other end spectrum are modern energy, though clean and more friendly to the environment, human health and climate change, they often tend to constitute less significantly to the energy basket of most households in Nigeria (Ogwumike et al., 2014). In an era of looming climate change concerns, some sources of modern energy, particularly renewable modern energy sources are eminently pivotal to ensuring sustainable economic growth while contributing to the global fight against climate change and environmental degradation. As electricity is a major component of modern energy, enhancing access to electricity is therefore crucial to achieving a twin objective of energy sustainability and economic growth while also contributing significantly to the global fight against disease burden, poverty and climate change.

Consequently, a shift of attention towards electricity as a means to achieving sustainable energy while also combating climate change is non-negotiable. Yet, Nigeria, despite being the largest economy in the continent has one of the lowest rates of net electricity generation per capita worldwide. The IEA reveals that the country's electricity generation fails to meet demand, resulting in load shedding, blackouts and a heavy reliance on fuel-powered private electric generators (IEA 2016). Nigeria ranks 171 out of 190 countries in getting electricity to its citizens, business and has one of the largest grid electricity deficits in the world (World Bank, 2020). In particular, IEA et al. (2018) disclosed that the overall electrification rate in Nigeria – i.e., the proportion of the country's population with access to electricity from the national grid (World Bank, 2019) – was just 59% in 2016. This dropped to 55% in 2017 before rising again in 2018 to 56% and stood at only 54% as per the 2019 reports of IEA (2018) and World Bank (2019) which are the latest publicly available statistics. A disaggregation over the same period shows that electrification rate stood respectively at 86% and 41% in urban and rural areas in 2016. Urban electrification rate increased marginally to 86.8% in 2017 after which it declined, though moderately, to 81.7% in 2018 before picking up again to about 84% in 2019. Rural electrification rate on the other hand, however, fell drastically from the 2016 rate of 41% to as low as 22% in 2017 before rising to 31% in 2018 and falling again, though moderately, to 26% in 2019. The apparent sharp fluctuation in the electrification rate is likely to be driven by variations in population and electricity generation such that electrification rate falls when a rise in population is unmatched by a commensurate increase in electricity generation and the converse also holds. The situation is worse in the North West zone of Nigeria, the study area, as more than 20% of the country's population without access to electricity are located in the zone (NBS, 2019b). As earlier highlighted, Nigeria has six zones and thus, the Northwest zone alone hosting more than 20% of the country's population without access to electricity makes it quite large.

Altogether, the AfDB has revealed that there are approximately 80 million people in Nigeria lacking access to sustainable and affordable sources of electricity (AfDB, 2018). To achieve universal access to electricity by 2030, AfDB (2018) estimates that Nigeria will need to connect between 500,000 to 800,000 households per year. In all of these, it is very compelling to reiterate that the substantial share of the country's population without access to electricity are located in the Northwest zone. This is a major source of concern because the zone is the most populous out of six geopolitical zones accounting for about 25% of the country's population. The zone is also generally poorer and has a lower level of economic development (World Bank 2019). Nonetheless, notable power sector reforms are currently under way in the country, including plans for electrification in rural and unserved as well as underserved communities (IEA, 2016). For instance, the federal government has since the 2016/17 fiscal year initiated a nationwide electrification project under the Nigeria Electrification Project (NEP). The project is envisaged by government to be driven mainly by the private sector. In line with the initiative, the NEP[2], with support from the AfDB and other partners seeks to extend clean, safe, reliable and affordable electricity through renewable sources to unserved and underserved communities in the country. Among other objectives, the NEP intends to provide electricity access to households, MSMEs and public institutions in a least-cost and timely manner through off-grid and mini-grid solutions. In particular, for the period 2018-2023 the project has targeted making electricity accessible to over 600,000 people, approximately 105,000 households and 70,000 MSMEs. Among existing users of electricity, the project further seeks to provide reliable and affordable power supply to 250,000 MSMEs and a million households. This project is expected to propel the country toward energy sustainability.

In the quest to achieving energy sustainability, it is also important to recognize that high levels of poverty and inequality still persist in the country. In particular, about 40% of Nigeria's total population which translates into almost 83 million people were reported by the Nigeria Bureau of Statistics (NBS) to be living below the country's annual poverty line of ₦137,430 ($381.75) per person in the 2019 fiscal year[3] (NBS, 2019a). The NBS (2019a) further estimates that about 63% are multidimensionally poor and also cook with dung, wood or charcoal, rather than cleaner energy. In addition, due its large population, Nigeria is also known to be among the top countries

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[2] NEP is being implemented by the Rural Electrification Agency (REA) in collaboration with the World Bank, AfDB and other partners. Some of the possible pathways to incentivize private sector participation in such electrification projects include independent power production schemes. Again, the private sector could be involved in the setup of off-grid solutions provided that these are profitable and they can charge market-based prices.

[3] This is the latest official poverty and inequality report issued by the NBS but various estimates suggest that poverty levels may have increased post-covid era due to the adverse impact the pandemic had on the Nigerian economy.

The official exchange rate in 2019 was $1: ₦360.06 (NBS, 2019a) with the largest number of largest number of people living in extreme poverty worldwide[4] (Katayama and Wadhwa, 2019). Incidentally, majority of the poor households also find themselves in rural communities where smallholder and peasant agricultural activities are often the mainstay economic activity. The incomes households generate from smallholder and peasant agricultural activities are often inadequate to even support basic subsistence. For instance, the NBS (2019a) estimates poverty rate among people engaged in only agriculture at almost 50% on average with the greater majority located in the rural communities of the country.

Clearly, some other economic opportunities could constitute a crucial catalyst to lift poor households to a higher, relatively improved welfare level capable of enabling a potential escape from chronic poverty. Unfortunately, there is often limited alternative economic opportunities and avenues for households to bolster their meagre incomes. Nevertheless, there are several studies that uphold non-agricultural entrepreneurship in the form of small and microenterprise development at the household level as vital in the fight against household income poverty (Bruton et al., 2013; George et al., 2016; Khavul et al., 2013). For instance, poverty rate, on average, among people engaged only in non-farm enterprises in Nigeria stood at about 22% during the 2019 national poverty and inequality survey (NBS, 2019a) – even though this is still high, it is considerably lower than the 50% prevailing in the agriculture sector. Yet, enterprise development and growth are widely perceived to be impeded by the lack of adequate access to quality and reliable electricity supply among households in many low-income countries and Nigeria in particular. This perception is corroborated by the arguments of World Bank (2019) and United Nations (2012) on the indispensable role of electricity in accelerating economic growth, poverty reduction and many other human development goals. In Nigeria, erratic power supply is very rampant to the extent that it has become almost an acceptable reality in the operation of many enterprises who often have to resort to diesel-powered personal electric generators, voltage stabilizers and motors to keep their machines running (Malik et al, 2014). Improvement in access to electricity could therefore be utilized as an effective poverty reduction tool. In this way,

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[4] India, Nigeria, Democratic Republic of Congo, Ethiopia, and Bangladesh are the top five countries with the highest number of extreme poor (Katayama and Wadhwa, 2019).

sustainable electricity supply could also be an effective policy tool towards the attainment of many aspects of some of the SDGs – notably 1, 2, 7 and 13.

2.1.2 Problem Statement

Access to modern energy is recognized by the United Nations (2012) and World Bank (2019) as a key precondition to achieving many development goals including some aspects of the SDGs. In 2015, the United Nations consequently established access to affordable, reliable and sustainable modern energy for all by 2030 as SDG 7 (Mustafa et al., 2022). Given that electricity is a major component of modern energy, then enhancing its accessibility, particularly among households, is undoubtedly expected to play an important role if this SDG is to be achieved. This SDG was established partly out of the evidence that many households in most developing countries are saddled with limited access to clean, reliable, quality and affordable electricity.

As poverty levels among households are still high in many developing countries despite various efforts to stimulate appreciable livelihood improvements, providing households with access to reliable, quality and affordable electricity could be one vital mitigating mechanism. As noted by Cabraal et al. (2005), socio-economic development especially in rural settings is significantly improved when electricity provision is channelled into productive uses. Bruton et al. (2013), George et al. (2016) and Khavul et al., (2013) have also emphasized the role of entrepreneurship, in the form of small and microenterprise development, in the fight against poverty. This is a vibrant indication that in Nigeria where smallholder agriculture is the dominant source of livelihoods to many people, households could utilize non-farm enterprises as a safety valve to cushion income levels. In this regard, access to electricity could act as a necessary catalyst empowering household not only to establish non-farm enterprises but also to expand existing income-generating economic activities (Bruton et al., 2013). Indeed, it must be acknowledged that the recent past decades have witnessed the country undertaking various energy-related initiatives, reforms and developments including electrification in unserved and underserved communities in the quest to accelerate economic development and poverty alleviation among other goals (World Bank, 2019).

Given the poverty and energy deprivation profile of Nigeria's Northwest zone in particular (World Bank, 2019), expanding and improving access to electricity in the zone therefore could potentially trigger various income-generating economic activities even at the household level. This could enhance household's productivity and potentially boost the profits of its enterprises and consequently contribute to job creation and thereby accelerating economic development and poverty reduction in the zone with potential favourable country-wide spillover effect. This is because access to electricity could, in specific terms, contribute to increased use of production-efficient modern machinery and equipment as well as adoption of newer modern technologies which are mostly electricity-dependent. Additionally, there are household-based businesses such as frozen foods, processing and light/basic manufacturing among others, that can only be established and effectively run when there is access to electricity. Again, enterprises with access to electricity could also enjoy extended business hours in the evenings due to better night lighting. However, these potential benefits may not be derived since electrification that only provide access to electricity (i.e., through extension of the grid distribution lines) does not always necessarily translate into availability and/or usage of electricity. This is particularly of great policy concern, especially, against the backdrop of unreliable power supply to end-users and the problems of affordability of electricity services, among others in the country.

Undeniably, various electrification programs and interventions have been undertaken even in recent decades by successive governments of the country to increase the number of households with access to electricity and also to improve supply. It is expected that these interventions, to some appreciable extent, improve households' livelihoods and enterprises' performances (AfDB, 2018). However, it appears that most electrification projects tend to emphasize disproportionately on connectivity at the expense of productive usage as well as the reliability, affordability, quality and other key attributes of the underlying electricity. We argue that electrification should lead to productive usage so that its benefits are maximized even by households. To achieve this, then the assessment of the effectiveness of the impact of electrification must progress beyond connection to focus on its usage and intensity of usage. Even though there is a growing body of research on the impact of electricity access, the aspect of moving beyond connection to usage and its intensity has not been examined by the several studies that have examined the impact of access to electricity on enterprises (see for instance Grimm, Hartwig and Lay, 2013; Neelsen and Peters, 2011; Kooijman-van Dijk, 2012; Kirubi, 2006). These studies focus entirely on whether or not an enterprise is connected to the grid without examining the quality, reliability, affordability and availability of the electricity services[5]. These studies therefore do not distinguish between enterprises with a few hours of electricity and those with several hours of electricity. Differently stated, enterprises with fewer hours of electricity are still considered to have the same level of electricity access as their counterparts with several continuous and/or nearly continuous hours of electricity. Similarly, these studies do not also account for power interruptions and voltage fluctuations even though enterprises with connection could experience significantly different levels of power interruptions and voltage fluctuations. This invariably results in harsher repercussions for some enterprises than others due to the non-negligible differences in the extent to which production and service delivery are halted as well as the severity in appliances and equipment damages across enterprises with connection. Furthermore, enterprises that are connected to electricity but cannot afford electricity services are still considered to have access equivalent to enterprises that are connected and can afford electricity services. There is also no distinction between enterprises with just connection and those with actual usage. Yet, these attributes of access to electricity are regarded as critical especially in the energy sustainability agenda as enshrined in the SDG 7.

This study argues that since the frequency and duration of power outages, the fluctuations in power voltages and the number of hours of electricity supply could differ significantly among enterprises having access to electricity, then these attributes of access to electricity should be central to any policy assessment of access to electricity rather than extensive electrification. This is because extensive electrification (i.e., the extension of grid distribution lines) only aims at ensuring higher rates of electricity connection or access. This is to suggest that access to electricity should not be considered complete unless electricity is actually available, reliable, stable, affordable and used. This is because enterprises would benefit more from electricity connection if these attributes of access to electricity are present at the highest standard.

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[5] As it becomes palpable in the empirical literature review in section 2.2.2, even though there are notable exceptions where studies have gone beyond connections, those studies often focus on one of the many attributes of access to electricity (see for instance, Cissokho and Seck, 2013; Khan, 2001; Arnold et al., 2008; Doe and Asamoah, 2014). While these studies are acknowledged as commendable progress, they also fail to account for the other equally important attributes and thereby mis-scoping overall access to electricity. This study is thus, an improvement over such studies by gauging access to electricity based on several important attributes as listed by World Bank (2019).

Therefore, the major point of policy and research concern should not be only about whether or not the enterprise has access/connection to electricity but also about the quality of the electricity to which the enterprise is connected. Chakravorty et al. (2014) and Escribano et al. (2009) among others have, for instance, confirmed that the reliability of electricity supply is more important than being connected to the grid and that poor quality electricity supply is the infrastructure component that has the strongest adverse effect on enterprise productivity, especially in poor African countries. While this may even be qualitatively known, extant literature has neither characterized access to electricity on the basis of actual usage and its attributes (Sedai et al, 2020) nor deployed the characterization in examining the impact of electricity access on enterprises' profits. This could be an avenue to verify if improving access to electricity beyond connection in itself necessarily boosts household's income via increased profitability of its non-farm enterprises. Suppose it does, then electrification could be regarded as an important catalyst for poverty reduction. The novelty of this study therefore is deeply rooted in the shift of focus away from and beyond grid connections to the actual usage of electricity services and its underlying attributes.

2.1.3 Research Objectives

The general objective that is of concern to the chapter relates to the analysis of the impact of intensifying access to electricity on the profits of non-farm enterprises beyond connections. Explicitly, this entails the following specific objectives

i. To estimate the impact of the usage and attributes of electricity on the profits of households' non-farm enterprises.
ii. To examine the distributional impact of access to electricity on the profits of households' non-farm enterprises.

2.1.4 Organization of the Study

The study is organized into five broad sections. The first section of the study commences with general background information. The aim is to establish the salient problems motivating the study and identifying the major objectives of concern. This is followed by the second section which reviews the theoretical constructs on electrification and the relationship between electricity and enterprises supported by review of empirical literature. The outcome of the second section is the statement of novel scientific contribution of the study. The third section demonstrates the effectiveness of matching methods in allowing for the estimation of causal estimands using observational data. The section also describes the data and strategies empirically deployed to provide evidence on the potential impact of access to electricity on the profits of non-farm enterprises of households. Section four presents and discusses the empirical evidence obtained while section five provides concluding remarks.

2.2 Literature Review

2.2.1 Theoretical aspects of electrification and its impact on enterprises

2.2.1.1 Electricity and non-farm enterprises

The theoretical role of electricity in the economic life of non-farm enterprises of households could be traced from the underlying importance of energy inputs in economic activities. This stems from the microeconomic theory of the firm which provide evidence that the demand for electricity by enterprises is a typical derived demand. This is because at the core of an enterprise's operations, electricity is deployed as a factor of production that is combined with other inputs to obtain output. Specific productive uses of electricity in various sectors could illustrate the theoretical role of electricity in the operations of households' non-farm enterprises more succinctly. Metal fabrication and welding enterprises, for instance, use electricity to power various machines that support the production of metallic gates, canopies, scaffolds and anti-burglary devices. Food processors and restaurants would need electricity to power blenders, microwave ovens, refrigerators, crushers, compressors etc. to facilitate food production. Within apparel-making enterprises, it is frequently observed that professionals such as tailors, seamstress and designers use electricity to power machines that sew, knit and design various clothing. Sachet and bottled water producers use electricity to power purifiers, sealants, cutters to fill polythene bags and plastic bottles with water, cut and then seal them for final consumption.

Earlier, it has been shown that access to electricity also allows for the adoption and use of modern efficient production equipment and technologies. These technologies could be employed in diverse ways to enhance a wide variety of economic activities including production, storage, distribution, powering of office machines and equipment and service deliveries among others. Moreover, a more basic use of electricity among almost all enterprises is for lighting (Mayer-Tasch, 2013). Lighting offers enterprises the opportunity to operate for several hours extending into the night. Again, electricity facilitates enterprise's communications as well as exchange and acquisition of business-related information such as information about local or national markets, new economic policies or tax regulations, new technologies, best practices etc. These kinds of information are often useful for the overall integration of the enterprise into the greater business community and the smooth and successful operations of the enterprise (Velasquez and Pitcher, 2010).

Access to electricity further enables enterprises to engage in business diversification because electricity enlarges the number and diversity of business and job prospects available. For instance, an enterprise trading grocery without electricity could diversify operation to include frozen food if it obtains access to electricity. Overall, the productive uses of electricity make it an integral infrastructure of the everyday economic activity of enterprises. All of these mechanisms ultimately do not only enhance productivity but also increases the entire operations which comes with higher costs but also much higher value production and therefore possibly net profit.

2.1.1.2 Channels and Technologies of Electrification

There are arguably two main ways to understanding the notion of providing access to electricity – extensive and intensive channels of electrification (Sedai et al, 2020). Historically, nationwide electrification is achieved through extensive electrification which involves the extension of the national grid to communities without access to electricity. This becomes the first attempt to make electricity accessible to the unelectrified communities. Kiribu et al. (2009) highlight three approaches for extensive electrification with the most basic approach being grid extension which makes electricity available to communities, households, enterprises etc. based on their relative proximity to the existing service networks. Area coverage and integrated development are other approaches but are not often used due to their heavy cost implications. For instance, the area coverage approach provides electricity to as many customers as possible within a designated area regardless of their proximity to the central grid while integrated development approach provides electricity as part of a wider package of complementary infrastructure, including but not limited to roads, telecommunication, health and educational facilities (Kiribu et al., 2009). In all cases, when the grid distribution lines are extended to a non-access region, the region is subsequently regarded as electrified regardless of the proportion of the community that can be supported by the capacity of the grid or the proportion of its households that actually incur the necessary expenditure to get electricity into their homes or enterprises.

The other channel of electrification, intensive electrification, however emphasizes on enhancing the extent of electricity access among those in actual usage of electricity. In its multi-tier framework, the World Bank identifies seven attributes that relate to the intensiveness or quality of electrification. These are considered as the main avenues by which electricity access among users could be enhanced. These are popularly referred to as attributes[6] of access to electricity by the World Bank (2019). These attributes are the capacity, availability, reliability, quality, affordability, formality, and health and safety of the underlying electricity services.

Obviously, to achieve the SDG 7 both extensive and intensive channels of electrification are very imperative because each has a unique way of ensuring that there is access to affordable, reliable and sustainable electricity for all by 2030. For instance, extensive electrification increases the rate of connections to the grid while intensive electrification is aimed at ensuring that electricity is available when needed, affordable, able to power all appliances and that there are reasonably low and anticipated power interruptions with little or no voltage fluctuations and there is minimal or no incidence of accidents, injuries or deaths associated with the use of electricity. In terms of the impact of access to electricity on profit, extensive electrification is the primary channel by which enterprises encounter electricity in economic activities. In other words, extensive electrification offers enterprises the first opportunity to access electricity. As enterprises get access to electricity, they are now able to adopt and use appliances in production and service delivery among others. This potentially enhances the efficiency of the economic activities of the enterprises which could ultimately influence such outcomes as profitability. But intensive electrification is paramount to stimulate sustained use of electricity by enterprises. This is because enterprises are likely to be greatly incentivized to continually use electricity when it is available, reliable, affordable, able to power all appliances and it is of good quality. These attributes of electricity services consequently make the use of electricity cost-effective and the outcome of this is a potential improvement in the

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[6] The attributes are discussed in detail at the methodology section.

efficiency of the economic activities of the enterprises which could ultimately influence profitability. This impact analysis eventually fits into the theory of the firm in which the profit maximizing firm make choices based on other market constraints – this is discussed in detail at the methodology section of the chapter.

Another aspect of the theoretical role of electricity in enterprise activity manifest itself in the technology carrying the electricity. While the literature identifies that there may be several technology carriers for electricity (Karumba and Muchapondwa, 2017; Bensch et al., 2011; Furukawa, 2014; Kiribu et al, 2009), they can be conveniently classified broadly into on-grid and off-grid. On-grid technology solutions include large/national grid and local mini/micro grid (Karumba and Muchapondwa, 2017; Bensch et al., 2011). The large /national grid is the principal technology utilized by countries to extend electricity distribution lines (Karumba and Muchapondwa, 2017). It is often cost-effective, mainly, for densely populated communities due to its colossal investment requirements. Usually, it has the capacity to power appliances of varied voltages and this uniquely distinguishes it from local mini grids that often has relatively moderate to low capacity and thus unable to power appliances above a threshold capacity. Therefore, local mini grids technologies are on-grid solutions suitable for sparsely population communities as well as instances where extensions from the main grid is likely not to be cost-effective.

The other technological carriers of electrification – off-grid electrification technologies – are deployed mainly in the form similar to on-grid local mini grids in that they are installed in less densely populated areas (Karumba and Muchapondwa, 2017; Bensch et al., 2011; Furukawa, 2014; Kiribu et al, 2009) or assigned to a specific community(s) (Kiribu et al, 2009). Off-grid technologies include solar PV mini-grids, standalone systems and diesel-fuelled electric generators[7]. While all carriers could facilitate the acquisition of access to electricity by enterprises, their impact may differ for various reasons. Foremost, by virtue of the limited capacity of off-grid carriers as well as on-grid mini grid technology, enterprises connected to them would not be able to use appliances with voltages exceeding the capacitors. Also, there are often tariff variations among these carriers with off-grid technology often relatively expensive and thereby increasing the cost and hence reducing the associated profitability of using electricity. Nonetheless, off-grid

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[7] Diesel-fueled generators are perhaps the most widely used off-grid technology in Nigeria.

technology is often perceived to offer less incidence of power cuts, a major feature of on-grid electricity in many developing countries. Thus, in terms of availability and reliability, off-grid options may be preferrable.

2.2.2 Review of Empirical Literature

There are two major views that are frequently advanced in the empirical literature regarding the potential impact of electricity on enterprise performance (Grimm et al. 2013). At the one hand, electricity is considered an indispensable infrastructure exerting positive influences on the successes of enterprises and the lack of which contributes to poor enterprise performances. However, at the other hand, electricity is seen only as necessary but not sufficient in the performances of enterprises. The latter view, as argued by Grimm et al. (2013) invariably suggests that unless other factors, such as credit, markets, road networks, etc. are also available, electricity does not have much effect on enterprise performance. Based on these views, the empirical literature could therefore be categorized productively into two broad stands. While the first strand comprises studies that find some positive impact, the second strand either finds no impact at all (Grimm et al. 2013; Neelsen and Peters, 2011) or finds the impact to be dependent on other prevailing economic structures (Kooijman-van Dijk, 2012; Kirubi, 2006). Following the principal objective of the chapter, we also review a third strand of literature whose focus goes beyond access to electricity towards the attributes of access to electricity. In what follows, the review is focused largely on these strands.

Asaduzzaman et al. (2010), in line with the first strand of literature, estimated the individual effect of electricity consumption as well as fossil fuel consumption on firm’s profit. They found that electricity consumption affects enterprise profits but for fossil fuels such as kerosene or diesel consumption no impact on performance was observed. This does not only affirm the positive effect of electricity consumption on profit but also imply that a switch to electricity or access to electricity is accompanied by potential gains to enterprises. Chauvet et al. (2018) also examined whether firms belonging to industries that tend to make more intensive use of electricity show better performance if such firms are located in areas with access to electricity. The authors, utilizing the binary framework and descriptive statistics, found that access to electricity provided by the national power grid tends to have a positive impact on manufacturing firms' profits. Using Pooled Mean Group (PMG) estimator to analyze a panel data spanning 1970-2000 for South Africa and a range of 19 infrastructure measures, Bogetic and Fedderke (2006) had previously confirmed that access to electricity is positively related to labour productivity and total factor productivity growth within the traditional binary framework. In 2009 Kiribu, Jacobson, Kammen and Mills in an attempt to clarify the mechanisms through which rural electrification could plausibly contribute to rural development conducted a thorough case study analysis of a community-based electric micro-grid in rural Kenya. Kiribu et al (2009) therefore utilized diverse survey instruments including interviews and direct observations to draw both qualitative and quantitative data from all artisanal SMEs in the selected communities. The authors found that access to electricity enabled the SMEs to use electric tools contributing to an increase in productivity per artisan in the order of 100-200% depending on the task at hand as well as an increase in revenues by about 20-80%. Productivity was similarly increased between 50-70%. Overall, the authors concluded that access to electricity even if it is emanating from a micro-grid still contributes positively to the performance of micro and small enterprises and thereby improving household income, poverty reduction and economic growth. Thus, Kiribu et al. (2009) obviously refuted the earlier conclusion of Kiribu (2006) which is reviewed in the second strand in the succeeding paragraph.

In respect of the second strand, Kirubi (2006) had earlier utilized qualitative and evidence methodology within the binary framework to demonstrate that it is only in combination with other infrastructure services and access to markets that the introduction of a rural electrification and extension project boosted the productivity per worker and gross revenue per day of enterprises in Kenya. Peters et al. (2010) focused exclusively on manufacturing enterprises to understand how rural electrification impacts on profit in northern Benin. Prior to the survey, electrification had been carried out in the sampled communities between 3 and 7 years. The authors therefore utilized firm-level data on 276 micro manufacturing firms in five electrified and five unelectrified communities. This comprised 146 and 130 firms in the electrified and unelectrified communities respectively. Using a binary propensity score matching estimation procedure the authors observed significant enterprise creation following electrification in the electrified community. There was however no statistically significant impact of electrification on the profits of the 55 firms that got connected to electricity in the electrified communities. In fact, firms that existed before the electrification project actually showed a non-significantly inferior performance relative to their matched counterparts from electrified communities. Similarly, Vernet et al (2019) also followed through a rural electrification program in Mwania and Kitonyoni communities of Kenya. They collected baseline data prior to the electrification project and end-line data two years after the project. With a total sample of 52 and 90 microenterprises for the baseline and end-line periods respectively, the authors employed the difference-in-difference estimator within the binary framework to examine the impact of access to electricity on entrepreneurial outcomes including but not limited to profit. In general, the study did not find evidence in support of the asserted positive effect of electrification on overall profit of the businesses in the experimental community. Similarly, utilizing representative samples of firms from seven West African cities, Grimm et al. (2013) examined the impact of access to electricity on the performance of informal micro and small enterprises using a standard OLS approach within the binary framework. The authors also found no evidence of a systematic contribution of access to electricity on enterprise performance. A more disaggregated estimation even revealed that access to electricity has adverse repercussions on the performance of enterprises in the manufacturing, construction, wholesale/retail, repair and transport sectors. The authors were however quick to admit that concentrating on a more homogeneous sample of tailors in Ouagadougou as well as those in the clothing and apparel sector, access to electricity tends to exert a positive influence on performance. In particular, electricity contributed to a significant uptake of modern machinery and extended business operations. In rural Southern Uganda, Neelsen and Peters (2011) also could not establish a robust effect of electrification on firm profits or worker remuneration using firm-level data from 200 micro firms within the binary framework even though some qualitative and descriptive evidence revealed a positive indirect effect of electrification in the form of increased local demand as people move to the electrified area. Also, Kooijman-van Dijk (2012) who had earlier given evidence that render some support to positive effect of electricity access was later quite pessimistic of the positive impact of access to electricity. In particular, Kooijman-van Dijk (2012) using cross tabulations and other descriptive statistics demonstrated with data from 264 small and mostly informal firms in rural India that even in cases where access to electricity is accompanied by the uptake of electric-powered machinery by firms, the positive impact on enterprise’s income is very meagre and the lack of a market tends to limit enterprise growth. Earlier in 2010, Bernard had made similar argument that electrification may lead to increased productivity of micro enterprises but revenue gains may not be realized due to market bottlenecks. Bernard (2010) had further revealed the limited employment opportunity in SSA, especially its rural settings and highlighted that this is worsened further not only by inadequate access to electricity but also by lack of market for goods that are produced by home enterprises.

In respect of the third strand of literature, Arnold et al. (2008) investigated the effect of the reliability of electricity supply as well as generator usage on total factor productivity (TFP) of enterprises. Using data from the World Bank Enterprise Survey on over 1,000 firms in 10 SSA countries, the authors found that unreliability of electricity services had a statistically significant negative impact on firms' TFP while generator possession had a statistically significant and positive effect. This is subsequently supported by Escribano et al. in 2009 and Burlando in 2010. In particular, Escribano et al. (2009) found that in Africa, unreliable electricity supply seems to be the infrastructure component with the strongest negative effect on enterprise productivity. Burlando (2010) also revealed that a month-long blackout in Zanzibar, Tanzania, caused a large decline in household income among those employed in jobs that required electricity. In particular, the employees were structurally compelled to reduce work hours by an average of 8% per day during the blackout period. These conclusions are reinforced further by Bah and Cooper (2012) who established that although the lack of credit together with an aversion to debt is reported to limit enterprise growth and prevent entrepreneurs operating small enterprises in urban areas of northern Myanmar from taking advantage of the prevailing high returns on investment, the quality, cost and access to electricity are still established as major constraints to business growth. Khan (2001) focused on how access to electricity could improve income-generating economic activities in Bangladesh. The author showed that availability of electricity during periods of peak economic activities is accompanied by appreciable rise in income-generation attributable to extension of business hours into the evenings. In particular, Khan (2001) showed that due to the availability of electricity throughout the day, tailors in Bangladesh for instance, worked for four more hours and thereby increasing their revenue by 30%. Opening hours for shops were also found to increase by an average of three hours a day. Cissokho and Seck (2013) like Khan (2001) and Arnold et al. (2008) concentrated only one of the attributes of access to electricity. Particularly, Cissokho and Seck (2013) focused on the reliability of electricity which they measured using the frequency and duration of power outages. They however adopted a much different approach to examine the impact of access to electricity on enterprise. Specifically, the authors utilized efficiency models (i.e., non-parametric approach based on Data Envelopment Analysis) to estimate cost, technical and scale efficiency indicators. Using a sample of 528 enterprises in Senegal, all of which are connected to electricity, they discovered that the duration and frequency of power outages had a positive and significant impact on productivity as measured by technical efficiency. Similarly, cost efficiency was also found to have been impacted positively. While these findings were not expected by the authors, they posited that frequent and longer power outages may had stimulated better management practices, which had mitigated any of its potential negative effects. Additionally, they asserted that the more inefficient and lower productivity firms may had gone out of business in the face of electricity insecurity. Cissokho and Seck (2013) highlighted further that power outages may have also compelled the affected enterprises to adopt innovative coping mechanisms such as aligning production sessions around periods that electricity outages are extremely unlikely. Other findings also revealed that SMEs performed better than large-scale firms in times of power interruptions. However expectedly, scale efficiency of SMEs was negatively affected by the both the frequency and duration of power outages. Doe and Asamoah (2014) also focused exclusively on the quality attribute of electricity which is often captured by the extent of power fluctuations from the grid. Specifically, Doe and Asamoah (2014) assessed the effect of electric power fluctuations on the profitability and competitiveness of 70 Ghanaian SMEs in Accra based on data collected through a purposively systematic sampling approach. Using quantitative methods such as cross tabulations and other descriptive statistics they found that frequent power fluctuations does not only reduce and halt production but also adversely impacts product and service quality leading to poor turnover. Using return on assets (ROA) and return on investment (ROI) as the proximate proxies of profit, Doe and Asamoah (2014) additionally established that power fluctuations detrimentally affect the profitability of the SMEs. In Nigeria, the impact of power interruptions on the productivity of firms has also been examined by various studies. For instance, Moyo (2012) used hours per day without power and percentage of output lost due to power disruptions as proxy for unreliable power supply. Econometric estimations from OLS and the Tobit models established a statistically significant negative impact of power unreliability on the productivity of small manufacturing firms but for large ones the impact of power unreliability on productivity was found not to be statistically significant. The author was therefore swift to highlight that this evidence could be due to the ability of large firms to circumvent with electric generators as this was also evident during the survey. In a related study, Akpan et al. (2013) examined the effect of both extensive and intensive electrification on profits with focus on rural micro enterprises in the Delta state of Nigeria. The study employed purposive sampling to carefully select four rural communities — two electrified and two non-electrified resulting in a sample of 62 and 44 enterprises respectively. A log-linear estimation revealed that neither connection to the grid nor number of hours of electricity supply had any impact on the profits of enterprises in communities connected to the electricity grid. Interestingly however, using electricity-generating sets for the purpose of providing back-up electricity was found to make micro-enterprises more profitable and thus enterprises with the capacity to afford electricity services from the electrical generator willingly do so. Nevertheless, the authors admitted that the total expenditure on the electric generator sets by some enterprises is up to about three times higher than the tariff charged for grid-electricity for rural users.

Overall, extant literature provides some evidences on potential benefits of grid electrification. Some noteworthy research gaps are nevertheless obvious from extant literature. Undoubtedly, it is observed from the above review that the focus of the overwhelming majority of the studies was not to make causal inference on the impact of access to electricity given that, to a very large extent, the findings established by most of these studies are not the outcome of any treatment evaluation methods. Furthermore, majority of the studies were interested on enterprise's productivity rather than profit; this approach ignores the cost burden access to electricity imposes on the enterprises. Whiles these are all potential gaps the study contributes to address; the greater concern of the study is the almost universal major drawback of existing literature as it tends to focus mainly on whether enterprises are connected to the grid or not and thus focusing mainly on connections. This is a misleading way of understanding access to electricity and hence evaluating the impact thereof. This is because such an approach fails to account for actual usage of electricity and its intensity in scoping access to electricity. From a pure policy perspective, connection to electricity only and usage of electricity have fundamentally distinct implications. Moreover, as argued earlier, the various attributes of access to electricity have far more reaching important considerations in contemporary enterprise operation and thus for policies on electrification. Consequently, a paradigm shift of emphasis to actual usage of electricity and its underlying attributes is not only a major novelty of the study but also a remarkable improvement of the conventional binary approach.

2.2.3 Statement of Contribution

It is obvious from the review that the extant literature has concentrated mainly on connectivity in assessing the potential causal impact of access to electricity. The principal weaknesses of this approach have been discussed extensively in section 2.1.2. One of the consequences is the risk of regarding all enterprises connected to the grid as having equivalent access to electricity. This has been shown not to be true as electricity-using may differ significantly across the various attributes of electricity services. Ultimately, the approach could potentially lead to understatement of the impact of access to electricity on the profits of households' non-farm enterprises. This could, in turn, create significant pessimism about the ability of electricity to drive poverty reduction via its positive impact on the profitability households' non-farm enterprises. This kind of pessimism could further discourage investment required to ensure that electricity is available, reliable, affordable and of good quality. The novel contribution of study is therefore hinged on shifting emphasis away from connections only towards the assessment of state of electricity use in the enterprise as well as the underlying attributes. We do this by utilizing a more comprehensive information on access to electricity which captures information on the attributes of electricity services. Although, research on the impact of the attributes of electricity access on profit is not necessarily recent, evidence from African countries is somewhat limited, and mixed, which could be due to data limitations. Moreover, bulk of the literature that considers the attributes of electricity access do not integrate them into a broader and wholistic framework of access to electricity. For instance, in the reliability literature, the focus tends to be on outages and the costs associated with those, rather than integrating reliability into a broader framework that considers electricity access in its various dimensions. The approach adopted by the study is an integration of several attributes of access to electricity (such as availability, reliability, capacity, quality, and affordability) into a comprehensive multi-tier framework of electricity access. This is one of the novel contributions of the study in general and in the context of Nigeria specifically. As Nigeria is already undergoing notable power sector reforms including rural electrification (AfDB, 2018; World Bank, 2019), it is imperative that policy is provided with evidence on intensive electrification which places considerable emphasis on productive usage, availability, reliability, affordability and quality of electricity services. Given that this incorporates the attributes, the approach properly accounts for access to electricity. Hence, it is likely to give optimism to the use of public and other donor funds for intensive electrification.

Another contribution of the study relates to the assessment of the extent to which electricity is more favourable to less profitable (i.e., vulnerable) enterprises. One mechanism by which access to electricity acts to reduce the profit vulnerability of less profitable enterprises could be traced to the amount of income/sales/revenues that accrue to these enterprises when they have no access to electricity relative to when they have access to electricity. For instance, microenterprises engaged in barbering, hairdressing, dressmaking, petty shop/trading are compelled to perform their activities manually if they have no access to electricity. Barbers and hairdressers would typically have to use manual mechanisms to do the hair of customers instead of using electric barbering machines or electric dryers while dressmakers would have to rely on manual sewing machine or charcoal-powered ironing machine to make dresses. Petty shop/traders would also be compelled to refrain from certain line of businesses if they don't have access to electricity. In this way, the enterprise's incomes/sales/revenues would be affected adversely which could contribute to profit vulnerability of these less profitable enterprises. A related aspect is that these enterprises without electricity cannot also operate in the night. Thus, when these enterprises get access to electricity, they would now be able to use electricity-powered machines and equipment which are often productively efficient relative to manual production processes. They would now also enjoy extended business hours in the evening due to better night lighting. Enterprise's incomes/sales/revenues could be enhanced and this can act to reduce the profit vulnerability of less profitable enterprises. Another mechanism by which access to electricity acts to reduce the profit vulnerability of less profitable enterprises could be linked to the argument that electricity is a major socio-economic infrastructure/intervention and thus its accessibility should act to reduce the profit vulnerability of less profitable enterprises. This is because one of the important justifications underlying the provision of socio-economic infrastructure/intervention (such as electricity) is that they tend to promote the wellbeing of underprivileged groups in society. This is further premised on the assertion that one of the notable expectations of socio-economic interventions is that they work to redistribute income towards the poor and thereby contributing to the fight against increased poverty and income inequality. This forms one of the foundations for the distributional impact analysis implemented by the study through the quantile treatment effects (QTE). This specific empirical assessment (i.e., distribution impact of access to electricity on profit through the QTE) is missing entirely in the literature on the electricity-profit nexus.

2.3. Methodology

2.3.1 Theoretical Framework

Theory of firm

The fundamental theoretical underpinning for the study, as highlighted at the theoretical literature review, is derived from the neoclassical microeconomic theory of the firm. At the core, the theory postulates that the firm acquires inputs such as capital, labour, materials among others. These inputs are then combined in production processes to obtain output (see Jehle and Reny, 2011). One input that is often not included in the basic neoclassical theory of the firm but it is almost indispensable in modern firm activities is energy (United Nations, 2012, World Bank, 2019, Aboagye and Alagidede, 2016). The production function could be therefore given as shown in (2.1).

$$Y = f(K, L, M, E, Z) \text{--} (2.1)$$

Where Y is the output while K, L, M and E represent capital, labour, materials and energy respectively and Z is a catchall variable denoting all other inputs/factors likely to influence output in the production function (Jehle and Reny, 2011). This shows that the production processes and the eventual output are theoretically influenced by the energy input (as well as the other inputs). By extension, this obviously implies further that electricity, the component of energy input of interest to the study, also potentially drive output as a natural consequence.

However, it is important to recognize that firms have to incur expenditure in order to procure and maintain electricity (as well as the other inputs). These expenditures are the production cost which could have the following basic form given in (2.2)

$$C = rK + wL + \upsilon M + \varphi E + \eta Z \text{ ----------------------------(2.2)}$$

Where K, L, M, E and Z have the same definitions as in (2.1) and r, w, υ, φ and η represent their respective unit prices/cost (see Jehle and Reny, 2011).

From (2.1) and (2.2), it is realistically valid to state that, in a firm's attempt to acquire inputs and combine them to produce output, it incurs cost on the inputs while the outputs produced are sold at a price to generate revenue. While a firm may have several objectives, the most basic objective of the rational firm is to maximize profit (Jehle and Reny, 2011). In general, profit is the excess of revenue over cost and because the inputs are related directly to both cost and output/revenue as observed in (2.1) and (2.2), then it is not unreasonable to view inputs such as electricity as directly related to profit. The profit equation could thus be simplified as given in (2.3)

$$\pi = pf(K, L, M, E, Z) - (rK + wL + \upsilon M + \varphi E + \eta Z) \text{----(2.3)}$$

Where π is profit and p is the output price while other variables are as previously defined in (2.1) and (2.2). Equation (2.3) is a conceptual/structural profit equation which is a function of output price (p), inputs (K, L, M, E, Z) and their respective unit prices (r, w, v, φ, η). This is not the estimatable profit function of the study. Taking cognizant of this conceptualization, the change mechanism described in section 2.3.2 and the study's objectives, a reduced form of the profit function is derived in equation (2.4b) and that constitutes the estimatable profit function of the study.

Since the study focuses on non-farm enterprises of households, it is therefore worth-noting that the households are the owners of the enterprises. As a result, the profits that accrue to the enterprises are for the households implying that the profits of the enterprises become part of the incomes of the households. In other words, since the members of the households are also consumers, they view the profit of the enterprises they own as part of the household's income. Accordingly, the more profit the firm can make the greater the income of the households which contributes to a potential improvement in households' command over goods and services. Consequently, firm owners (i.e., households) would invariably insist that all decisions on acquiring and combining inputs into output and on marketing the output are aligned with the overarching goal of maximizing profit (Jehle and Reny, 2011). This demonstrates that at the household level therefore, the argument of profit-maximization and its direct link with access to electricity is even more appealing. Accordingly, households are prepared to expend effort and resources to establish enterprises mainly as a means to economic livelihoods and/or to supplement income.

In developing countries such as Nigeria where high poverty rates continue to persist among many households and economic opportunities are also limited, it is even more plausible to expect these income-generating enterprises to be the only obvious avenue some households utilize to support their livelihoods and incomes. In that regard, households are interested not only in having access to electricity to their non-farm enterprises but also and perhaps more importantly interested in how the access to electricity contributes ultimately to profit. It is against this background that the study finds it conceptually compelling to examine the impact of the different levels of electricity access and/or usage on the profit of enterprises instead of any other performance outcomes such as productivity, revenue etc.

2.3.2 Change Mechanism

When a community gets connected to grid electricity there are households that decide to incur the necessary expenditure to get connected whiles others do not. Households that are established post-electrification may also decide to connect to the grid or not. In the same way, there are some existing households' non-farm enterprises whose owners would decide to incur the necessary expenditure to get the enterprise connected whiles others do not. The extension of electricity to the community may, in itself, also contribute to the creation of new non-farm enterprises and some households may also decide to connect their newly established non-farm enterprise to the grid by incurring the necessary initial expenditure while others may not[8]. In all connection decisions the expenditure could include the initial cost of external and internal wiring. There are two mechanisms by which the profits of these firms could be impacted by the connection to electricity and its ultimate usage intensity. Foremost, electricity connection allows for the use of modern machinery and equipment most of which are electricity-dependent. The efficiency of these modern

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[8] Thus, the decision to connect to the grid is entirely a choice variable (i.e., random) rather than deterministic. This is true even if the community was connected by statutory decisions. This is an important requirement for the fulfilment of the unconfoundedness assumption for estimating unbiased causal effects of an intervention. See section 2.3.4.4.

machinery and equipment enhances productivity and service delivery which could reduce operation cost, boost revenue and possibly profits.

The second mechanism is expressed in the extended operating hours in the evenings by firms with access to electricity. If more business hours translate into increased sales, then profits improvement could be inevitably expected. However, given that access to electricity comes with additional cost (both fixed and variable costs), the contribution of access to electricity to profit may largely depend on how much electricity adds to the costs and revenues of the enterprises. This invariably also depend on the extent to which electricity is channelled into the core production activities of the enterprises. Enterprises that choose not to connect to the grid may also enjoy or suffer from potential spill-over effects of those that connect. Hence, profits may or may not be realized as a result of access to electricity and the question of causal impact becomes eminently a matter of empiricism rather *a priori* known

2.3.3 Empirical Strategy

Following the conceptual/structural profit function in equation (2.3) above and the change mechanism just discussed in the preceding section the underlying optimal profit function is simplified below in equation (2.4a).

$$\pi = f(P, X) \text{ ----(2.4a)}$$

Where P is a vector of both output price (p) and input prices (r, w, φ, η) as listed in equation (2.3) while X is a vector of covariates, such as access to electricity, that can potentially impact profit other than P. In this way, equation (2.4a) is our optimal profit function which is generally consistent with the microeconomic theory of profit maximation where optimal profit is a function primarily of output and input prices (Jehle and Reny, 2011). Taking cognizant of the objectives of the study equation (2.4a) is cast into an estimatable reduced-form profit function as given in equation (2.4b) to incorporate the different levels of treatment the enterprises attain in respect of access to electricity and its underlying attributes.

$$\pi_i = \alpha + \tau W_i + \beta X_i + \varepsilon_i \text{ ------------ (2.4b)}$$

Where π_i is the profits of household's non-farm enterprises. The choice of profit as the main outcome variable has been previously justified in section 2.3.1. However, to reiterate and construct it more formally, it is justified on the grounds that having access to electricity comes with instantaneous increase in cost but only a potential increase in output/productivity. Consequently, analysing the impact of electricity on such enterprise outcomes as productivity, revenue or operating hours rather than profit is an obvious neglect of the cost burden electricity imposes on the enterprises. For instance, if the electricity supply from the grid is of poor quality it could lead to voltage fluctuation and power outages that can halt production, damage equipment and adversely affect product quality; all of which could increase the cost burden for the enterprises in addition to the periodic electricity bills the enterprise pays to the utility provider as long as it uses electricity. Besides, as argued earlier, households get their enterprises connected to electricity not only to enhance output/productivity or revenue as an end in itself but to ensure that the associated net gain/income (profitability) is nonnegative. This is because, as previously established, household members are also consumers who take the profits of the enterprise they own as part of the household's income. Therefore, the theoretical behaviour of profit maximization which relates marginal cost to marginal revenue practically implies that a profit maximizing enterprise is incentivized to incur an additional cost such as electricity service expenses only if that expenditure could generate profit. As a consequence, examining the impact of access to electricity on enterprise profitability is a much more pragmatic, attractive and fruitful approach to understanding how access to electricity impacts on household enterprises and eventually income. To ensure comparability across enterprises regardless of size and sector, profits are normalized based on the number of employees. It is important to highlight that two specifications of the profit model were initially tested – one with normalization and the other without the normalization. I noticed that the results were not sensitive to the normalization. And since normalization is frequently recommended in the literature, I decided to focus only on the results with normalization.

X_i is a vector of relevant covariates including enterprise type, age, formality, size and operating hours. In the absence of clearly-defined entrepreneurial variables some socio-economic characteristics of the enterprise owner are also included in the set of covariates to account and control for differences in entrepreneurial skill set. They include owner's highest education, gender, age, marital status, financial inclusion and access to credit. Thus, altogether the covariates are enterprise type, age, labour force, operating hours (day), operating hours (night), as well as owner's gender, age, highest education, marital status, access to credit, formal financial service and informal financial service. It is important to highlight that the optimal profit function in (2.4a) from which the reduced-form profit function is derived is a function of both output and prices and this should have entered into the reduced-form profit function in (2.4b) as well. However, data on both output and prices are unavailable in the World Bank dataset and thus are omitted in the analysis. This explains the absence of the vector P in equation (2.4b). Factors such as technology, location, education of spouse or children, etc are important covariates that are often controlled for in a typical household non-farm firm's profit function. Again, data on these variables are either unavailable or insufficient in the World Bank dataset and thus are omitted in the analysis. Both exclusions are acknowledged as a major limitation of the study. Similarly, the study also acknowledges the inability to control for unobservable covariates as another key limitation. Consequently, our results must be interpreted within this context of missing key variables that make up an optimal profit function as well as other important control covariates.

W_i is the treatment assignment variable which always takes the value 0 if the enterprise is in the control group of electricity access but takes the values 1, 2, 3 depending on the nature or type of treatment to which an enterprise belongs in respect of electricity access and its attributes. τ captures the estimands to be estimated while ε_i is the error term assumed to be independently and identically distributed. The empirical strategy below (specifically sub-section 2.3.4.1) presents a detailed description and discussion of the different treatments and treatment assignment procedure.

2.3.4 Estimation Strategy

The empirical strategy adopted by this study is to analyze access to electricity in a manner that focuses more on the *usage* of electricity and the *attributes* of the electricity services rather than connection to electricity. Fortunately, the dataset (see section 1.4) contains comprehensive information on several attributes of access to electricity which allows for the implementation of this strategy. There are, at least, two ways or approaches in which the information on electricity connection, usage and its attributes can be exploited or harnessed to understand the dynamics of access to electricity and how it is likely to impact on profits of household non-farm enterprises.

One of the approaches conducts a distinction between enterprises on the basis of connection and usage of electricity while the second approach relies on the attributes of electricity access to determine the exact level of electricity access enjoyed by an enterprise. The major feature of both approaches is that they translate the analysis of the impact of access to electricity on the profits of household's non-farm enterprises into multiple treatment evaluation which is discussed in the succeeding section.

2.3.4.1 The Multiple Treatment Effects

As just highlighted, the first approach focuses on whether enterprises are in actual *usage* of electricity or are simply connected to the grid. This is particularly important because in the literature, an enterprise is typically said to have access to electricity as long as it is connected to electricity regardless of whether or not it is used. This results in two groups of enterprises where one group is connected to electricity and the other group is not connected. This is the binary characterization of access to electricity that is frequently reported in the literature. The classical assumption associated with the traditional binary framework of access to electricity is that any firm connected to the grid must necessarily be using electricity. However, some of the firms connected to the grid do not have electric power flowing to any appliances of the firms as was observed during the ESMAP/WB MTF Global survey. We assume that this group of enterprises may have only used electricity at some point in their operations. The strategy adopted by the study is to separate this group of enterprises from their counterparts whose connection to the grid does not end with the electricity meter-boards but also have electric power flowing to their appliances.

This shows that even enterprises connected to the grid differ significantly with regards to the *usage* of electricity. In the ESMAP/WB dataset sourced for the study there are 468 and 592 enterprises that are connected and unconnected to electricity respectively. Following the binary approach that is frequently reported in the extant literature all the 468 enterprises are considered as belonging to the same treatment group. This is improved upon by the first approach of this study by further differentiating the 468 connected firms into two separate treatment groups. This comprises 357 enterprises that are connected but not using electricity and 111 enterprises that are connected and using electricity. It is important to reiterate that the 357 enterprises that are connected to electricity but not using the service are those that have no power flowing to any of their appliances even though they are connected to the grid. As argued earlier, these enterprises may have used electricity services in the past, possibly prior to the survey but are currently not using perhaps due to disconnection resulting from non-payment of electricity bills. It could also be that these enterprises have undertaken a general switch from electricity to alternative energy sources out of the disincentives associated with the zone's enormous irregular and frequent power outages (World Bank, 2019).

The survey conducted by the World Bank did not probe the factors underlying firm's connection to electricity but not using the service. Thus, the exact determinants and reasoning why the enterprises have incurred the necessary fixed cost of connection but not using the electricity service remains unclear. However, it could be conjectured that this behaviour or situation could be linked to issues of lack of affordability, reliability and availability of grid electricity which may have disincentivized or compelled the enterprise to stop using electricity services from the national grid and perhaps switched to alternative energy sources. This conjecture is based on the evidence that, for instance, some enterprises in the survey reported to have experienced more than 80 power interruptions, on average, in a typical month while nearly 90% of the enterprises do not find electricity to be affordable. Moreover, none of the enterprises in the survey has had electricity available for the entire 24-hours in a day. Clearly, these are potential disincentivizing factors that could contribute to the situation of not using electricity even though connected[9]. In this way, the 357 enterprises do not have sustained access to electricity while the 111 enterprises could be considered as having some sustained access to electricity. It must be highlighted that even though the 357 are currently not using electricity, given that they may have been in contact with electricity before, they cannot also be put in the same category as those never connected (i.e., the unconnected group)[10]. This is a vital source of difference in treatment with respect to access to electricity that requires the attention of both research and policy.

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[9] From a policy perspective, this undoubtedly has stern implication for sustainability of electricity access at the household particularly as a tool for improving household income and overall wellbeing through its potential impact on household's non-farm enterprises. Therefore, separating these firms from those unconnected and those with actual usage is extremely important to the understanding of the impact of electricity access.

[10] Hence, it is not unreasonable to consider this group of enterprises that are only connected but not using as entirely different from firms that are never unconnected and also as entirely different from firms that are connected and using.

Consequently, by focusing on whether enterprises are in actual *usage* of electricity or are only connected to the grid, it becomes obvious that there is one untreated group (i.e., firms unconnected to electricity) and two distinct treatment groups where one treatment group (Treated group 1) has electricity only flowing from the grid to the firm's meter-board but not flowing through any appliances; these are firms that are connected to grid but not using electricity. The other treatment group (Treated group 2) has electricity moving from the grid to the firm's meter-board and then to appliances of the firm; these are firms that are connected and using electricity. As treatment differs across these two treatment groups, it translates the analysis into a multiple treatment effect in which Treated groups 1 and 2 serve as the two distinct treatment groups and unconnected firms as the control. The foregoing discussion is succinctly summarized in Table 2.1 and the treatment variable W_i is defined as follows:

$$\boldsymbol{W}_i = \begin{cases} 0 \text{ if enterprise is unconnected} \\ 1 \text{ if enterprise is connected but not using electricity} \\ 2 \text{ if enterprise is connected and using electricity} \end{cases}$$

Table 2.1: Distribution of households' non-farm enterprises by connection and usage (Traditional and Multiple Frameworks)

Nature of Access to electricity	Traditional Treatments	Multiple Treatments
Unconnected	Untreated = 592 (56%)	Untreated = 592 (56%)
Connected but not using	Treated Group = 468 (44%)	Treated Group I = 357 (34%)
Connected and using		Treated Group II = 111 (10%)
Total	**1,060 (100%)**	**1,060 (100%)**

The second approach of exploiting the information on access to electricity focuses on the attributes of electricity services among enterprises are in actual usage of electricity. In this approach the

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Besides, the outcome of interest of the study is the *regular* profits of the enterprises and not current profits. Note that the profit in equation (2.4) is regular (normalized) profit – this is explained in detail under *Model variables* below.

traditional binary framework simply splits the enterprises into those using and those not using under the assumption that enterprises using electricity have the same level of access to electricity. Again, this is not the case because among the firms that are using electricity, it has been previously argued that some could have more hours of electricity than others. Likewise, some may experience frequent and longer outages than others while some may encounter more irregular voltage fluctuations than others. This obvious defect of the traditional framework is improved upon by the second approach adopted by the study. In particular, the second approach allows for the reclassification of electricity-using firms into distinct groups based on the attributes of access to electricity. In the study, the attributes include the availability (day and night-time hours), quality, capacity, reliability and affordability of grid electricity.

A major feature of the attributes is that, within the World Bank MTF Global survey, each attribute has different number of tiers ranging from two-tier to six-tier scales (World Bank, 2019). For instance, while attributes such as quality and affordability have only two tiers, availability has six tiers whereas reliability has three tiers. Thus, for each attribute the enterprises are placed in tiers depending on how much of the attribute they attain such that higher tier is always better. The information from all the five attributes is then utilized to assess households' overall level (or tier) of access to electricity which could have as many as six-ordered-tiers in this study. In particular, an enterprise's overall level of access to electricity is determined by the lowest level (or tier) obtained among the five attributes (World Bank, 2019; Bhatia and Angelou 2015). The rationale for using the lowest tier among the set of attributes to gauge overall access is to ensure that deprivations are well accounted for so as to assist policy on efforts required towards improvement. In this way, enterprise's overall access to electricity is a reflection of the availability of the electricity (i.e., hours of electricity available/used by the firm), quality of the electricity services (i.e., fluctuation in voltages leading to damages of appliances), reliability of electricity (i.e., frequency and the duration of unexpected disruptions), affordability of electricity services (i.e., ability to purchase the minimum amount of electricity) and capacity of electricity (i.e., appliances that can be powered). This is consistent with our earlier argument that even among the enterprises that are using electricity, how much of electricity treatment they receive is different based on the attributes.

Hence, by focusing on the *attributes* of electricity services, this second approach as reported in Table 2.2 results in four distinct treatments regarding overall access to electricity (i.e., treatment level 1=tier 0; treatment level 2=tier 1; treatment level 3=tier 2; treatment level 4=tier 3)[11]. Tier 0 are enterprises not using electricity while enterprises attaining varying levels of the attributes of electricity usage are distributed across Tier 1 up to 3 (see last column of Table 2.2). Thus, even though there are six attainable tiers the enterprises in the study attained only up to tier 3. This is because of the manner in which overall access is measured as previously highlighted (also see World Bank, 2019; Bhatia and Angelou 2015). The tiers are marked by intensity of electricity usage or access. Like the first approach, this approach also translates into multiple treatment in which Tiers 1, 2 and 3 are the distinct treated groups and Tier 0 acts as control. The treatment variable W_i in this second approach is defined as follows.

$$W_i = \begin{cases} 0 \text{ if enterprise is not using electricity and thus in Tier 0 of electricity usage} \\ 1 \text{ if enterprise overall electriciy access is in Tier 1 of electricity usage} \\ 2 \text{ if enterprise overall electriciy access is in Tier 2 of electricity usage} \\ 3 \text{ if enterprise overall electriciy access is in Tier 3 of electricity usage} \end{cases}$$

Table 2.2: Distribution of households' non-farm enterprises by tiers (Multitier Framework)

Tiers	**Availability (Daily)**	**Availability (Night)**	**Reliability Attribute**	**Quality Attribute**	**Affordability Attribute**	**Capacity Tier**	**Overall Access**
Tier 0	949 (89.53)	949 (89.53)	949 (89.53)	949 (89.53)	949 (89.53)	949 (89.53)	949 (89.53)
Tier 1	19 (1.80)	22 (2.14)					33 (3.11)
Tier 2	33 (3.13)	29 (2.83)			110 (10.38)		40 (3.77)
Tier 3	41 (3.89)	22 (2.14)					38 (3.58)
Tier 4	13 (1.23)	2 (0.19)	22 (2.08)	28 (2.64)			
Tier 5			42(3.96)				
Tier 6		2 (0.19)	47 (4.43)	83 (7.83)	1 (0.090)	111 (10.47)	
Total	**1,055 (100)**	**1,026 (100)**	**1,060 (100)**	**1,060 (100)**	**1,060 (100)**	**1,060 (100)**	**1,060 (100)**

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[11] It is important to mention that the tiers have already been defined and categorized by the World Bank in the survey. The study simply extracted the number of households belonging to the different tiers of the attributes, both the individual attribute level and the overall level. Refer to section 2.4.1 for details on the ratings that place enterprises into the different tiers.

2.3.4.2 Matching and Estimations

As the study utilizes observational data, estimations rely on matching methods in order to make causal inferences in both approaches. A major step in the matching methodology is the construction of propensity scores (Rosenbaum and Rubin, 1983; Imbens, 2000) to generate a statistical comparison group of firms, using an appropriate discrete choice model of the probability of having a certain level of access to electricity based on the observed characteristics of the firms. In the study, the matching process proceeds with the construction of generalized propensity scores (GPS) using multinomial probit models (Imbens, 2000). Actual matching is subsequently performed based on the computed GPS after which the inverse probability of treatment weighting (IPTW) is applied to the various matched samples to ascertain the estimands of interest following Imbens (2000), Feng et al. (2011) and McCaffrey et al. (2013).

The main estimands of interest are the average treatment effect (ATE) and the average treatment effect of the treated (ATT) as well as the potential outcome means (POM). The ATE measures the causal impact of access to electricity between a particular treatment level and the control (or category deemed as a reference) while the ATT yields the causal impact of access to electricity within a particular treatment. These estimands are measures of central tendency. In the study, the procedure adopted estimates pairwise ATE/ATT across the various treatments (Hott, Brunelle and Myers, 2012). For instance, in the first approach the ATE for “unconnected” versus “connected but not using” is estimated using equation (2.5) while equation (2.6) is used to estimate the ATE for “unconnected” versus “connected and using”. The ATE for “connected but not using” versus “connected and using” is estimated by equation (2.7)

$$ATE_{w_0,w_1} = \tau_{w_0,w_1} = E[Y_i(w_0)] - E[Y_i(w_1)] \text{ ----------------- } (2.5)$$

$$ATE_{w_0,w_2} = \tau_{w_0,w_2} = E[Y_i(w_0)] - E[Y_i(w_2)] \text{ ----------------- } (2.6)$$

$$ATE_{w_1,w_2} = \tau_{w_1,w_2} = E[Y_i(w_1)] - E[Y_i(w_2)] \text{ ------------------ } (2.7)$$

Where $w_0, w_1, w_2 \in W$ with w_0, w_1, w_2 denoting unconnected, connected but not using and connected and using respectively.

In the same way, in the second approach the ATE for “Tier 1” versus “Tier 0” is estimated using equation (2.8) while equation (2.9) is used to estimate the ATE for “Tier 2” versus “Tier 0”. Also, the ATE for “Tier 3” versus “Tier 0” is estimated by equation (2.10). Equation (2.11) estimates the ATE for “Tier 1” versus “Tier 2” and equation (2.12) estimates the ATE for “Tier 2” versus “Tier 3”

$$ATE_{w_0,w_1} = \tau_{w_0,w_1} = E[Y_i(w_0)] - E[Y_i(w_1)] \text{----------------- (2.8)}$$

$$ATE_{w_0,w_2} = \tau_{w_0,w_2} = E[Y_i(w_0)] - E[Y_i(w_2)] \text{----------------- (2.9)}$$

$$ATE_{w_0,w_3} = \tau_{w_0,w_3} = E[Y_i(w_0)] - E[Y_i(w_3)] \text{----------------- (2.10)}$$

$$ATE_{w_1,w_2} = \tau_{w_1,w_2} = E[Y_i(w_1)] - E[Y_i(w_2)] \text{----------------- (2.11)}$$

$$ATE_{w_1,w_3} = \tau_{w_1,w_3} = E[Y_i(w_1)] - E[Y_i(w_3)] \text{----------------- (2.12)}$$

Where $w_0, w_1, w_2, w_3 \in W$ with $w_0, w_1, w_2, w_3 \in W$ denoting Tiers 0, 1, 2 and 3 respectively.

2.3.4.3 Quantile Treatment Effects (QTEs)

ATE, ATT and POM are not only estimands of great interest to researchers and policy/project evaluations but are also the most frequently used measures of a treatment’s effect. Nonetheless, they do not give any information about the effectiveness of a treatment across the different ranges of the potential outcome even though treatments may reasonably have heterogeneous distributional effects. Therefore, it is not unreasonable to expect the impact of access to electricity on profit of household’s non-farm enterprises to differ across different quantiles of the profit distribution. For instance, enterprises in upper quantiles of the profit distribution are likely to be in sound financial position to pay for electricity services than their counterparts in lower quantiles as the former is more profitable than the latter. It is also plausible to expect enterprises in a higher quantile of the profit distribution to be able to acquire highly efficient and advanced electrical appliances to support production relative to less profitable enterprises. More profitable enterprises may also possess the ability to cope better with power outages and voltage fluctuations compared to less profitable enterprises. One may also argue to the contrary that, enterprises in lower quantiles, by virtue of their little profit may not be heavily reliant on electricity and thus may be least affected adversely during outages and fluctuations relative to more profitable firms that are more likely to be heavily dependent on electricity. This shows that even though the attributes of access to electricity are external to the enterprises, the extent of electricity utilization and coping strategies may depend on where an enterprise lies along the profit distribution. It may also depend on the vulnerability or otherwise of the enterprises. Hence, quantiles of potential outcome distributions can reveal the effectiveness of access to electricity that differ significantly and importantly from those obtained from the ATE, ATT or POM estimations. Consequently, the study extends the analysis to generate *decile* QTEs in attempt to uncover whether access to electricity has more favourable effects towards the less profitable enterprises. This is in line with the argument that electricity, being a major socio-economic infrastructure ought to contribute to the bridging of inequality gaps in addition to poverty reduction, among others. This is qualitatively similar to the typical pro-poor analysis suppose the outcome of interest were to be household's income. This obviously also reveals the range of profit at which access to electricity has the greatest beneficial and/or detrimental impact (if any). Following from the basic model of the study given by equation (2.1), the QTEs can be estimated by the model in equation (2.13)

$$Y_i = \alpha + \tau_j W_i + \beta X_i + \varepsilon_i \text{-----------------} \ (2.13)$$

Where ***j*** corresponds to a particular quantile of the distribution of profit. All other variables remain as previously defined in (2.4)

2.3.4.4. Reverse causality

The literature recognizes potential reverse causality between electricity access and profit (Abeberese, 2017; Rao, 2013; Rud, 2012). This is particularly true when electricity access is measured by electricity consumption. In such an instance, the reverse causality is much expected as profitability can impact on the quantity/amount of electricity consumption as much as electricity consumption impacts on profitability (Abeberese, 2017; Rao, 2013; Rud, 2012). This scenario results in endogeneity where access to electricity – measured by electricity consumption – is an endogenous covariate in the profit model. In cases where access to electricity is measured by attributes such as availability, reliability, capacity, quality, and affordability – as it is the case in this study – the tendency of reverse causality is less likely. This is because the extent to which electricity is available, reliable, of good quality and have the required capacity, is not determined by the profitability of the enterprises. They rather depend on the institution/organization responsible for generating, transmitting and distributing the electricity power for consumption by end-users. For instance, in Nigeria, the availability, reliability and quality of electricity supply is the responsibility of National Electric Power Authority (NEPA) and not the end-users such as the enterprises under consideration in this study. Perhaps, the only attribute that is likely to be influenced by profit is the affordability of the electricity. This is because more profitable enterprises are expected to have the financial resources to pay for electricity service. This demonstrates that the variable generated to proxy electricity access in this study (i.e., "overall access" which simply summarizes these attribute information) is less likely to create the problem of reverse causality with profit. This is because the endogeneity-prone attribute (i.e., affordability) constitutes only one out of six variables utilized to generate the "overall access" variable. Nonetheless, the potential for reverse causality is still acknowledged regardless of how minimal it may be. Instrumentation is frequently recommended in the literature in dealing with endogenous covariates. However, we could not find valid instruments in the World Bank dataset to address this potentially minimal endogeneity. This is acknowledged as a limitation of the study. However, given that the source of the potential endogeneity is minimal, the results are not expected to suffer from much biases. Nevertheless, the results and the eventual conclusions must be embraced with a bit of caution.

2.3.4.5 Key Assumptions

There are vital axiomatic requirements to be satisfied in order to estimate unbiased causal effect of an intervention. In the case of multiple treatments using the GPS, Leite et al. (2019) identifies weak ignorability/unconfoundedness of treatment assignment, overlapping and the stable unit treatment value assumption (SUTVA) as among the central assumptions. Using $\boldsymbol{Y}$ and $\boldsymbol{X}$ to represent the outcome of interest and pre-treatment covariates respectively and $\boldsymbol{W}$ and $\boldsymbol{w}$ respectively as treatment assignment variable and a particular treatment level, we discuss two notable assumptions applied in the study.

Assumption 1 (Unconfoundedness): Unconfoundedness prescribes that the probability of assignment to a treatment does not depend on the potential outcomes conditional on observed covariates (Busso et al., 2013). When estimating ATE and ATT with the IPTW a relaxed version of this assumption can be adopted (Imbens, 2000). This is because, to estimate the ATE_{w_1,w_2} for instance, the IPTW only requires that $\forall\, w \in W, Pr[W_i(w) = 1 \mid Y_i(w), X_i] = Pr[W_i(w) = 1 \mid X_i]$. This implies that selection into the intervention or treatment is random (i.e., exogenous) conditional on a set of observable covariates i.e., $Y_t \perp W \mid X$. In experimental studies such as Randomized Controlled Trials (RCTs) satisfying the assumption of randomness of participants is feasible as agents could be completely randomized through the survey process. As this study is observational, nonexperimental methods are the only alternatives to satisfy the unconfoundedness assumption. The construction of statistical comparable groups of firms with different level of treatment based on their propensity scores and subsequently matching them is an acceptable approach to satisfying the unconfoundedness assumption. This is exactly the purpose of applying the GPS and IPTW methods in the study.

Assumption 2 (Overlapping): Overlapping requires the existence of sufficient common support for each treatment level/group among the group of controls so that for each individual in the population we are able to find comparable individual(s) in terms of covariates (Busso et al., 2013). Thus, for all characteristics of interest and treatment levels the probability of being assigned to any treatment group should be bounded away from zero (Imbens, 2000). In other words, the assumption restricts the population of enterprises to the covariate space where each enterprise has a non-zero probability of receiving any of the treatments regarding access to electricity. The standard overlapping assumption in both binary and multiple treatments settings require the propensity score to be strictly between zero and one i.e., $0 < \Pr(W_i = t \mid X = x) < 1$. The importance of the assumption is that without effective common support, there will be values of *x* for which estimands cannot be generated without relying on extrapolation. In the study, the assumption entails the estimation of multinomial probit models for all treatment scenarios. The probabilities are then predicted for the construction of kernel conditional densities to allow for the evaluation of the fulfilment of the overlapping assumption. According to Busso et al. (2013), for each treatment level *w*, the kernel plots the estimated density of the predicted probabilities conditional on each possible treatment level. If any estimated density displays a sufficient mass near 0 or 1, the predicted probabilities are too close to 0 or 1, and the semiparametric estimators would probably not perform well in finite samples, even when unconfoundedness is satisfied (Busso et al., 2013).

2.4 Results and Discussions

2.4.1 Descriptive Statistics

Before discussing the major findings of the study, we provide some summary statistics of the key variables used in the various estimations. We focus mainly on statistics that describe the data relevant to addressing the research objectives. One advantage of descriptive statistics is that they reveal important information about the data and may further act as lead indicators of key findings. The descriptive statistics are reported in Tables 2.3, 2.4 and 2.5 and are discussed herewith.

Attributes and overall access to electricity

Table 2.3 reports the six attributes of access to electricity among enterprises in current usage of electricity. The table tells the number and percentage (in parentheses) of household's non-farm enterprises attaining various tiers of the attributes. In its last column, the table also shows enterprise's overall access to electricity which, as defined earlier, is the lowest tier achieved by an enterprise among the set of attributes. In terms of the availability[12] (daily) attribute it is observed that none of the electricity-using enterprises attained Tiers 5 and 6 but nearly 88% of them are found across Tier 1, 2 and 3. This implies that, out of the possible 24 hours, none of the electricity-using enterprises had electricity available for more than 15 hours in a day while for an overwhelming 88% electricity was only available for 0 – 10 hours. The state of electricity availability (daily) is a potential impediment to production especially for enterprises that need several hours of electricity for production activities. Relatedly, out of the possible 12 hours of electricity available during the night approximately 95% of the electricity-using enterprises had to manage only 0 – 5 hours of electricity. These enterprises are located across Tiers 1, 2 and 3 of the attribute. There are about only 3% of the electricity-using enterprises that have electricity available for 9 – 12 hours in the night and are thus located in Tier 6 of the attribute.

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[12] Availability ("Is power available when I need it?"): The availability attribute of electricity supply refers to the amount of time during which electricity is available. It is measured through two indicators: the total number of hours per day (24-hour period) and the number of evening hours (the four hours after sunset) during which electricity is available (World Bank, 2019).

The frequency and duration of power outages are summarized in the reliability[13] attribute. Almost 20% of the electricity-using enterprises are found in Tier 4 of the reliability attribute. This is the worst or least tier among the three tiers of the attribute. The enterprises in this tier of the attribute are those that experience at least 15 power interruptions in a typical month with some of them in the tier suffering as many as 84 power interruptions in a typical month. The nearly 38% of the enterprises in Tier 5 suffer between 3 and 14 power interruptions in a typical month. Fortunately, there are about 42% of the electricity-using enterprises that experience less than 3 power interruptions in a typical month and are classified under Tier 6 which is the best attainable tier. The information conveyed by the reliability attribute obviously suggests that electricity is scarcely reliable as more than half of the electricity-using enterprises experience severe form of power interruption every other day in a typical month.

The quality[14] of electricity, measured in terms of voltage fluctuations, points to a much positive situation as an overwhelming 75% of the electricity-using enterprises have neither experienced any form of voltage fluctuations nor made any extra expenditure on repair and maintenance of appliances damaged as a result of grid voltage fluctuations. These enterprises are found in Tier 6 which is the best attainable tier of the attribute. The remaining 25% of the enterprises are located in Tier 4, the worst accessible tier. These enterprises have experienced some form of voltage fluctuations which may have also resulted in some extra expenditure of up to about $16 on repair of damaged appliances. Regarding the affordability[15] attribute, electricity services are considered

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[13] Reliability ("Is my service frequently interrupted?"): The reliability attribute of electricity supply is a combination of the frequency and the duration of unexpected disruptions. In this report, the Reliability attribute is measured only for households connected to the grid (World Bank, 2019).

[14] Quality ("Will voltage fluctuations damage my appliances?"): The quality of the electricity supply refers to the absence of severe voltage fluctuations that can damage a household's appliances (World Bank, 2019).

[15] Affordability ("Can I afford to purchase the minimum amount of electricity?"): If the household's non-farm enterprise spends more than 5% of the its expenditure on electricity, then electricity service is considered unaffordable for that household's non-farm enterprise (World Bank, 2019).

Capacity ("What appliances can I power?"): The capacity of the electricity supply (or peak capacity) is the ability of the system to provide a certain amount of electricity to operate various appliances, ranging from a few watts for light-emitting diode (LED) lights and mobile phone chargers to several thousand watts for space heaters or air conditioners.

not affordable to almost all the enterprises. Specifically, the over 99% of the electricity-using enterprises found in the Tier 3 of the affordability attribute spend more than 5% of their revenue on payment of electricity bills. This criterion is consistent with World Bank (2019) which considers electricity not to be affordable if the expenditure incurred by an enterprise on electricity bills exceeds 5% of its income/revenue. There are no issues regarding the appliances that can be powered by the electricity emanating from the national grid as all the enterprises are found in the best attainable tier of the capacity attribute (i.e., Tier 6). Differently stated, the capacity of the grid electricity is such that it is able to power all types of electrical appliances used by all the electricity-using enterprises.

The last column of the table shows enterprise's overall access to electricity. All things being equal, an enterprise with a higher overall access has, on average, a better ranking across the five attributes and thus, a greater electricity use intensity. However, it is important to emphasize that, the fact that an enterprise attains a higher overall tier does not necessarily imply that such an enterprise also attains higher tiers across all the five individual attributes and the converse also holds. Indeed, not all of enterprises in a higher overall even attains equal higher tiers across all the five individual attributes. At best, there is a greater likelihood that enterprises in higher overall tier also attain higher tiers across most, if not all, of the five individual attributes. This is because it is an enterprise's level of access to the individual attributes of electricity that determines its level of overall access of electricity (World Bank, 2019). In this way, we utilize enterprise's overall electricity access to capture intensity of both attributes and usage/access. From the table, there appears to be an almost even distribution of enterprises across the three attained tiers regarding overall access to electricity. The enterprises with Tier 1 overall access to electricity are those characterized by up to two hours of electricity available during the day and at most an hour of electricity available during the night. They are also either in Tier 4 or 6 in terms of quality of electricity and Tier 5 of reliability. However, since an enterprise's overall access to electricity is determined by the least tier obtained across the five attributes, they are found in Tier 1 status entirely as a result of the availability attribute in which they attain Tier 1.

Similarly, Tier 2 overall access enterprises are those with 3 – 5 hours of electricity available during the day and 2 – 3 hours of electricity available during the night. Like their counterparts in Tier 1 of overall access, the Tier 2 overall access enterprises are also either in Tier 4 or 6 of quality of electricity and Tier 5 of reliability but are bound in Tier 2 entirely due to the availability attribute in which they attain Tier 2. Finally, Tier 3 enterprises have at least 6 hours and 4 hours of electricity available during the day and night respectively. However, unlike their counterparts in Tiers 1 and 2 of overall access, they are rather either in Tier 5 or 6 of quality of electricity and Tier 6 of reliability. The overall access to electricity of these enterprises in Tier 3 is because of the affordability attribute in which they attain Tier 3. Thus, about 66% of the enterprises are trapped in Tiers 1 and 2 as a result of limited hours of available electricity supply and the remainder stuck in Tier 3 as a result of unaffordable electricity services.

It may be argued, from the above, that the focus of Nigeria's electrification appears to have been largely extensive rather than intensive. This is because more than 70% of those using electricity hardly access the service at the highest standard of its attributes. Consequently, the major implication from the foregoing discussion is that availability, reliability and affordability are the focal aspects of any intensive electrification in the country particularly its Northwest zone.

Table 2.3: Distribution of households' non-farm enterprises by attributes among electricity-using enterprises

Tiers	Availability (Daily)	Availability (Night)	Reliability Attribute	Quality Attribute	Affordability Attribute	Capacity Attribute	Overall Access
Tier 1	19 (17.92)	22 (28.57)					33 (29.73)
Tier 2	33 (31.13)	29 (37.66)					40 (36.04)
Tier 3	41 (38.68)	22 (28.57)			110 (99.10)		38 (34.23)
Tier 4	13 (12.26)	2 (2.60)	22 (19.92)	28 (25.23)			
Tier 5			42 (37.84)				
Tier 6		2 (2.60)	47 (42.34)	83 (74.77)	1 (0.90)	111 (100)	
Total	**106 (100)**	**77 (100)**	**111 (100)**	**111 (100)**	**111 (100)**	**111 (100)**	**111 (100)**

Enterprise types and treatment levels

The four main categories of enterprises are manufacturing, shop/trading, cottage and services. The remaining enterprises are grouped under the category of "other" as each constitutes an almost negligible share. In terms of their distribution across the various treatment levels of access to electricity, it is observed in Table 2.4 that the greater majority of enterprises in the manufacturing and cottage are unconnected to the grid altogether. Indeed, there are less than 6% of enterprises in the manufacturing sector that are using electricity. This is particularly surprising as electricity is expected to feature prominently in modern manufacturing processes with the advent of advanced equipment and machineries some of which are electric-dependent. The use of electricity in enterprise activities is dominated by those in the services and shop/trading sectors. In particular, there are about 24% and 19% of the enterprises in the services and shop/trading sectors respectively making use of electricity. The impression created is that electricity is perhaps principally useful in the delivery of services and marketing rather than production of goods. The proportion of enterprises that have previously used electricity is quite significant ranging from about 30% to 55%. This reaffirms the assertion that enterprises without sustainable access to electricity are non-negligible and special attention ought to be paid to this phenomenon. Indeed, this observation must be a major point of concern for policy as it could adversely affect the cost and productivity of the enterprises as well as profit as an inevitable consequence.

Table 2.4: Distribution of households' non-farm enterprises over treatments (Scenario I)

Treatment	**Manufacturing**	**Cottage**	**Shop/Trading**	**Services**	**Other**	**Total**
Unconnected	405 (65.11)	46 (53.49)	103 (44.21)	23 (28.75)	12 (34.29)	**589** (55.78)
Connected but not using	180 (28.94)	33 (38.37)	86 (36.91)	38 (45.50)	19 (54.29)	**356** (33.71)
Connected and using	37 (5.95)	7 (8.14)	44 (18.88)	19 (23.75)	4 (11.42)	**111** (10.51)
Total	**623 (100)**	**86 (100)**	**233 (100)**	**80 (100)**	**35 (100)**	**1,057 (100)**

Using the attributes to gauge an enterprise's exact level/tier of access to electricity, it is observed from Table 2.5 that among electricity-using enterprises the greater majority of those in the manufacturing sector are in Tier 1. On the other hand, the greater majority of enterprises in the cottage, shop/trading, services and even other sectors are either in Tier 2 or Tier 3. One implication is that electricity is likely to be more available, reliable and affordable to enterprises in the cottage, shop/trading and services sectors but not those in the manufacturing sector. Another implication could be that electricity is predominantly utilized by enterprises in the cottage, shop/trading and services sectors relative to their counterparts in the manufacturing sector.

Table 2.5: Distribution of households' non-farm enterprises over treatments (Scenario II)

Treatment	Manufacturing	Cottage	Shop/Trading	Services	Other	Total
Tier 0	586 (94.06)	79 (91.85)	189 (81.12)	61(76.25)	31(88.57)	**946** (89.50)
Tier 1	14 (2.25)	2 (2.33)	10 (4.29)	6 (7.50)	1(2.86)	**33** (3.12)
Tier 2	13 (2.09)	4 (4.66)	14 (6.01)	7 (8.75)	2 (5.71)	**40** (3.78)
Tier 3	10 (1.61)	1 (2.26)	20 (8.58)	6 (7.50)	1(2.86)	**38** (3.60)
Total	**623 (100)**	**86 (100)**	**233 (100)**	**80 (100)**	**35 (100)**	**1,057 (100)**

Model variables

Table 2.6 also reports summary statistics of the outcome of interest, monthly profit, together with other relevant covariates[16]. In the World Bank dataset and for that matter in this study, profit is defined as "*regular profit*[17]" which is the kind of profit the enterprises obtained in a month during a normal business climate i.e., a month that is neither the busiest nor the slowest of the year. The notion of regular profit, "normal business climate", "busiest" and "slowest" month could be explained through the concept of business/economic cycles. In particular, there is seasonality in the business cycle which is connected to some things happening in the economy. Explicitly, both the economy and economic agents such as households and enterprises have ups and downs such that there are months in which businesses would tend to have more sales because of some happenings in the economy or community. This could include holidays such as Christmas, Ramadan, related festivals etc. A month that is typically characterized by these happenings could be referred to "busiest" month in the operation of the enterprise. Similarly, there are periods when businesses are slowest – this is when households or economy might be focusing on something in particular such that household incomes tend to be directed to that particular thing and starving the

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[16] See Appendix A1 – A6 for information on other summary statistics on the covariates based on detailed inspection.

[17] Foremost, in the World Bank data that was used for the thesis, there is a question that specifically asked the household's non-farm enterprises to state their regular profit. In the questionnaire, the World Bank defines regular profit as the profit obtained during a normal business climate (i.e., neither the busiest and slowest month).

other sectors of the usual business opportunity. An example could be the opening of schools when households are focusing on being able to have the requirements for their children to go back to school and in that case their expenditure is more directed to the "back to school" sector rather than other sectors. A month that is typically characterized by these happenings could be referred to "slowest" month in the operation of the enterprise. Outside these busiest and slowest months would become typically normal months which could be referred to as "normal business climate". The profit that accrues to the enterprise during these normal month(s) is the typical profit or simply regular profit. Hence, the regular profit is basically a way to take out seasonality in cases where you conduct a survey during a period which is not very typical/normal.

Recall that, profits are normalized based on the number of employees to ensure comparability across enterprises regardless of size and sector. Thus, it is important to highlight that the profits under discussion in the study is monthly profit per employee. For simplicity, "monthly profit per employee" is used interchangeably with "monthly profit" or simply "profit". It is observed that the monthly profits per employee of the household's non-farm enterprises range from subnormal profit of $974 to supernormal profit of $3,618, averaging at approximately $4. A detail inspection further reveals that about a third of the enterprises earn subnormal profit of different magnitudes (see Appendix A1). Also, in terms of distributions across enterprise types[18], the manufacturing sector tends to dominate the business space surveyed accounting for nearly 60% and is followed by the services sector which represents about 22%. Cottage and shop/trading are equally represented in the business space with each accounting for approximately 8%. All the other enterprises constitute less than 4% and are thus put in the same basket for analytical purposes. It is also observed that more than 10% are just a year older or even less and nearly 70% have been in operation for at most a decade. This shows that, in general, the enterprises under consideration are much younger. Indeed, enterprises aged above 20 years are very negligible as there are more than 90% of the enterprises that are not older than 20 years (see Appendix A2). Also, there are about 98% of the enterprises that do not have more than five employees (see Appendix A3). Enterprises with between 6 – 25 workers are just 2%.

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[18] Tables 2.3 and 2.4 above give additional information on the distribution of the enterprises.

In terms of formality, about 99% of the enterprises are not officially registered. A detail inspection of the data on ownership reveals that, consistent with male-headed domination, ownership of household's non-farm enterprises is also dominated by males as nearly 82% of all enterprises are owned by males (see Appendix A4). Also, more than half of the enterprise owners are aged 15 – 35 years. It is further observed that almost 70% of the owners are below the age of 40 years while another less than 10% of them are above 55 years (see Appendix A5). This reflects greater youthfulness among the enterprise owners. Reconciling the ages of the owners with that of the enterprises it could be deduced that many of the enterprises may have been created by the owners themselves and perhaps a few bequests. Analysis of the financial characteristics of the owners also show that almost 80% of the enterprise owners do not have any bank accounts in any formal financial institution. Similarly, about 75% of enterprise owners neither use any informal saving groups (see Appendix A6) nor have access to any form of credit. This demonstrates that enterprise owners generally are financially excluded and face potential credit constraints.

Table 2.5: Outcome variable and other Covariates

Variable	Obs.	Mean	Std. Dev.	Min	Max
Profits – *outcome* (US$)	1,057	3.871732	131.3678	-974.25	3,618.65
Enterprise age	1,056	9.919508	8.973059	1	78
Labour force	1,057	.3301798	1.500558	1	25
Operating hours (day)	1,057	8.024598	3.799342	1	18
Operating hours (night)	1,057	1.446547	2.396579	0	12
Enterprise type	1,057	1.881741	1.182342	1	5
Gender (1=Female)	1,057	.1825922	.3865148	0	1
Access to credit (1=Yes)	1,056	.2376894	.4258696	0	1
Formal Financial service (1=Yes)	1,056	.2414773	.4281818	0	1
Informal Financial service (1=Yes)	1,056	.2159091	.4116465	0	1

Mean Profits estimations across treatments[19]

The estimated means of monthly profit per employee over the various treatment scenarios are presented in Tables 2.7 and 2.8. In Table 2.7, the estimated mean profit for enterprises currently using electricity substantially exceeds the mean profit of their counterparts that have only previously used electricity. The enterprises unconnected to electricity altogether record the least mean profit. In Table 2.8 where emphasis of access to electricity is based on its attributes it is observed that the mean profits of those in Tier 2 is largest. This is followed by Tier 3 with Tier 0 enterprises having the least mean profits while that of enterprises in Tier 1 is not statistically different from zero. The evidence on the mean estimation does not give an obvious systematic trend in the impact analysis. This is certainly pin down precisely by the empirical estimation in the succeeding section.

Table 2.6: Mean estimation of monthly profit across treatments (First approach)

Treatment	**Mean**	**Std. Err.**	**[95% Conf.**	**Interval]**
Unconnected	9.903754	1.382657	7.190684	12.61682
Connected but not using	14.51686	2.474181	9.661987	19.37174
Connected and using	50.39603	32.63946	-13.64961	114.4417

Table 2.7: Mean estimation of profits across treatments (Second approach)

Treatment	**Mean**	**Std. Err.**	**[95% Conf.**	**Interval]**
Tier 0	11.64695	1.269385	9.156147	14.13775
Tier 1	122.4436	109.3841	-92.19126	337.0785
Tier 2	23.57203	7.849477	8.169679	38.97437
Tier 3	16.06417	4.758049	6.727865	25.40047

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[19] Profits are expressed in USD for period of data collection September 2017 to March 2018 (US$1 = N359.25) to allow for cross-country comparisons.

2.4.2 Discussion of Findings

The causal effects of access to electricity on the profit (i.e., monthly profit per employee) of non-farm enterprises of households are estimated under the two approaches discussed at the methodology section. To reiterate, the first approach measures access to electricity on the basis of whether enterprises are in actual *usage* of electricity or are only connected to the grid. The second approach evaluates access to electricity based on the *attributes* of electricity services. In both approaches, the study estimated ATEs, ATTs and POMs[20].

2.4.2.1 Multiple Treatment Effects

2.4.2.1.1 First Approach: Connection to grid as focus of electrification

ATE

It is observed from Table 2.9 that the ATE of moving from the level of being unconnected to electricity to the level of being connected to electricity but not using, though positive, is not statistically significant. This implies that, relative to those that have never been connected to the grid, access to electricity has no causal impact on profits of enterprises as long as electricity is not deployed in deployed in current operation. This still holds even if the enterprise has previously used electricity. However, the ATE of using electricity as against having no connection is positive and statistically significant at 10%. This demonstrates that moving a step further to the level of deploying electricity in current operations of the enterprise generates some additional profit. In particular, a switch from a state of non-connectivity to the grid to a state of usage of the grid electricity results in a causal increase of monthly profit per employee by $13. This unequivocally supports the strand of the literature that concludes that access to electricity on its own could exert favourable effect on profitability (see for instance Asaduzzaman et al., 2010; Chauvet et al., 2018; Kirbu et al., 2009).

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[20] The Kernel densities corroborating the existence of valid common support for all treatment levels in both approaches are reported in Appendix C. The associated numeric statistics summarizing the predicted conditional probabilities are reported in Appendix B

ATT

In all cases of treatment comparison, the estimated ATT (1) are not statistically significant. This shows that suppose all enterprises are conditioned to the treatment level of being connected without usage, access to electricity has no systematic causal impact of the profits of these enterprises regardless of the pairwise comparison analyzed. Given the ATE results, this observation is unsurprisingly. However unexpectedly, the ATT (2) also shows that access to electricity still has no causal impact on the profits of household's non-farm enterprises. The lack of evidence on ATT (2) even though a favourable ATE exist could be that electricity may not have been used by the enterprises in ways aligned to the core business of the enterprises. For instance, suppose household's non-farm enterprises typically use electricity mainly for basic activities such as lighting and communication while relying heavily on other energy sources for production of goods and services[21]. In such a scenario, it may not be entirely unreasonable to expect the difference in the conditional mean monthly profits per employee between the non-farm enterprises to be equivalent to zero.

POM

Unlike ATEs/ATETs where the effect of each treatment of electricity access on profitability are expressed relative to the base/control treatment of no connection, the POMs are a very useful way of comparing adjacent treatments. Particularly, POM allows us to express the gains to enterprises that are using electricity relative to those connected but not using electricity. This is an outcome unachievable when estimating ATE and ATT. As reported in the last panel of Table 2.9, the addition to the profits of households' non-farm enterprises using electricity relative to those that are simply connected to the grid without using electricity is $12.5 – this profit is almost the same as the profits that electricity-using enterprises make relative to those unconnected to the grid altogether.

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[21] Household's non-farm enterprises may opt to rely on alternative energy sources for production of good and services because they may be relatively less expensive and cost effective relative to electricity. Electricity may be used primarily for lighting and communication.

Table 2.8: Impact of access to electricity based on connection

Estimands	Coefficient	Robust Standard Errors
ATE		
Connected but not using vs. Unconnected	3.279	6.089
Connected and using vs. Unconnected	13.41*	8.087
ATT (1)		
Connected but not using vs. Unconnected	4.439	6.823
Connected and using vs. Unconnected	11.04	7.449
ATT (2)		
Connected but not using vs. Unconnected	-3.489	26.85
Connected and using vs. Unconnected	30.62	42.94
POM		
POM: Unconnected	-0.866	5.266
POM: Connected but not using	2.412	3.122
POM: Connected and using	12.54**	6.149

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

2.4.2.1.2 Second Approach: Attributes of electricity usage as focus of electrification

ATE

Moving away from connection towards usage intensity based on the attributes of access to electricity, we find that the estimated ATE of having Tier 1 access to electricity relative to Tier 0 is not statistically significant. However, relative to Tier 0 the estimated ATE associated with progressing to Tier 2 causes nearly $11 additional monthly profit per employee at 5% level of significance. Similarly, at 10% level of significance, access to electricity results in a causal increase in the monthly profits per employee of Tier 3 enterprises by approximately $18.45. Overall, the evidence established based on the attributes of electricity among users is quite remarkable because it demonstrates that the impact of access to electricity on profitability increases with consistent improvement in the attributes of electrification. Interestingly, the results also show that Tier 1 enterprises are no different from Tier 0 since neither benefit from the favourable causal effect of access to electricity on profitability. Thus, if the profit of an electricity-using enterprise is to be boosted by access to electricity, then the enterprise must necessarily be in at least Tier 2.

Table 2.9: Impact of access to electricity based on attributes

Estimands	Coefficient	Robust Standard Errors
ATE		
Tier 1 vs. Tier 0	10.19	10.96
Tier 2 vs. Tier 0	10.56**	4.482
Tier 3 vs. Tier 0	18.45*	9.772
ATT (1)		
Tier 1 vs. Tier 0	105.1	109.5
Tier 2 vs. Tier 0	16.80	10.35
Tier 3 vs. Tier 0	14.81	11.99
ATT (2)		
Tier 1 vs. Tier 0	96.09	113.2
Tier 2 vs. Tier 0	28.48*	15.66
Tier 3 vs. Tier 0	19.44	14.17
ATT (3)		
Tier 1 vs. Tier 0	-9.357	25.36
Tier 2 vs. Tier 0	27.48	20.79
Tier 3 vs. Tier 0	-13.13	29.91
POM		
POM: Tier 0	-0.230	2.595
POM: Tier 1	10.17	10.66
POM: Tier 2	10.54***	3.612
POM: Tier 3	18.42**	9.366

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

ATT

The average treatment effects conditional on enterprises actually being in Tier 1 of access to electricity [ATT (1)] are not statistically significant. However, in the analysis of ATT (2), it is estimated at 10% that access to electricity tends to causally increase profits by about $28 per month per employee. Surprisingly, conditional that enterprises are actually in Tier 3 of access to electricity [i.e., ATET (3)] does not have any statistically significant impact on profits even at 10%. Broadly, the ATT results are consistent with the ATE results established for Tier 1 and Tier 2 enterprises while the contrary is found for Tier 3 enterprises. The lack of adequate ATT evidence in this second approach is comparable to those established in the first approach. This points to a likely intrinsic firm behaviour whereby electricity may not have been used by the enterprises in ways aligned to their core business; otherwise, positive statistically significant ATTs were expected for Tier 3 enterprises in the presence of some favourable ATE evidence.

POM

It is also observed that a move from Tier 0 to Tier 1 of electricity access is not statistically significant and thus no additional profit is accrued to an enterprise for moving to Tier 1. However, climbing up from Tier 1 to Tier 2 sees enterprises registering extra profits of almost $11 each month per employee. In the same way, progressing from Tier 2 to Tier 3 is associated with a causal increase of monthly profit per employee by about $18. Unlike the ATT results, the findings obtained from the POMs are generally consistent with those established under ATE.

2.4.2.1.3 Robustness Check – Comparison with the Binary Approach

It has been shown earlier that the binary procedure is the conventional approach that has been utilized to examine the causal effect of access to electricity on profitability. Nevertheless, it has been argued extensively that more insights could be obtained with the multiple treatment procedure implemented by the study. Therefore, while the binary procedure is not a focus of the study, it could be shown, although used primarily to check robustness of our main results, that it tends to underestimate the potential effect of access to electricity relative to the multiple treatment procedure. To demonstrate this claim, we estimate the two approaches adopted by the study but treating access to electricity as binary instead of multiple. The results as reported in Table 2.11 show that, following the first approach in which connection to grid only is the focus of electrification, the binary ATE is $7.5 which is significantly lower than the $13.4 generated based on the multiple treatment procedure for those using electricity. The underestimation of nearly 80% is a consequence of the evidence that the binary procedure splits the firms into only two categories

– unconnected vs. connected. Even though among those connected, we have seen that some are in actual usage of electricity while others are not and thus having different treatments regarding access to electricity. Yet, the binary procedure still considers them as having the same treatment and hence puts them into the same group. Therefore, in the binary procedure the sample of treated firms is much larger than in the multiple procedure such that firms connected but not using electricity dampens the causal effect on those in actual usage of electricity. Therefore, when the treated group are further recategorized into two distinct treatment groups by the multiple procedure, it is observed that the positive causal effect on the month profits per employee of those using electricity is magnified to the $13.4 while that of those merely connected but not using is no longer statistically significant. Similarly, following the second approach whereby attributes of electricity usage is focus of electrification, the binary ATE is $12.55 but in the multiple procedure the ATE for Tier 1 is not statistically significant and Tier 2 is 10.45 while that of Tier 3 is $18.45. Thus, the binary procedure does not only assign the same ATE for all those using electricity but also overestimates the effect on those in Tiers 1 and 2 while underestimating that of Tier 3 enterprises. Again, by splitting electricity-using firms into distinct tiers based on the intensity of the attributes of electricity access, the multiple procedure corrects the anomaly by showing that even among those using electricity, higher intensity of electricity access (i.e., improved attributes) yields relatively larger gains.

Table 2.10: Binary procedure to the analysis of the causal effect of access to electricity

Approach	Type of treatment	Coefficient	Rob. Std. Err
First Approach	Connected (Treated)	7.346*	3.553
	Unconnected (Control)		
Second Approach	Attributes-Using (Treated)	12.54**	6.820
	Non-using (Control)		

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

2.4.2.2 Quantile Treatment Effects

2.4.2.2.1 First Approach: Connection to grid as focus of electrification

As previously highlighted, we utilize deciles in estimating the QTE. When connection only is the focus of electrification the output in Table 2.12 shows that prior to the median, the estimated quantile effects of electricity access, if statistically significant, are negative. Indeed, the positive gains of access to electricity to monthly profits per employee are observed for firms located at the median and/or higher. For instance, before the 0.5 decile access to electricity causally reduces the profits per employee of unconnected enterprises by about $3.34 up to as high as $22.27 each month. Similarly, access to electricity causally reduces the profits of enterprises that have previously used electricity by approximately $4.17 up to about $27.84 each month. This generally implies that access to electricity has a detrimental causal impact on the profits of household non-farm enterprises that are at the tail-end of the profit distribution. This is observed, especially, among enterprises that are unconnected to electricity and enterprises that connected to electricity but not using it with the latter witnessing the worst impact. As these enterprises are not using electricity the negative causal impact of access to electricity could be understood as adverse spill-over effect of electrification. Profit is adversely affected even among those using electricity but located at the very bottom of the quantile to the tune of $11.13.

However, as we move from the median decile, we observe that where access to electricity has any impact at all, it is positive. It is also observed that electricity-using enterprises tend to accrue the highest gains as we reach the apex of the distribution. Specifically, at 1% level of significance, access to electricity is accompanied with causal increase in the monthly profits per employee of the current users by nearly $56 while their counterparts who are either unconnected or connected but not currently using electricity only obtain $22 and $27 respectively. Thus, enterprise in actual usage of electricity generates more than 100% additional profit monthly per employee. The general conclusion emanating from these results is that access to electricity does not only have a favourable causal impact on the profits of household non-farm enterprises that are at upper-end of the profit distribution but also generates a relatively greater positive impact on profits of enterprises that are in current actual usage of electricity.

2.4.2.2.1 Second Approach: Attributes of electricity usage as focus of electrification

Among enterprises that are at different tiers of electricity usage based on the attributes of access to electricity, the estimated causal impact of access to electricity on profit at the lower deciles are largely negative (see Table 2.13). Specifically, access to electricity causally reduces the profits of enterprises at Tier 0 and Tier 3 of electricity usage by approximately $22 and $6 each month respectively. As previously established, since Tier 0 enterprises are not using electricity the adverse causal impact of access to electricity observed here could be understood as spill-over effect of electrification. The coefficients for their counterparts in higher tiers of electricity usage (i.e., Tier 1 and Tier 2) are however not statistically significant even at 10%. This shows that access to electricity has no causal impact on the profits of household's non-farm enterprises in Tiers 1 and 2 of access to electricity at the lower-end of the profit distribution.

In general, these findings indicates that where access to electricity has any causal impact, it tends to decrease rather than increase the profits of household non-farm enterprises that are at lower decile of the profit distribution. At the median and higher quantiles however, the estimates show that access to electricity begins to have a positive statistically significant causal impact on the profits of household's non-farm enterprises. At the uppermost limit, for instance, access to electricity causally increases the monthly profits of enterprises at Tier 0 of electricity usage by approximately $26. For the Tier 2 and Tier 3 enterprises the causal impact of access to electricity on enterprise profit is a rise of approximately $40 and $70 respectively. The coefficients for their counterparts in Tier 1 are however not statistically significant even at 10%. This largely indicates that access to electricity causally improves the profits of household non-farm enterprises that are at mid-to-end of the profit distribution except for enterprises that are Tier 1.

Table 2.11: Quantile impact of access to electricity based on connection (Deciles Analysis)

Tiers	0.1 Decile	0.2 Decile	0.3 Decile	0.4 Decile	0.5 Decile	0.6 Decile	0.7 Decile	0.8 Decile	0.9 Decile
A	-22.27***	-8.907***	-3.340***	0.001	1.392**	3.340***	6.402***	11.13***	22.27***
	(2.982)	(1.526)	(1.248)	(0.455)	(0.551)	(0.850)	(0.956)	(1.601)	(3.036)
B	-27.84***	-12.53***	-4.175**	0.001	2.227***	5.010***	6.959***	13.08***	27.84***
	(4.261)	(2.442)	(1.647)	(0.571)	(0.595)	(0.744)	(1.476)	(0.638)	(5.222)
C	-11.13*	-2.784	-0.0835	0.001	2.032	4.175*	5.567	20.04	55.67***
	(6.548)	(2.440)	(1.034)	(0.826)	(1.415)	(2.500)	(5.013)	(13.49)	(15.17)

Standard errors in parentheses are bootstrapped. *** p<0.01, ** p<0.05, * p<0.1. Also, A = Unconnected; B = Connected but not using; C = Connected and using

Table 2.12: Quantile impact of access to electricity based on attributes (Deciles Analysis)

Tiers	0.1 Decile	0.2 Decile	0.3 Decile	0.4 Decile	0.5 Decile	0.6 Decile	0.7 Decile	0.8 Decile	0.9 Decile
Tier 0	-22.27***	-9.743***	-3.340**	0.001	1.392**	4.175***	6.959***	13.08***	26.44***
	(3.844)	(1.300)	(1.650)	(0.308)	(0.579)	(1.000)	(1.224)	(0.407)	(1.975)
Tier 1	-41.75	-13.92*	-1.392	-1.392	0.001	0.001	1.670	4.175	13.92
	(42.59)	(8.312)	(5.082)	(5.018)	(3.295)	(4.038)	(6.819)	(27.70)	(33.04)
Tier 2	-5.567	-2.784	0.001	2.032	2.784	2.784	5.567	12.53	40.36***
	(25.71)	(2.357)	(2.041)	(1.420)	(4.384)	(9.121)	(8.745)	(11.73)	(10.64)
Tier 3	-5.567**	-4.175	0.001	1.392	11.13	13.92	27.84	41.75*	69.59***
	(2.701)	(2.595)	(2.391)	(3.404)	(7.919)	(10.01)	(17.47)	(22.20)	(23.71)

Standard errors in parentheses are bootstrapped. *** p<0.01, ** p<0.05, * p<0.1.

2.5 Conclusions

Electricity remains an important infrastructure in the activities of the modern economy. The United Nations in 2015 established access to affordable, reliable and sustainable modern energy for all by 2030 as SDG 7. This is partly in recognition of the indispensable role of electricity to enterprise creation, employment, poverty reduction, economic growth, socio-economic development among others. Electrification interventions with the objective of increasing the number of communities, firms or households with access to electricity is at the centre of development agenda in several developing countries where access to electricity is still considerably low. The focus and hence impact of these interventions is mostly on a nominal count of the proportion of households, firms or communities with access to electricity. This approach of measuring access to electricity fails to account for the non-negligible differences in available hours (day and night), duration and frequency of outages, voltage fluctuation and affordability of electricity services. Sometimes, there are even enterprises that are connected to the grid but are not in usage of electricity and yet are still counted among those with access to electricity when evaluating the impact of electrification interventions. These enterprises may have only previously used electricity but are no longer using it possibly because of issue regarding affordability, reliability or quality of grid electricity. The study contributes to literature and policy firstly by focusing on profits as a potential poverty reduction pathway as opposed to other firm’s outcomes such as productivity, operating hours or revenue which do not contribute directly to household’s income and hence poverty reduction. Secondly and most importantly, the study focuses on actual electricity usage as well as attributes of electrification rather than the electrification itself or mere connection to the electricity grid. This latter contribution is regarded as a major novelty of the study.

Utilizing the GPS and IPTW methods of matching and estimation, the study examines the causal impact of access to electricity on the profit of household’s non-farm enterprises beyond connections. The ATE results demonstrated, in scenarios where the emphasis of electrification is on connection, that access to electricity has limited causal effect on profitability of non-farm enterprises of households that are in current usage of electricity. However, if the emphasis of electrification is shifted away from connection only to the attributes of access to electricity/usage, the estimated ATE revealed that access to electricity has a more accentuated positive causal impact on the profits[22]. It must be admitted however that this accentuated effect is only witnessed by household's non-farm enterprises located in Tier 2 and Tier 3 of overall access to electricity. Also, at the level where electrification policy focuses on connection to the grid the QTE estimates show that, for enterprises in the lower quantile of the profit distribution, access to electricity generally tends to cause a decline in the mean profit. However, median and upper quantile electricity-using enterprises witness a causal rise in their profit levels as a result of access to electricity. On the other hand, where the focus of electrification policy is about the attributes of electricity services the QTE estimate show that, for Tier 0 and even Tier 1 enterprises in the lower-end of the profit distribution, access to electricity has an adverse causal impact on their profit while at the median and upper-end of the profit distribution, Tier 2 and Tier 3 enterprises respectively benefit from access to electricity with the latter recoding the highest gains in profit.

Overall, access to electricity appears, on average, to have positive causal effect on the profits of household's non-farm enterprises as long as it is put into productive use except in a few cases. Specifically, those in Tier 2 and 3 enterprises tend to witness positive causal effect of access to electricity on profit when they are, at least, at the median of the profit distribution. Thus, only moderately and highly profitable Tiers 2 and 3 enterprises tend to witness a positive causal effect of access to electricity on profitability while less profitable Tiers 2 and 3 enterprises are neutrally affected. It must be also noted that Tier 0 and Tier 1 firms in the lower quantile explicitly record adverse causal effect from access to electricity. It is therefore reasonable to conclude that the causal impact of access to electricity on profits of household's non-farm enterprises is further dependent, principally, on where an enterprise lies along the profit distribution. Consequently, access to electricity is not entirely favourable to the vulnerable enterprises (i.e., less profitable enterprises) particularly those in Tier 1.

Clearly, electrification policies, in addition to extending grid lines ought to put more emphasis on improving the underlying attributes if its benefits are to be maximized. This is because, as it has

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[22] This conclusion does not attempt to ignore the fact that electricity may provide some benefits that are not captured directly in profits, for example, supporting the well-being of employees or community members. Thus, even in instances where electricity does not cause profit to increase, it may still be beneficial to the enterprises in ways that enhance productivity.

become palpable, electrification could be deployed as a livelihood empowerment and poverty reduction tool when channeled into productive use and provided at appreciable standard. Achieving this necessarily requires sufficient improvement in intensive electrification in areas of reliability and availability of access to electricity. At this stage, these implications for policy are only indicative of the substantive policy recommendations which are thoroughly discussed in chapter 5. It is also worth-mentioning that the study suffered some notable limitations. Prominent among them relates to the lack of data on key variables such as input and output prices as well as other important control covariates. Consequently, our results must be interpreted within this context of missing key variables that make up an optimal profit function as well as other important control covariates. Similarly, there was limited amount of data on the use of electricity provided by the various technologies such generator sets, solar home systems etc. Another major limitation relates to paucity of information about enterprise’s behaviour regarding the use of electricity and the extent to which electricity-using enterprises channel electricity into core businesses or production activities. There are also potential endogeneity issues from possible reverse causality between profitability and electricity access. While these limitations are discussed in detail in the chapter 5 of the thesis with suggestions for future studies, they are highlighted here so that the findings/conclusions of this chapter are properly contextualized.

CHAPTER THREE

The nexus between cooking solution and household health: Insights from the attributes of modern cooking solution and gender perspectives

Abstract

The widespread cooking practice of burning biomass in traditional cookstove has been linked with various health complications. Despite the growing body of evidence, the dimension relating to the isolated effects of the individual attributes of cooking solution still remains largely unexploited in the ongoing discourse. This study, which embraces aspects of SGDs 3 and 7, therefore conducts a comprehensive analysis into the attributes of modern cooking solution with an overarching objective to examine how they, individually and/or jointly, affect respiratory health particularly cough and total health expenditure at the household level. Utilizing the probit and Heckman models respectively to the cough and expenditure specifications the study observed that when attributes such as exposure and safety of primary cookstove are improved, they tend to be important catalyst to reducing both cough incidence and total health expenditure (per capita) of the household. At the positive limits of fuel availability and affordability attributes households also experience declines in both cough incidence and total health expenditure (per capita). Similar qualitative findings are established for cooking convenience attribute. Nevertheless, lower levels of fuel availability and cooking efficiency attributes tend to worsen both health outcomes by increasing both cough incidence and total health expenditure (per capita) of the household. Ultimately, improving household's overall access to modern cooking solution is associated with reduction in both cough incidence and total health expenditure (per capita) especially for households. In the process, the study has revealed the attributes that could serve as critical catalyst in improving two major health outcomes which present vital lessons on policies intended to improve household's health outcomes resulting from cooking. This important evidence could not have been learnt if the attribute dimension of the debate had not been evaluated – this is considered as one of the novel contributions of the study.

3 Health-cooking solution nexuses

3.1 Introduction

3.1.1 Background

There is no doubt that the provision of affordable, reliable and sustainable energy services is pivotal to addressing many of today's global problems, including climate change, poverty, food security and human health, among others (World Bank 2019; Bazilian et al. 2012; United Nations, 2012; Aboagye, 2019). Many households in most developing countries however continue to witness various forms of energy deprivations. This invariably contributes to other forms of economic and health deprivations among households in developing countries. The UN's SDGs emphasize greatly not only on sustainable energy but also on good health and wellbeing (United Nations, 2015). In particular, the SDG 3 details out various targets to achieving good health and wellbeing at all levels, including illness and deaths related to pollution. The SDG 7 on the other hand is instructive on the need to ensure access to affordable, reliable and sustainable modern energy for all with a specific target (SDG 7.1) on ensuring universal access to affordable, reliable and modern energy services by 2030. This obviously includes modern cooking fuels and technologies. The attainment of SDG 7.1, therefore, has a direct implication for the realization of SDG 3 and there is no doubt that the household cooking sector is central in this regard.

Historically, cooking has been a very important basic household socio-cultural activity that ensures the physical and healthy survival of the human race by means of providing household members with healthy edible meals. Even though, many households in various parts of the globe resort to diverse energy sources to meet their cooking fuel needs, the major phenomenon observed all over the developing world is that, traditional biomass is the fuel predominantly used by households for cooking (IEA, 2016; Heltberg, 2004). A widespread practice of burning solid biomass over open fires, three-stone stoves and/or poorly designed traditional stoves during cooking has also been observed widely in most developing countries (IEA, 2016; Heltberg, 2004). For instance, out of the approximately 3 billion people that use biomass fuels such as wood, charcoal, crop residues or dung for cooking worldwide, about 2.4 billion are found in developing countries (IEA, 2016). In SSA in particular, the estimated number of people using solid biomass as the main cooking fuel was estimated at approximately 800 million over the same period (IEA, 2016). This implies that the developing world and the SSA region respectively accounts for almost 80% and 35% of the world’s population relying on solid biomass as primary cooking fuel. Incidentally, this represents only three percentage points decline since the start of the second millennium (IEA, 2017). The situation is even worse in rural communities in SSA where an overwhelming 90% of households rely on biomass as their primary energy source for cooking and heating with the aid of the traditional three-stone fires or highly inefficient stoves. This is because, relative to cleaner alternatives, solid biomass fuels are almost always available and at little or no cost to households in many rural communities. Indeed, firewood, agricultural residues, animal dung and other forms of biomass fuel were estimated to account for about 11% of total primary energy consumed globally (Johnson et al., 2017). Similarly, the use of biomass by households in developing countries alone accounted for almost 7% of world primary energy demand (IEA, 2016). Also, in developing countries 80% of total energy consumption is accounted for by the household sector with cooking energy representing about 90% of household’s total energy consumption (IEA, 2015).

In Nigeria, the household cooking sector is estimated to be the largest consumer of energy using around 80% of the country’s total energy (IEA, 2015). It is also reported that about 90% of all energy used by the household sector for cooking activities is derived from biomass, with fuelwood accounting for over 80% (IEA, 2015). The other sources of cooking energy in the country, such as liquefied petroleum gas (LPG), kerosene and electricity are considered very expensive by households and even more so when compared with biomass fuels which are seemingly free or come at little cost. Nigeria is known to be among the top countries with the largest number of people living in extreme poverty worldwide (Katayama and Wadhwa, 2019). This, obviously, makes biomass the preferred energy source for household cooking purposes in the country. The trend is further exacerbated by the evidence that the other cooking energy sources considered relatively expensive are also scarcely available in many parts of the country, particularly, in rural communities compared to biomass. For instance, even though Nigeria has a national electrification rate of nearly 54% (World Bank, 2019), there is still significant incidence of power interruptions – which could be as high as nearly 80 interruptions in a typical month (World Bank, 2019) – to the extent that many households rely on private power generators to meet their electricity needs. Using electricity as a source of cooking fuel is therefore practically and economically unfeasible. Although, with urban electrification rate of 84%, some urban dwellers tend to use modern energy such as electricity and LPG for cooking purposes, fuelwood still remains the greatest component of all energy sources utilized for cooking by households in Nigeria (IEA, 2015) mainly for the same reasons earlier espoused. Hence, even though the heavy reliance on solid biomass by households to meet cooking energy needs may be largely concentrated in rural areas, it is not unreasonable to argue that there is also considerable use of biomass among urban households. Indeed, there are less than 10% of the Nigeria's population with access to modern energy such as natural gas, LPG, electricity and liquid fuels (Gift and Olalekan, 2020). It is thus very obvious that the cooking energy crises experienced by Nigeria in the early 2000s as highlighted by Anozie et al. (2007) continue to persist even after almost two decades. This level of energy poverty is, undeniably, a major impediment to improving the living standards of the greater majority of the Nigerian population (World Bank, 2019; United Nations, 2012). A move towards clean cooking fuels is a major progress towards the realization of SDG 7.1 as well as some aspects of SDG 3.

The IEA (2017) has, however, observed that current efforts in the transition towards modern energy in many developing countries, particularly Nigeria, appear to have been overtaken by the scale in population growth. To halt and possibly reverse the ever-increasing dependence on biomass by the Nigerian household cooking sector and thereby ensuring the overall attainment of SDG 7.1 would require well-coordinated policy actions and considerable investments into modern and renewable energy. Fortunately, Nigeria is already heavily endowed with diverse energy sources which includes fossil fuels (oil, gas and coal), hydropower and other renewable energy sources such as solar, wind, and geothermal power (also see IEA, 2015). The country is also the sixth largest producer of crude oil in the world and has the second largest crude oil reserves in Africa. With an estimated liquid natural gas (LNG) of 187 trillion standard cubic meters, the country also has the largest natural gas reserves in Africa and ranked in the top ten worldwide (IEA, 2015). This provides enough leverage to ensure a pragmatic transition away from biomass to modern energy as primary cooking fuel in the country.

3.1.2 Problem Statement

One of the major concerns of the lack of access to modern cooking solutions relates to the growing evidence that the widespread cooking practice of burning solid fuels such as wood, charcoal, animal dung, coal and crop waste emit considerable indoor air pollutants (IAP) that are a chief threat to public health, *inter alia* (IEA, 2017; Ekouevi and Tuntivate, 2012; WHO, 2017). Explicitly, the WHO in 2017 ranked IAP from solid fuels as the world's eighth largest health risk, causing 2.7% of global losses of healthy lives. They further revealed that about 3% of the total global disease burden emanates from wood smoke, resulting in nearly 1.6 million premature deaths annually. IAP from burning of biomass in open fires and traditional stoves usually without chimneys is also considered a lead cause for respiratory diseases and premature deaths (Smith and Mehta, 2003). Furthermore, the IEA disclosed that nearly 600,000 premature deaths occurring in Africa is attributable to households' use of solid biomass energy (IEA, 2015).

There are additional millions of persons that, on daily basis, endure difficulty in breathing and chronic respiratory diseases as a result of IAP (WHO, 2017). In 2016 for instance, the International Centre for Energy, Environment and Development (ICEED) disclosed that open-fire cooking methods produce toxic particulates that contribute to around 4 million premature deaths per year, especially among women and children (also see Lim et al. 2013; Mohapatra and Simon, 2017; ICEED, 2019). In many cases, women and children are reportedly the main impact point of IAP. This is because they, especially women, by cultural and social orientations, are those often directly involved in cooking and thus spend several hours near cooking fires (Ifegbesan, Rampedi and Annegarn, 2016). Worldwide, there are approximately 4.3 million people who have died as a result of the illnesses attributed to IAP; these deaths also include 534,000 children under five years of age (WHO, 2012). It is also estimated that more than half of all under-five mortality is caused by ARI resulting from IAP emitted through the burning of solid fuels (WHO, 2012). Some other notable diseases frequently linked to the use of biomass for cooking include heart diseases, pneumonia, chronic respiratory diseases, cancers, burns and cataracts (IEA, 2018) as well as child pneumonia, COPD and lung cancer (WHO, 2012; Smith et al., 2012; Dherani et al., 2008).

In spite of this growing body of evidence, Pratiti et al. (2020) has recently revealed that an estimated 3.5 billion people worldwide are still exposed to cooking related IAP caused by solid fuel combustion. Again, this exposure is highest for the vulnerable population of women and children resulting in significant cumulative health effects (Pratiti et al., 2020). In Nigeria, deaths ranging from 79,000 to 95,000 are recorded annually from biomass-related IAP (ICEED, 2019;

WHO, 2017). It is further estimated by WHO (2017) that the country's under-five mortalities resulting from ARI constitutes nearly 90% of the total number of deaths from IAP, with the remainder 10% attributed to chronic obstructive pulmonary disease in adults. The ICEED (2019) further estimated that over 120 million Nigerians are vulnerable to illness from daily exposure to cooking smoke. Undoubtedly, the incomplete combustion of solid cooking fuels is detrimental to human health and further worsens global burden of disease particularly through the emission of substantial quantities of harmful air pollutants and contaminants such as carbon monoxide (CO), particulate matter ($PM_{2.5}$) polyaromatic hydrocarbons (PAHs), benzene and formaldehyde, ash, sulphur and mercury (Smith et al., 2012).

Obviously, proper understanding of the linkages between health and sustainable energy could offer great insights into how cooking contributes towards IAP-related diseases. This can inform policies aimed at improving the health-cooking energy nexus. To achieve this, the study argues that, then it is important to recognize that cooking is not only about the cooking fuel and/or even the cookstove but also about the specific attributes of the cookstove, fuel and the cooking activity itself. This is because the same cookstove may emit different levels of IAP depending on the type of solid fuels used, the nature, space and ventilation properties of the cooking area as well as the average cooking time, among others. Also, even if all households use traditional cookstoves, the emission levels could still be expected to differ significantly if their combustion efficiency of the are significantly different. Furthermore, different LPG or electric stoves could possess different levels of safety canons. Moreover, household's choice of a particular cookstove invariably depends on the availability and affordability of its complementary fuel. Thus, a tremendous availability and affordability of wood fuel is likely to result in heavy use of traditional cookstoves just as a tremendous availability and affordability of LPG is likely to result in heavy use of LPG cookstoves. This ultimately influences the amount of the resulting IAP. In this way, the effects of cooking on the health of households could be potentially driven by cooking attributes such as the efficiency of the cookstove, the level of exposure during cooking, the cooking convenience, safety of the cookstove, as well as the availability and affordability of the cookstove and/or fuel. This also implies that the various adverse health effects of the lack of clean cooking solutions could be mitigated or moderated by the extent to which these attributes of modern cooking solution work separately or jointly. Thus, even in the absence of modern cooking technology as primary cooking solution, the adverse health effects of the use of biomass fuel and poorly designed traditional stove could still be reduced by improving some aspects/attributes of cooking.

Consequently, given the overwhelming use of biomass for cooking in Nigeria, focusing on these attributes could be an extremely useful approach to addressing the specific aspects of the existing cooking solution that require immediate and urgent policy attention in the quest to reducing the immense adverse health effects of cooking-related IAP. Indeed, the World Bank has recently highlighted these attributes as the key components of any policy intended to improve upon access to modern cooking solutions (World Bank, 2019). It is against this backdrop that the study sets out to assess how the various attributes of access to modern cooking solution work, either individually or concurrently, to influence household's health outcomes as a way of contributing to the global bid to achieving the SDG 3 by 2030.

3.1.3 Research Questions

i. What are the health effects of the various attributes of access to modern cooking solutions?

ii. How does the degree of access to modern cooking solution affects household health outcomes?

3.1.4 Organization of the chapter

The chapter is organized into five broad sections. The first section of the chapter is the introduction which commences with general background information highlighting the various arguments, statistics, contexts and perspectives. The aim is to establish the salient problems motivating the study. This is followed by the second section which reviews the theoretical aspects of disease causation, demand for health, health outcomes. The section also reviews the empirical evidence on the health effects of cooking with special emphasis on respiratory health and total health expenditure, the two main outcome variables of the study. The product of the section is the statement of novel scientific contribution of the study. The third section discusses the strategies adopted to empirically model and estimate the various nexuses between health and cooking attributes. Section four presents and discusses the evidence obtained while section five concludes the study by highlighting the major implications of the study.

3.2 Literature Review

3.2.1 Theories of energy choice

The theoretical basis for examining the health effects of cooking solutions, and the attributes of modern cooking solution for that matter, could be effectively traced to the cooking energy choices of households. While there may be several theories or hypotheses on household energy choice, the energy ladder hypothesis and the fuel stalking hypothesis are dominant in the literature. In particular, the "*energy ladder"* hypothesis explains household cooking fuel choice and switching behaviour and further highlight factors that potentially underpin the behaviour. At the core, the energy ladder hypothesis posits that income is the topmost, if not the sole, determinant of household's energy choices particularly cooking energy choice. In its original formulation, the hypothesis describes a three-level fuel switching process in which the first level is marked by household's reliance entirely on only biomass such as animal dung, firewood, agricultural waste etc. The household then climbs up to the next level of the ladder which is characterized by a complete switch from the use of biomass to exclusive use of 'transitional' fuels such as kerosene, coal and charcoal in response mainly to higher incomes. The last level of the ladder is where households switch to cleaner cooking energy sources such as LPG, natural gas and electricity once their income is sufficiently adequate to afford the transition (Heltberg, 2004; Barnes et al., 2009). The hypothesis thus implies that a switch *up* to a new fuel is simultaneously a switch *away* from fuels previously used. Suppose the hypothesis holds, then the emergence and adoption of a new superior cook fuel will phase out traditional fuels.

However, there is enormous evidence showing that households often choose to maintain energy portfolio. For instance, Heltberg (2004), Masera, Saatkamp, and Kammen (2000) have shown that even at different levels of the energy ladder, households tend to consume from a collection of energy mix, a phenomenon described in the literature as *"fuel stacking"* (Masera et al., 2000). Also, suppose the fuel stacking phenomenon holds, then the promotion of clean fuels may not necessarily displace traditional fuels. This conclusion appears to be a true reflection of household energy choice in many developing countries particularly Nigeria where households use of traditional fuels persists even in the face of adopting modern cooking fuels. Consequently, there has been a growing consensus towards the notion of fuel stacking in the literature (Masera et al., 2000; Heltberg, 2004). Following both hypotheses, it is clear that even if biomass use cannot be phased out completely there is enough room for a transition towards modern cook fuels. Hence both hypotheses have direct implications for the amount of ambient IAP which directly influence various health outcomes including respiratory health such as cough, pneumonia, ARI, lung cancer as well as household's total healthcare expenditure.

3.2.2 Theories of disease causation and health

There are several theories that attempt to explain the sources of diseases, illnesses and health ranging from medical to non-medical (Kahissay et al., 2017; Hughes et al., 2011). These theories could be however classified broadly into four major categories which are based on genetics, nutrition, lifestyle and environment (see Kelly and Russo, 2018; Russo and Williamson, 2011; Wellay et al., 2018; Folland et al., 2013; Kahissay et al., 2017; Holman and Borgstrom, 2016; Hughes et al., 2011; Spoth et al., 2008; Boyd, 2000; Bishaw, 1990).

For instance, one of the medical theories of disease causation and health, the germ theory, asserts that diseases are caused by microorganisms (Kelly and Russo, 2018). Consequently, the theory prescribes that health improvement and disease control could be achieved through antibiotics and vaccines. However, the theory has been criticized on the grounds that the prevalence of almost all major infectious diseases begun to fall several decades prior to the advent and proliferation of antibiotics and vaccines (Russo and Williamson, 2011).

The lifestyle/behavioural theory, on the other hand, attributes the incidence of diseases and adverse health outcomes entirely to the unhealthy behavioural and lifestyle choices people make (Kelly and Barker, 2016; Spoth et al., 2008). The theory further holds that, to the extent that substantial resources allocated in many healthcare budgets, especially in rich countries and recently in some developing countries, are used for the treatment of lifestyle-related conditions demonstrates that heathy lifestyle modifications is the catalyst to ensure drastic decline in prevalence of diseases (Folland et al., 2013). Even though there is a growing consensus that lifestyle modifications should be the foundation of any healthcare system, it appears this requires overall social change which may be practically unattainable in its entirety (Holman and Borgstrom, 2016; Kelly and Doohan, 2012; Kelly et al., 2014). Besides, the incidence of a critical mass of chronic diseases and health complications, according to the environmental theory of disease causation, are as a result of toxins, pollutants and other contaminants in the environment (Hughes et al., 2011). Proponents of the theory further argue that industrial productions and household emissions are major sources of the toxins, pollutants and other contaminants in the environment (see for instance Hughes et al., 2011). The environmental theory is extended further to account for the health implications of occupational hazards and synthetic additives to organic foods (Hollands et al., 2013; Folland et al., 2013). The environmental theory therefore argues that diseases prevention, instead of requiring medical treatments or personal hygiene, demands change in the industrial and household production technologies and emission abatement investments and regulations among others (Hollands et al., 2013; Folland et al., 2013).

In economics particularly, the microeconomic human capital theory of demand for health developed by Grossman (1972) is often cited to understand the choices individuals and households make to influence their health outcomes. The theory adopts an intertemporal utility function in which the individual is assumed to derive utility from the stock of good health and other consumption goods. Folland et al. (2013) and Parker and Wong (1997), among others have shown that the demand for health (or healthcare utilization) is derived. Thus, it could be expressed through a simplified utility function that reflects the health stock of all members in the household. This is achievable on the assumption that households derive utility from overall consumption and health conditional on household composition (demographic factors) and constrained by its socio-economic characteristics. The theory further argues that, the stock of health, in addition to contributing to utility, is also capital (Grossman, 1972). Consequently, the acquisition of health stock requires that households produce it through the utilization of production inputs such as health care services and the time of household members subject to various market and resource constraints. Over time, the health stock may grow or remain constant (Folland et al. 2013) which could be explained from multiple outlooks such as through aging, health investment or from the perspectives of the various theories of disease causation and health as discussed earlier. As capital, the stock of health of household members may also depreciate over time either slowly through age or more quickly with illness or injury. Improvement in one's health is therefore partly the outcome of investment in health stock using health inputs such as medical care, exercises, diet and vaccination. Grossman (1972) also demonstrated that the stock of health, in addition to wealth, prices of health inputs and education, is influenced by genetic features, behaviour/lifestyle choices and the environment – factors highlighted by the theories of disease causation and health discussed in the preceding paragraph. Therefore, the microeconomic theory of health, in addition to developing the economic perspective of health, is also inextricably related to the other theories of disease causation and that makes it widely applicable.

Altogether, the incidence of adverse health outcomes or otherwise is thus the consequence of several factors including environmental emissions, toxics and pollutants, lifestyle and behavioural choices, genetics; all of which could be moderated or exacerbated by healthcare utilization decisions of the households as espoused by Grossman (1972), Folland et al. (2013). As we evaluate the health effects of the attributes of modern cooking solution in the chapter, the study theoretically draws considerable inspirations from the environmental and lifestyle/behavioural theories of disease causation as well as the human capital and healthcare utilization decisions of the household.

3.2.3 Empirical Literature review

The review of the empirical literature focuses on the health effects of various cooking solutions which include biomass-driven cooking solutions and improved cookstove (ICS)-driven cooking solution, the two dominant cooking solutions in developing countries. The review also touches, though briefly, on cooking solutions driven by LPG and electricity which are incidentally utilized by only a small proportion of households in most developing countries. The preceding sections, particularly sections 3.1.1 and 3.1.2, have however highlighted the health effects of biomass-driven solutions extensively. Thus, the review that follows is concentrated largely on the health effects of the other cooking solutions particularly ICS-driven solutions as well as solutions driven by LPG.

In developing countries in Asia, Chengappa et al. (2007) utilizing measured carbon monoxide (CO) and fine Particulate Matter ($PM_{2.5}$) concentrations as proxy for IAP, analyzed the impact of ICS on household health outcomes in Bundelkhand, India. The authors conducted 48-hour tests of indoor kitchens in a year-long before-and-after experiments with 60 randomly sampled households of varied family sizes. They found substantial and moderate declines in CO and $PM_{2.5}$ concentrations respectively in homes that regularly use ICS. Following a switch from traditional smoky cookstove to ICS, Hosgood et al. (2008) also estimated lung cancer mortality in China. The incidence among both men and women was observed to have significantly reduced among those who switched to ICS relative to those who remained traditional smoky cookstove users. Ludwinski et al. (2011) also reported over 48% and 63% reductions in respiratory symptoms respectively among mothers and children who reside in households that switched from traditional stove to ICS. These conclusions are later confirmed by Zaman et al. (2017) who conducted a quasi-experimental study that examined the impact of ICS on maternal health in rural Bangladesh. The authors focused on mothers having at least one child under the age of five years and no history of cigarette smoking and lung disease. They sampled 300 households evenly distributed across intervention group of ICS-users and control group consisting of users of poorly designed traditional cookstove. After the intervention period of six months, the measured mean concentrations of $PM_{2.5}$ for the intervention and control group respectively were 259 μg/m3 and 1,285 μg/m3. This outcome affirmed the efficacy of ICS to contributing appreciably to decline in IAP. Nevertheless, a formal lung function test did not show any systematic differences between the two groups.

Elsewhere in Central America, Latin America and the Caribbean, the findings are also striking. For instance, Romieu et al. (2009) interrogated the respiratory health impact of improved biomass stove intervention in rural Mexico using a randomized controlled trial approach. A sample of 552 women belonging to different households in six communities in central Mexico were randomized to receive the Patsari stove (i.e., a type of ICS) or keep their traditional open fire. The experiment comprised monthly follow-up visits over 10 months to evaluate stove use, respiratory and other symptoms and to obtain lung function measurements. Adjusting for plausible confounders, Romieu et al (2009) found that Patsari-using, compared with those using the open fire, mostly showed significantly lower risk of respiratory symptoms (cough and wheezing) as well as eye discomfort, headache and back pain. Similarly, Clark et al. (2009) quantitatively traced the effect of ICS on pulmonary functions and respiratory symptoms caused by CO and $PM_{2.5}$ among a cross section of 79 Honduran women who uses traditional or ICS for cooking. The authors reported that the use of ICS is accompanied by substantial declines in both air pollutants. At the individual level, the levels of $PM_{2.5}$ and CO concentrations were observed to have respectively reduced by 63% and 87% with the use of improved cookstove compared to traditional stoves. Likewise, indoor $PM_{2.5}$ and CO concentrations were 73% and 87% respectively lower for ICS compared to the poorly designed traditional stove. Clark et al. (2009) further noted frequent reported cases of pulmonary and respiratory symptoms such as cough, phlegm, wheeze and headache during cooking as well as shortness of breath among women using traditional stoves symptoms relative to those using improved stoves. In respect of children, Smith et al. (2012) randomized pregnant women and infants of 534 Guatemalan households to an ICS and traditional stove within the conventional Randomized Exposure Study of Pollution Indoors and Respiratory Effects (RESPIRE). Even though initial results showed a non-significant reduction in the incidence of physician-diagnosed pneumonia, inclusion of behavioural covariates in further analysis generated a statistically significant reduction in physician-diagnosed severe pneumonia as well as an additional 50% reduction in personal child exposure to CO. In the same country, Duflo et al. (2008) had previously examined the health effects of biomass cooking fuel. The authors however concentrated only on households burning solid fuels using open fires and found that almost 35% of adults and 50% of the children in the survey had experienced symptoms of respiratory illness in the past 30 days which could be attributable to the use of solid fuels for cooking. These conclusions generally corroborate an earlier study in the same country in which Albalak et al. (2001) also established significant reductions in several respiratory symptoms such as dry cough, chest tightness, difficulty breathing and runny nose among mothers and children in homes that used improved cookstoves compared to those that used traditional cookstoves. Later on, Faizan and Thakur (2019) utilized an individual-level data on 117,752 persons with various chronic diseases including respiratory complications. A logistic regression established about 17-60% higher incidence of asthma/chronic respiratory failure among individuals living in households where crop residue and coal/lignite are used as the primary cooking fuels relative to individuals living in households with no or little biomass cooking fuels. However, Beltramo and Levine (2013) earlier did not observe any evidence that the use of solar ovens reduced the incidence of cough and/or sore throat in a study that compared respiratory symptoms in 465 women who purchased solar ovens and 325 control women who stuck to firewood.

In Africa, Berkouwer and Dean (2022) examine, among other things, the effect of charcoal efficient cookstove adoption in a randomized experiment of 1,000 households in Nairobi, Kenya. The authors observe a self-reported 0.5 standard deviation improvement in health as well as an annual emissions reduction of 3.5 tons of CO2 equivalent (CO2*e*) per household, valued at US$147 when applying a social cost of carbon of US$42. These benefits were the outcome of an immediate and persistent 39% reduction in charcoal consumption. The reduction also yielded private financial fuel savings of US$237 over the two-year lifetime of the stove—about two months of income for the average respondent. In Nigeria specifically, Oluwole et al. (2013) also examined the extent of household air pollution from biomass fuels and the effectiveness of stove intervention to improve IAP as well as exposure-related health problems and lung function. The authors used data from 59 firewood-exclusive using households in three rural communities in southwest Nigeria. Utilizing CO, $PM_{2.5}$ and exposure-related health complaints as outcome variables, Oluwole et al. (2013) found noticeable reductions in the frequency of *ex post* respiratory symptoms (i.e., dry cough, chest tightness, difficult breathing and runny nose) in mothers and children. Prior to the intervention however, more than a quarter of the women and children had specifically experienced various lung health complications as a result of the prolonged exclusive use of firewood for cooking by the household. Thus, the introduction of low-emission stoves was effective at improving IAP and reducing exposure-related symptoms. Onyeneke et al. (2017) also analyzed the impact of an improved cookstove on several welfare and health indicators of 280 households in Kaduna State and found significant reductions in fuelwood consumption, fuelwood collection time, cooking time, CO exposure and incidence of sore eyes. Two years later, Onyeneke et al. (2019) randomly sampled 400 (i.e., 80 ICS users and 320 non-ICS users) married women. The women were surveyed from eight rural communities with the highest concentration of wood cookstove users in the country. Applying the inverse propensity score weighting (IPSW), Onyeneke et al. (2019) established significant fuel and time savings from the adoption of the ICS. However, after controlling for stove design and users' socio-economic characteristics the authors did not find any evidence in support of reductions in the incidence of self-reported ailments (i.e., cough and sore eyes) associated with indoor smoke exposure both in the entire population and the subpopulation of the treated. Olopade et al. (2017) compared the results of using bioethanol clean cookstoves among women during their first trimester of pregnancy with a similar set of women who continue to use firewood/kerosene powered cookstoves. The main outcome of interest was tumour necrosis factor alpha (TNF-α), an important inflammatory cytokine in the pathway leading to development of cardio vascular diseases (Jang et al., 2021). Even though Olopade et al. (2017) could not find a significant difference between pregnant women randomized to ethanol as against those randomized to firewood, it was still evident that households that used firewood prior to experiment had benefited from the switch to ethanol fuelled clean cookstove. Explicitly, the ex-post TNF-α observed was 68% higher in firewood-using control group relative to firewood-randomized intervention group. Ezeh et al. (2014) was particularly interested in determining whether children below five years of age residing in households using solid fuels were at higher risk of death. The authors therefore examined the extent to which the use of firewood as cooking energy affects the incidence of child mortality based on the 2013 Nigeria Demographic and Health Survey (DHS) data involving 38,522 households. In particular, the authors deployed the Cox regression analyses and established that the use of solid fuels for cooking at the households could explain approximately 0.8% of neonatal deaths, 42.9% of post-neonatal deaths and 36.3% of child deaths. In addition, living in the rural communities was found to strongly accentuate the risk of child mortality.

Empirically, various studies have also used household's data to examine the behaviour of healthcare expenditure – the other dependent variable utilized in this study. Many of these studies however sought to identify the drivers of household's spending on healthcare rather than the effects of cooking solutions on it. For instance, Molla et al. (2017) using the 2010 household income and expenditure survey of Bangladesh examined the determinants of healthcare expenditure of households. An Ordinary Least Squares (OLS) estimation revealed that household income, presence of ill-health, family size, among others were found to be factors inducing healthcare expenditure. In addition, households in urban areas were observed by Molla et al. (2017) to spend more on healthcare than rural dwellers. Similarly, Brinda et al. (2014) with exclusive focus on adults, examined the factors influencing the level of out-of-pocket health expenditure in Tanzania. Based on multiple generalized linear and logistic regression models the authors observed age, gender, obesity, functional disability, domestic gender violence, large household size and visits to traditional healers as key determinants. In a related study in China, You and Kobayashi (2011) utilized the 2004 China Health and Nutrition Survey (CHNS) data to evaluate the factors responsible for rising out-of-pocket health expenditure. On the assumption of potential expenditure selection bias the authors adopted the Heckman selection model. They found that people tend to spend more on healthcare as their age increases. Again, households residing in urban communities and those living with well-educated household heads and higher incomes, on average, spend more on healthcare. Also, Malik and Syed (2012) assessed healthcare expenditure in Pakistan with the view to identifying its underlying predictors. The authors applied the OLS estimator to the 2004/5 Pakistan Standard of Living Measurement (PSLMS) dataset. They observed non-food household expenditure and household characteristics as major predictors of household healthcare expenditure in the country. Azorliade (2019) is, perhaps, among the few studies to have explicitly characterized the effect of household's cooking energy choice on its healthcare expenditure. In particular, the author estimated a Tobit health expenditure model and utilized data from the sixth and seventh rounds of the Ghana Living Standards Survey (GLSS) conducted in 2012/13 and 2016/17 respectively. It was established in both periods of the survey that households using charcoal and gas are less likely to spend on healthcare services relative to their counterparts using wood as main cook fuel. Specifically, using charcoal and LPG for cooking reduces the probability of spending on healthcare by about are 54.40 percentage points and 115.90 percentage points respectively in the 2012/2013 survey while in the 2016/2017 the probability stood at 28.15 percentage points and 103.25 percentage points. Alongside, the age of household head, years of education, illness reporting, household size, income and region of residence were found as other significant factors explaining healthcare expenditures of the households in both surveys. Similarly, Badamassi et al. (2017) while using panel approach investigated the impact of residential combustion of fuels on health expenditures in 44 SSA countries from 1995-2010. Utilizing the General Method of Moments (GMM) technique, they observed that residential sector combustion of fuel especially biomass fuel was significantly correlated with higher health expenditures. In Nigeria, Olasehinde and Olaniyan (2016) adopted Engel curve approach that was structured to take care of life-cycle implications to examine the drivers of household healthcare expenditure. They utilized data from the 2010 Harmonised Nigeria Living Standards Survey (HNLSS). Based on an OLS estimation, Olasehinde and Olanrewaju (2016) found that household income, size and other characteristics of the household head such as age, religion, education tend to significantly influence healthcare expenditure in Nigeria. The authors also observed intergenerational transfer of healthcare by the working population to the young and older generations. They further admitted that the household-level variables possess stronger significant effects among the rural households. Socio-economic factors such as marital status and employment also had differential location effects. In the South-south zone of the country, Oyinpreye (2014) utilized the same datasets in assessing the underpinning factors of whether a person who falls sick spends out-of-pocket for healthcare. Consequently, the authors employed the Heckman selection two-step model and observed state of residence, age of household head, family size, per capita consumption and adult equivalent weight as the most important predictors of the probability that a sick person incurs healthcare expenses as well as how much is spent.

Overall, the review of extant literature shows that there is a growing body of evidence on the adverse health effects of biomass and a parallel favourable health effects of modern cooking solution. However, empirical analysis on the effects of the various *attributes* of modern cooking solutions on household health remains either sparse or almost completely unexamined. Modern cooking solutions have various attributes (World Bank, 2019) including but not limited to exposure, efficiency and safety of cook stove. The effects of these attributes are not uniquely isolated in any rigorous quantitative studies analysing the effect of cook fuel or stove on household's health outcomes. As a result, it is unclear which aspects of the solutions to modern cooking need urgent policy attention especially if the desire is to improve household's health outcomes through the enhancement of household's cooking energy deprivations.

3.2.4 Statement of Contribution

First, the study progresses from previous studies by analysing several attributes of access to modern cooking solutions. These attributes are cooking exposure, safety of primary cookstove, cooking convenience, stove efficiency, fuel availability and fuel affordability. This approach is expected to provide broader and comprehensive evidence relative to previous studies on the cook fuel which focus mainly on whether the underlying cooking solution is clean or otherwise. Second, the study extends the assessment of access to modern cooking solution beyond the traditional binary (two-tier) measure to an innovative multi-tier (six-tier) measure. The novelty of the approach is that it takes into account information from the several attributes of access to modern cooking solutions. Along this line of contribution, the study therefore treats access to modern cooking solution as a package that comprise attributes of both the fuel and the cookstove as well as the cooking activity itself. From a policy perspective this study further provides evidence on the specific attributes that require the greatest and urgent policy attention in the quest to moderate the adverse health effects of cooking in low-income countries which are predominated with biomass-driven cooking solutions.

3.3. Methodology

3.3.1 Theoretical framework

As seen from the theoretical literature review, there are several theories that have shaped the understanding of disease causation and health. In the study, two major theoretical dimensions of health are deployed to conceptualize the health-cooking solution nexus. One of them could be based on the non-economic determinants of disease causation and health outcomes earlier discussed (see Kelly and Russo, 2018; Russo and Williamson, 2011; Wellay et al., 2018; Folland et al., 2013; Holman and Borgstrom, 2016; Kahissay et al., 2017; Hughes et al., 2011; Spoth et al., 2008; Boyd, 2000; Bishaw, 1990). In general, these theories emphasize the role of behavioural/lifestyle choices that are often in the hands and under the control of the individual. They also highlight the environmental conditions of residence and dwelling characteristics in the form of hygiene, sanitation and pollution as major source of health. In understanding health outcomes, therefore, these theories obviously also account for the role of socio-economic characteristics of individuals and/or households (Wellay et al., 2018; Folland et al., 2013). This includes, though not necessarily limited to income, household size, sources of drinking water, toilet facilities (Molla et al. 2017; Onyeneke et al., 2017; Faizan and Thakur, 2019; Heltberg, 2004; Brinda, et al, 2014) and other environmental characteristics of household’s residence such as type of cooking solution among others (Azorliade, 2019). Additional socio-economic characteristics could include the age, gender and level of education of members of the household, particularly the head (Faizan and Thakur, 2019; Folland et al., 2013; Grossman, 1972).

The other fundamental theoretical underpinning to our conceptual framework of household health is carefully derived from the demand for health theory originally developed by Grossman (1972). The theory is based on the microeconomic human capital theory and utility maximization. Among other assumptions, households are assumed to obtain utility from better health of its members. As a result, the stock of health capital enters household's utility function in ways similar to other consumption goods (Brunello et al, 2013). Household's utility function could therefore be represented simply as **U = f (H, C)** where H is the household's health and C captures all other consumption goods. In a constrained optimization setting, the optimal level of health demanded by the household could be ascertained with household's income and vector of prices as arguments. Altogether, the study synchronizes the economic theory of demand for health and non-economic theories of disease causation to draw its conceptual framework of household's health and health expenditure. The study consequently hypothesizes household's health outcomes as a function of the nature/attributes of its cooking solution and a range of conditions of living variables and other socio-economic characteristics. Thus, a basic structural model of health outcomes is of the form given by equation (3.1)

$$H = f(P, Y, W, Z) \text{ -------------------- } (3.1)$$

Where *P* and *Y* are the unit prices of healthcare and household's income which frequently feature as arguments in the constrained utility maximization while *W* captures the main covariates of the study, the attributes of cooking solution (both individual and overall) and *Z* is a catchall variable including household's characteristics, health status of the household members, health insurance etc. *H* is the health outcome variable.

3.3.2 Empirical Strategy

Following recent debates of World Bank (2019) in a collaborative MTF study with the ESMAP it is obvious that access to modern cooking *solutions* should not be restricted only to having access to modern cook *fuels* such as LPG, natural gas or electricity. In particular, World Bank (2019) argues that emphasis should also be given to the many attributes of cooking such as the safety and combustion efficiency of the cookstove, availability and affordability of the cook fuel and exposure levels among others. The argument is that these cooking attributes have unique direct implications on household's health outcomes that could differ significantly from the health effects of just the cookstove/fuel in itself. Specifically, access to modern cooking solutions is measured using six attributes including: cooking exposure, cookstove efficiency, cooking convenience, safety of primary cookstove, affordability of the cooking solution and fuel availability (World Bank, 2019).

The empirical strategy therefore adopted by the study in assessing the health effects of access to modern cooking solutions is to utilize the attribute information in two distinctive ways. In the first instance, the effect of each of the six attributes of access to modern cooking solutions on the various household's health indicators is examined. Following (3.1) and the empirical strategy and taking cognizant of the objective of the chapter, these estimations are guided by the following empirical estimatable reduced-form health outcome model given by equation (3.2)

$$H_i = \alpha + \beta_i Attribute_i + \delta_i X_i^{'} + \varepsilon_i \text{ ------------------- (3.2)}$$

Where *H* measures household's health outcomes in both the conceptual/structural health model in (3.1) and in the reduced-form health models in (3.2) and (3.3). Also, *X* in the reduced-form health models in (3.2) and (3.3) encompasses *P*, *Y* and *Z* contained in the conceptual/structural model (3.1). Similarly, *W* in the conceptual/structural model (3.1) is captured in the reduced-form health model (3.2) and (3.3) as *Attribute* and *HHAccess* respectively. Thus, there is no loss of generality between the conceptual/structural health model in (3.1) and the reduced-form health models in (3.2) and (3.3). Explicitly, in the study, *X* is a vector of the following household's characteristics – head's gender, age, marital status, primary occupation, primary occupation, cooking frequency, as well as household's income, drinking water source, toilet-in-dwelling, formal finance access, informal finance access, access to credit. Thus, it is evident that household's income and the catchall variable that are captured separately as *Y* and *Z* respectively in equation (3.1) are now part of the vector of covariates *X* in equations (3.2) and (3.3). Also, the vector of covariates *(X)* in both (3.2) and (3.3) must have included the cost of health services (to serve as proxy for health input prices, *P*) as prescribed by the conceptual/structural health model (3.1) while additional relevant catchall variables (*Z*) such as health status of the household members, health insurance etc should have been included in *X* as well. However, the World Bank MTF Global survey from which the study draws data does not have such health covariates. This is acknowledged as a limitation of the study and discussed in section 3.5 of this chapter as well as section 5.4 of chapter 5.

Attribute, captured in (3.1) as *W*, is the main right-hand-side variable of interest in (3.2). The variable *Attribute* captures each of the six attributes of access to modern cooking solutions. Thus, the approach is to estimate equation (3.2) in six different ways with each accounting for how each of the six attributes affects household's health outcomes. It is important to highlight that each attribute has five tiers (see the succeeding section for further details about each attribute).

Then in the second instance, rather than focusing on the attributes themselves the study uses the attributes information utilized in the first instance (i.e., equation 3.2) to generate another variable, *HHAccess*. The variable *HHAccess* denoted by *W* in (3.1) captures each household's overall level (or tier) of access to modern cooking solutions is the main right-hand-side variable of interest in (3.3). The World Bank MTF Global survey defines a household's overall level (or tier) of access to modern cooking solution as the lowest level (or tier) the household attains among the six attributes with tier 5 representing having full access to modern cooking solution and tier 1 reflecting having the least access to modern cooking solution (World Bank, 2019). Equation (3.3) is utilized to estimate the effect of household's overall access to modern cooking solution on the household's health outcomes.

$$H_i = \alpha + \beta_i HHAccess_i + \delta_i X_i^{'} + \varepsilon_i \text{ ------------------- } (3.3)$$

Where *H* and *X* have the same meaning as in model (3.2) and thus, the composition of *X* and the associated limitations highlighted under model (3.2) also apply to *X* in model (3.3). *HHAccess* is the main covariate which captures overall tier or level of access to modern cooking solutions attained by a household. In both equations (3.2) and (3.3), the behaviour of the error term is discussed in section 3.3.5.

The motivation for considering several attributes of modern cooking solution is that existing literature has focused mainly on either the cook fuel or cookstove in analyzing the effects of modern cooking solution on household health outcomes. Specifically, in respect of the cooking fuel, emphasis of the literature is mostly on whether it is clean or not (e.g., Zaman et al., 2017; Faizan and Thakur, 2019; Smith et al., 2012; Beltramo and Levine, 2013; Ludwinski et al., 2011) while studies on the health effect of the cookstove is often focused on its combustion and thermal efficiency (e.g., Berkouwer and Dean, 2022; Oluwole et al., 2013; Onyeneke et al., 2017; Onyeneke et al., 2019). While such studies provide some appreciable insights on the nexus, they ignore the specific attributes of the underlying fuel and/or stove. Focusing on the attribute is very important for policy consideration. This is because, for instance, a given clean fuel could be available/accessible or affordable to some households but unavailable/inaccessible or unaffordable to others. This implies that, even though these households use the same clean fuel, they are at different levels of these two attributes of clean fuel i.e., fuel accessibility and fuel affordability attributes. Similarly, two households may be using biomass for cooking but one may be cooking indoor while the other may be cooking outdoor. Here too, it could be deduced that even though both households are using biomass, they would be at different levels of exposure to the smoke being emitted. Again, the combustion efficiency of biomass stove could differ significantly across households depending on the manufacturing parameters of the stove. This would imply that, even though, both households may be using biomass stove, they would be at different levels of stove efficiency. In the same way, safety of stove differs even across the same type; for instance, different LPG stove could differ substantially in terms of their safety due to differences in manufacturers. Furthermore, two households using biomass may have different biomass collection time depending on location or distance to the fuel gathering site/place and this can result in different cooking convenience despite using the same type of fuel. Each of these attributes, thus, places households in different levels of access to modern cooking solution. Yet, the approach adopted by the literature places all those using the same type of fuel and/or stove at the same level of access to modern cooking solution.

The foregoing demonstrates that households ought to be accurately categorized to reflect these differences. Also, as the attributes (exposure, efficiency, safety etc.) can impose unique individual health effects, it is imperative to examine these differences as well. This is the principal motivation underlying the quest by this study to go beyond the cook fuel and/or stove and rather consider several attributes of modern cooking solution of existing cooking solution against the evidence of widespread use of biomass in Nigeria. This is considered novel relative to the extant literature. This is because, despite the plethora of evidence on the health effects of modern cooking solution, these aspects have not been evaluated explicitly by previous studies. As evident in the empirical literature review section (i.e., section 3.2.3), almost none of the empirical studies reviewed explicitly evaluate these attributes, either separately or jointly. At best, it could only be inferred that, by analyzing biomass stove as against LPG/electric stove, the health effects of some of the attributes are implied. However, they fail to empirically characterize the effects in ways that make it plausible to distinctively determine the effect of each attribute or the precise level of access to modern cooking solution enjoyed by households cooking with the same modern cooking solution or different cooking solutions. Thus, rather than seeing this approach adopted by the study as a disconnection from the empirical literature reviewed in this study in section 3.2.3, it is better to consider our approach as a point of departure from and an improvement to the literature.

3.3.3 Attributes of cooking solutions[23]

1. **Cooking Exposure**

This attribute assesses household members' exposure to pollutants from cooking activities. This often depends on stove emissions and ventilation parameters such cooking location and kitchen volume. In the study, cooking exposure is defined by the nature of cooking space, ventilation and proximity to sleeping area.

$$\textbf{Cooking Exposure} = \begin{cases} 1 \text{ if cooking is normally done in-dwelling in sleeping area} \\ 2 \text{ if cooking is normally done in-dwelling but not sleeping area} \\ 3 \text{ if cooking is normally done in a separate kitchen} \\ 4 \text{ if cooking is normally done in a veranda (roofed platform)} \\ 5 \text{ if cooking is normally done outdoors} \end{cases}$$

2. **Cooking Convenience**

Convenience is measured through the length of time household members spends collecting or purchasing cooking fuel and preparing the fuel for cooking (in minutes per week) plus the amount of time needed to prepare the cookstove for cooking (in minutes per meal). In the study, the attribute is defined as the amount of time household members spend preparing the cookstove and fuel for each meal on average, including setting up the fuel and turning on the stove but excluding cooking time. As a result of the range of numbers indicated by the respondents in respect of the time used for fuel gathering and stove preparation prior to cooking, we wanted to recode the variable into binary so that it is "Convenient" if time is less or equal to say 5 minutes, otherwise it is "Not Convenient". However, to ensure consistency and conformity with the approach adopted by the World Bank/ESMAP (the source of the data) and the general adaptation made by the study, it is kept categorical. This explains why the attribute has five categories despite the few minutes

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[23] The definitions of the attributes are adopted entirely from World Bank (2019) with slight adaptations to suit the purpose of the study.

which is perhaps inconsistent with the notion of time required for fuel gathering and stove preparation.

$$\textbf{Cooking convenience} = \begin{cases} 1 \text{ if fuel gathering and stove preparation takes more than 10 minutes} \\ 2 \text{ if fuel gathering and stove preparation takes between 7 and 10 minutes} \\ 3 \text{ if fuel gathering and stove preparation takes between 2 and 7 minutes} \\ 4 \text{ if fuel gathering and stove preparation takes 2 minutes} \\ 5 \text{ if fuel gathering and stove preparation takes 1 minute or less} \end{cases}$$

3. Safety of Primary Cookstove

The attribute refers to all health-related risk associated with the use of the stove for cooking. This includes exposure to hot surfaces, fire or potential for fuel splatter, occurrence of injury or fire. It is worth-noting that the degree of safety can vary substantially by the type of cookstove and fuel. Thus, in the study the safety of primary cookstove is defined in reference to the stove type and the incidence of death or permanent damage, burns/fire/poisoning, severe cough/respiratory problem, minor injury, fire with no injury, itchy/watery eyes, light cough, and any other major injury/harm/damage experienced by member(s) of household in the last 12 months from the use of primary cookstove.

$$\textbf{Cookstove Safety} = \begin{cases} 1 \text{ if household has suffered any health risk from cooking} \\ 2 \text{ if household uses biomass stove and has suffered any health risk from cooking} \\ 3 \text{ if household uses biomass stove but suffered no health risk from cooking} \\ 4 \text{ if household uses kerosene stove but suffered no health risk from cooking} \\ 5 \text{ if household uses LPG/Electric stove and suffered no health risk from cooking} \end{cases}$$

4. Fuel Availability

The attribute is fundamentally concerned with whether or not cook fuel is available when a person needs it for cooking. The importance of the attribute in respect of health outcome is that availability of a given fuel can affect the regularity of its use and shortages can force households to switch to inferior fuel types. In the data, the attribute is originally defined based on three dimensions of frequency of availability – always, mostly and sometimes but recast into five categories by the study taking cognizance of whether the fuel is modern or not.

$$\textbf{Fuel Availability} = \begin{cases} 1 \text{ if cookfuel is sometimes or mostly available} \\ 2 \text{ if cookfuel is biomass and always available} \\ 3 \text{ if cookfuel is transitional and always available} \\ 4 \text{ if cookfuel is modern but sometimes available} \\ 5 \text{ if cookfuel is modern and always available} \end{cases}$$

5. Cooking Efficiency

The attribute deals with the amount of fuel actually expended during cooking. It combines the combustion and heat transfer efficiency properties of the cookstove. Both heat and combusting features can easily be assessed and rated in laboratory testing. In the study, cooking efficiency is determined by taking into account cooking parameters such as cooking space, ventilation, stove type to reflect both combustion and heat transfer efficiencies.

$$\textbf{Cooking Efficiency} = \begin{cases} 1 \text{ if household cooks in-dwelling with 3-stone/open fire stove} \\ 2 \text{ if household cooks in separate kitchen or veranda with manufacturing stove} \\ 3 \text{ if household cooks outdoors with kerosene stove} \\ 4 \text{ if household cooks with LPG/Natural gas stove} \\ 5 \text{ if household cooks with Electric stove} \end{cases}$$

6. Affordability

The attribute examines household’s ability to pay for both the stove and the fuel. Affordability is measured using the levelized cost of the fuel. In the study, a cooking solution is considered affordable if a household spends less than 5% of the total household expenditures on its cooking fuel; otherwise, the cooking solution is not affordable. To ensure that higher premium is placed on affordability of modern fuels relative to traditional ones, the definition of the attribute further incorporates the fuel type.

$$\textbf{Affordability} = \begin{cases} 1 \text{ if expenditure on biomass fuels exceeds 5\% of total expenditure} \\ 2 \text{ if expenditure on transitional fuel exceeds 5\% of total expenditure} \\ 3 \text{ if expenditure on modern fuels exceeds 5\% of total expenditure} \\ 4 \text{ if expenditure on cook fuels is below 5\% of total expenditure} \\ 5 \text{ if expenditure on modern fuels is below 5\% of total expenditure} \end{cases}$$

3.3.4 Dependent variables

It must be emphasized from the very outset that there are hardly sufficient data on many of the health indicators in the World Bank's MTF Global Survey dataset. Consequently, the study was constrained in the choice of dependent variables. Notwithstanding, the study utilizes two household's health outcome variables – incidence of cough and total healthcare expenditure (per capita). Medically, cough is associated with the respiratory system with smoke and other forms of IAP being prominent among its causes (WHO, 2012). The incidence of cough essentially describes all forms of illnesses with cough and cough symptoms. This ranges from light to severe and also includes ARI. In the literature, cough as described here is a notable respiratory health complication associated with household indoor air pollution (WHO, 2012). In the literature cough is one of the important health outcomes utilized in assessing the health impact of IAP and it has been used in several related studies (Faizan and Thakur, 2019; Onyeneke et al., 2019; Oluwole et al., 2013; Beltramo and Levine, 2013). In the World Bank dataset, cough incidence is recorded when any member of a household reports/exhibits illness with cough/cough symptoms at any time in the last 14 days prior to the survey. This implies that the incidence of cough is self-reported and not medically tested and thus, the variable is subjected to subjectivity bias and this has implications for the validity of the responses – this is acknowledged as potential weakness and limitation of the study.

Total healthcare expenditure was defined in the World Bank dataset to comprise all expenses made by the household on hospital/doctor visits and diagnostic tests (e.g., consultations at private hospitals, public hospitals, traditional healers) as well as medical/pharmacy expenses (e.g., tablets/syrups, insecticide, pharmacy/chemist, traditional/herbal medicine). As health could be very wide-ranging, total healthcare expenditure (per capita) is used as a broader measure of the overall health level of a household since higher healthcare expenditure is arguably a reflection of poor health outcome. Similarly, household's health expenditure that was captured during the survey is simply self-declared and not guided by any concrete evidential records or supporting documents/receipts. Thus, like the incidence of cough, the healthcare expenditure variable is also subjected to subjectivity bias and this has implications for the validity of the responses – again, this is acknowledged as potential weakness and limitation of the study. In the World Bank dataset, while household's total health expenditure is a continuous variable the incidence of cough is discrete. Also, unlike the health expenditure which, in the dataset, has been already aggregated across members of the households regardless of gender and/or age and there is no means for any innovative disaggregation, the incidence of cough variable comes originally as a variable disaggregated into five major gender and age classification (i.e., females and males aged 15 years or older, females and males between 5 – 14 years and females and males below 5 years). Thus, for the case of cough incidence we utilize both its aggregated and disaggregated versions. This is advantageous as it allows for the evaluation of the potential heterogeneity in the effect of the cooking attributes across gender and age. For instance, it enables us to evaluate the assertion that women are the most vulnerable group to IAP since they are frequently responsible for cooking for the household. As a consequence, they spend several hours in the cooking area and thus are the immediate and principal impact point of any IAP effect (Stabridis and van Gameren, 2018; Chen and Modrek, 2018; IEA, 2016; Barnes et al., 2009). In other narratives, mothers (women) often either have to carry their babies or young children with them to almost everywhere they may be or the children themselves follow the mothers (or women) to almost everywhere including the cooking area (kitchen). Moreover, young children are particularly susceptible to diseases. Both pathways explain the predominance of children in the statistics for premature deaths due to the use of biomass for cooking (IEA, 2016). Therefore, children are expected to suffer similar effect as women or follow women closely in terms of impact (IEA, 2016 and Barnes et al., 2009). Older children (girls and boys) are sometimes required at the kitchen to render various kinds of support to women unlike men who spend virtually no or little times in the kitchen since they are culturally unexpected to do cooking even though some men may cook occasionally for themselves or the households or provide some basic support during cooking. Consequently, the health impact of cooking on girls, boys and especially men is likely to be much lower relative to women and children. This assertion is in line with Bielecki and Wingenbach (2014), for instance, who argued that as a result of social and cultural norms in certain countries women spend most of their time in the home with children making them more vulnerable than men to breathe in the unhealthy smoke from burning of biomass for cooking. Moreover, WHO (2012) estimates further underscore this assertion as ARI in children younger than five years accounted for about 90% of 79,000 deaths linked to IAP emitted during biomass burning. COPD in adults of 30 years or older accounting for the remainder.

3.3.5 Estimation of models

As previously highlighted in section 1.3.2 of chapter 1, the incidence of cough is discrete but have been productively transformed into binary taken cognizant of objective of the study. This transformation has been performed both for the aggregated and disaggregated versions of the variable. In the literature, probit/logit models have been used to estimate binary models. The choice between the probit and logit binary models depends entirely on the assumption made about the error term. Besides, since there hardly exists any major differences between the results of the logit and probit regressions in practice, the choice between them is sometimes by preference (Paap and Frances, 2000). Therefore, the study utilizes the probit model, on the assumption of normally distributed disturbance components, to investigate the effects of the attributes of access to modern cooking solutions on the probability of cough incidence among households. A more general formulation of the probability of the incidence of cough among members of a household is thus given by equation (3.4)

$$\Pr\,(\mathrm{y}_i = 1 | \mathrm{x}_i) = F(\mathrm{x}_i\beta) \text{ --------------------- (3.4)}$$

where *F* is some function that returns values in the [0, 1] interval.

Following a latent variable formulation, we conceptualize that underlying the observed discrete outcome *y* (i.e., incidence of cough) there is a continuous propensity *y** which changes a household's cough status from state of no incidence of cough to a state of some incidence of cough once a certain critical level of *y** has been reached. Specifically, this implies that

$$y_i^* = \mathrm{x}_i\beta + \varepsilon_i$$

$$y_i = 1(y_i^* > 0)$$

$$y_i = \begin{cases} 1 \; if \; y_i^* > 0 \\ 0 \; if \; y_i^* \leq 0 \end{cases}$$

Where households' incidence of cough, $y_i = 1$ if any member(s) of the household contract(s) cough and $y_i = 0$ otherwise. Note that in the above formulation, ***X*** comprises the attributes of modern cooking solution as well as a set of covariates capturing various household characteristics while β is a vector of parameters to be estimated. Thus, the empirical models in equation (3.2) and (3.3) in general could be expressed as: $y_i = X_i^{'}\beta + \varepsilon_i$. Where y_i denotes *H* in (3.2) and (3.3) while *X'* encompasses the variables *Attribute*, *HHAccess* as well as the *X* vector in (3.2) and (3.3). The Hosmer-Lemeshow test and McFadden's R^2 are conventionally applied to evaluate the goodness of fit of binary models.

Household's health expenditure (per capita), the second outcome variable requires different estimation strategy as it is continuous rather than discrete. Often the OLS is a preferred estimator for linear models with continuous dependent variable. However, household health expenditure has many zero values which could be genuine, particularly, when households do not make any monetary spending on health. To avoid sample selection bias, the standard practice is that these genuine zero health expenditure observations are not excluded from the analysis (Jelani and Tan, 2012) but modelled together with the positive health expenditure observations. In the literature, the Heckman model is one of the workhorse models for handling regressions in which positive continuous outcome variable possesses genuine zero observations and thus, there is potential for sample selection bias. The notion of the Heckman model is closely related to censoring regression which observes the covariates of the censored observations. The model is also particularly useful when the decision to spend on healthcare and the actual healthcare expenditure made are correlated. The Heckman model could have the following basic functional forms as given in (3.5) and (3.6) below.

$$y_{1i} = \mathrm{x}_i\beta + \varepsilon_{1i} \text{ ------------------------ } (3.5)$$

$$y_{2i} = \begin{cases} \mathrm{z}_i\gamma + \varepsilon_{2i} \\ 1(\mathrm{z}_i\gamma + \varepsilon_{2i} > 0) \end{cases} \text{ ----------------------- } (3.6)$$

Where y_{1i} $\left(y_0, \mathrm{x}\right)$ is observed if y_{2i} =1. Furthermore, $(\varepsilon_{1i},\ \varepsilon_{2i}) \sim N(0,\ 0,\ \sigma^2,\ 1,\ \rho)$. It is the correlation between ε_{1i} and ε_{2i} that generates the "sample selection bias". Given that ε_{1i} and ε_{2i} are bivariate normal, Heckman (1974) suggested that the $\boldsymbol{\beta}$ vector could be consistently estimated in a two-stage procedure. In the first stage the selection model given by equation (3.6) could be estimated consistently by a probit model. The estimated of γ could then be used to form the inverse Mills ratio ($\hat{\lambda}$) which could then be added to the regression model in (3.5) as given in equation (3.7).

$$y_i = \mathrm{x}_i\beta + \alpha\hat{\lambda} + \eta_i \text{ ----------------------- } (3.7)$$

Where the new error term η_i have mean zero. The statistical significance of $\hat{\lambda}$ is evidence of the presence of sample selection bias in the underlying data which then justifies the appropriateness of using the Heckman model to correct for the sample selection bias. Alternatively, equation (3.7) could also be estimated using Maximum Likelihood (ML). Theoretically the same covariates could be used in both the selection equation as in the main (health expenditure per capita) equation. However, for robustness, there must be at least one variable in the selection equation that is not in the health expenditure per capita equation. Also, the entire procedure hinges on the normality assumption and yet the ML approach does not deal with the fact that the model is not robust to departures from normality. These show that even though the Heckman model addresses the problem of sample selection bias, it suffers from other econometric flaws. Hence, results emanating from the Heckman should be embraced with some caution.

It is important to highlight that the empirical models of the study could suffer from potential endogeneity. The endogeneity could emanate from various sources including the potential differences among households across the various tiers of the attributes which are not properly accounted for, both at the individual attributes and overall levels (see last paragraph of section 3.4.2.1). While in the health expenditure model, the Heckman model is able to address endogeneity from sample selection bias, it does not correct entirely for other sources of potential endogeneity. Instrumentation is frequently recommended in the literature in dealing with endogenous covariates. However, the study could not find valid instruments in the World Bank dataset to control for such endogeneity issues. This is acknowledged as a limitation of the study and the results and the eventual conclusions must therefore be embraced within the context of potential endogeneity.

3.4 Results and Discussions

3.4.1 Descriptive Statistics

Outcome variables

Respiratory Health – incidence of cough

From Table 3.1 it is evident that the number and percentage of household members with cough is highest among women[24]. There are 2,498 households in which at least a woman with cough resides. This is followed by girls and children as there are 1,891 and 1,879 households in which at least a girl or child with cough is found. Boys are next in order and men are least affected with cough in the household. Overall, there are 2,799 households in which at least a member was reported to have had cough. The minimum and maximum the number of members with cough in a household, are reported respectively in the last two columns of Table 3.1. This shows that, originally, the cough variable is discrete. But since the study is only interested in the incidence of cough at the household rather than its intensity, the cough variable is productively transformed into binary. Hence, the incidence of cough equal one if any household member gets cough and zero otherwise.

Health expenditure – total healthcare expenditure per capita

There are two separate healthcare expenditure variables in the dataset that are summed up to obtain household's total health expenditure which is subsequently transformed into 'per capita terms' to control for household size and then utilized as the second outcome variable. One of the healthcare expenditure variables relates to medical/pharmacy expenses incurred by households on monthly basis – this is captured in Table 3.2 as 'Medical & Pharmacy Expenditure (US$)'. This includes expenditure on tablets/syrups and insecticides obtained from pharmacy/chemist as well as traditional/herbal medicine. The other healthcare expenditure variable is an annual expenditure variable and relates to expenses incurred on hospital/doctor visits and diagnostic tests (e.g., consultations at private hospital, public hospital, traditional healer) – this is captured in Table 3.2 as 'Hospital & Doctor Visits Expenditure (US$)'. To ensure that both healthcare expenditure

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[24] In the study, female and male household members aged 15 years or older are labelled as women and men respectively while their gender counterparts between 5 – 14 years are labelled as girls and boys. Household members below 5 years are regarded as children.

variables are additively conformable the ‘Medical & Pharmacy Expenditure (US$)’ which is in monthly form is annualized. The summation of these two separate health expenditure variables results in our ‘Total Health Expenditure (US$)’ variable which is subsequently divided by household size to ascertain ‘Total Health Expenditure Per capita (US$)’. For the purposes of the econometric analysis, ‘Total Health Expenditure Per capita (US$) is subsequently transformed to natural logs to bring all values to a common range and to reduce the power of outlier expenditures as well as minimizing the possibility of non-constant error variance. Thus, the second health outcome variable employed in the estimation by study is ‘Total Health Expenditure Per capita (logs)’. The foregoing is succinctly summarized in Table 3.2.

Table 3.1: Health Outcomes: Incidence & Count of Cough (Dependent variables)

Gender Category	Incidence	Freq.	Percent	Min	Max
	Yes	2,498	77.10	0	5
Women	No	742	22.90		
	Total	**3,240**	**100**		
	Yes	498	15.37	0	5
Men	No	2,742	84.63		
	Total	**3,240**	**100**		
	Yes	1,891	58.36	0	5
Girls	No	1,349	41.64		
	Total	**3,240**	**100**		
	Yes	1,462	54.88	0	3
Boys	No	1,778	45.12		
	Total	**3,240**	**100**		
	Yes	1,879	57.99		7
Children	No	1,361	42.01	0	
	Total	**3,240**	**100**		
Total Cough Incidence	Yes	2,799	**86.38**	0	13
	No	441	13.61		
	Total	**3,240**	**100**		

Table 3.2: Health expenditure variables

Health Expenditure Variables	Obs.	Mean	Std. Dev.	Min	Max
Medical & Pharmacy Expenditure (US$)	3,240	7.709	14.53	0	194.85
Hospital & Doctor Visits Expenditure (US$)	3,240	33.67	158.0	0	4,175.36
Total Health Expenditure (US$)	3,240	126.1	250.9	0	4,509.39
Total Health Expenditure Per capita (US$)	3,240	23.35	48.70	0	872.65
Total Health Expenditure Per capita (logs)	***3,240***	***2.045***	***1.577***	***0***	***6.772***

It is evident from Table 3.2 that the average total heath expenditure per capita, the health expenditure variable whose natural log version is selected as the second outcome variable, stood at approximately $23 and ranges between $0 – 873. A detailed inspection shows that 25% of the households did not spend on healthcare for the entire year while almost 50% of the households spent about $10 or less on healthcare over the same period (in per capita terms). There are about another 17% of households whose total health expenditure per capita ranges between $10-20. The percentages of households that spent (in per capita terms) between $21 – 30, $31– 40 and $41– 50 accounts respectively for only 10%, 6% and 5% of the sample. This shows that nearly 90% of households spent less than $50 on healthcare annually (in per capita terms). Actually, only about 5% of households incur annual healthcare expenditure per capita exceeding $100. Even though, it may seem that the greater majority of households spent relatively less on healthcare (in per capita terms), given the high levels of poverty in Nigeria in general and its Northwest zone in particular, these per capita expenditures are by no means negligible.

Main covariate: Attributes of access to modern cooking solution

In terms of the **cooking exposure** attribute, it is observed that nearly 21% of the households reach the highest attainable tier, Tier 5. Also, there are about 53% and 15% of households in Tiers 4 and 3 respectively while only a little over 10% are distributed between Tiers 1 and 2. This implies that the overwhelming majority of the households cook in either open areas or highly spacious well-ventilated kitchens. As exposure has a direct implication for IAP concentration, the observation suggests relatively lower concentration of IAP and consequently lower incidence of respiratory complications such as cough as well as lower total health expenditure (per capita). The **cooking**

efficiency attribute reveals that less than 4% of households are found in Tier 5 while about 48% and 36% are respectively located in Tier 4 and Tier 1. This implies that the greater majority are found in tiers 1 and 4. Thus, only a few of the households use cookstoves that have high combustion and heat transfer efficiency with the greater majority using cookstove with moderate to low combustion and heat transfer efficiency. This is consistent with the distribution of cookstoves reported in Table 3.5 below, where nearly 83% of households use three-stone/open stove which has poor combustion and heat transfer efficiency. Those ranked in Tier 4 are a group of households who, despite using 3-stove/open stove or traditionally-made stove, cook in well-ventilated space which improves the thermal efficiency component of the attribute. Poor combustion and heat transfer efficiency implies the use of more fuel and in the case of biomass fuel, this would further imply more IAP and eventually higher cough incidence and total health expenditure (per capita) especially if cooking exposure of these specific households is concurrently poor. The **cooking convenience** reveals that about 37% of households are found in Tier 3 which implies that it takes between 2 – 7 minutes for these households to gather and prepare the fuel and stove before actual cooking commences. There is also another 37% of households in Tiers 1 and 2 as they take at least 10 minutes to gather and prepare the fuel and stove before cooking; with some taking as many as more than 3 hours. It is not obvious that convenience is necessarily related to the incidence of respiratory health or total health expenditure (per capita) directly. However, greater convenience could invariably afford households the opportunity to invest the extra time in other activities including health-related activities such as health exercises, doctor visits, check-ups etc. It is also observed that more than 80% of the households have very **safe primary cookstove** attaining Tiers 4 and 5 of the safety attribute while the remainder 20% are distributed across the other tiers with Tier 1 accounting for the chunk of it. Moreover, cooking fuel is considered **available** to many households as more than 66% are found in Tiers 4 and 5 of the availability attribute. Since majority of households are using 3-stone/open fire stoves, this could also imply greater availability of biomass which could further imply greater IAP and thus higher incidence of respiratory health as well as higher health expenditure (per capita). In terms of **affordability** of cook fuel, 64% of households are found in Tiers 1 and 2 as they do not consider their cooking solution to be affordable. Since majority of households are using 3-stone/open fire stoves, it is not clear whether households actually pay for biomass. Nevertheless, one implication is that if cooking fuel becomes increasingly unaffordable, households are likely to switch to cheaper alternatives which invariably include worst forms of biomass which could have stern direct adverse respiratory and other health outcomes such as health expenditure (per capita). Finally, the **overall access** to modern cooking solution by households reveals that there are about 66% of households in Tier 1 of overall access. Tier 2 accounts for 22% while about only 6% and 4 % are ranked in Tiers 3 and 4 respectively. Clearly, no household reaches the highest attainable tier (i.e., Tier 5). Given that many households attained relatively lower tiers at the attribute level, the observation at the overall access dimension is not surprising.

Table 3.3: Distribution of households across attributes of access to modern cooking solutions (Main Regressors)

Tier Levels	Cooking Exposure	Cooking Efficiency	Convenience Attribute	Safety Attribute	Fuel Availability	Affordability Attribute	Overall Tier
Tier 1	286 (9.12)	1,104 (35.64)	281 (9.94)	372 (13.02)	641 (20.52)	420 (13.44)	2,144 (66.17)
Tier 2	57 (1.82)	265 (8.55)	767 (27.13)	36 (1.26)	283 (9.06)	1,590 (50.90)	724 (22.35)
Tier 3	475 (15.15)	129 (4.16)	1,034 (36.58)	123 (4.30)	109 (3.49)	96 (3.07)	218 (6.73)
Tier 4	1,669 (53.22)	1,491 (48.13)	598 (21.15)	2,223 (77.78)	1,991 (63.73)	1,005 (32.17)	154 (4.75)
Tier 5	649 (20.70)	109 (3.52)	147 (5.20)	104 (87.51)	100 (3.20)	13 (0.42)	
Total	**3,136 (100)**	**3,098 (100)**	**2,827 (100)**	**2,858 (100)**	**3,124 (100)**	**3,124 (100)**	**3,240 (100)**

Model variables

In addition to the main covariate (attributes of access to modern cooking solutions) a few other regressors were included in the models as control variables. These control variables are classified into characteristics of the household, its head, dwelling and finances. The major statistics of these control variables are summarized in Table 3.4 below. The percentage distribution of categorical variables such as marital status, cooking frequency, source of drinking water and primary occupation are also reported in Appendix G.

In respect of gender, it is observed that more than 90% of households are headed by males. This is consistent with the socio-cultural norm in many parts of the African continent where the greater majority of households are headed by males. It is important to acknowledge that male leadership at the household level is also observed elsewhere around the globe. The implication is that most decisions regarding the households are driven and dominated by the opinions of males including decisions regarding cooking, cooking solution choices and health. We also observe that the youngest and oldest household heads are aged 18 and 95 years respectively even though there is only one person each at of these minimum and maximum ages. A careful categorization of the age composition reveals that there are about 19% of household heads aged between 18 – 30 years while there are almost 30% and 25% household heads aged between 31– 40 years and 41 – 50 years respectively. Household heads aged between 51 – 60 years also account for about 15% of the sample with the remaining 15% also made up by heads older than 60 years. This shows that middle aged household heads represent more than two-thirds suggesting that majority of households are headed by youthful individuals within active working ages.

Also, there are more than 90% of household heads that are married with the remaining less than 9% distributed across widows, cohabitation, separation, divorced and singles (see Appendix G). Even though, cooking may be done regardless of one's marital status it could be regarded as more prevalent among households with married heads. As the sample is overwhelmingly dominated by married household heads, then it is not unreasonable to assume that cooking is a daily activity among the sampled households which makes the sample also appropriate for a study that investigates into the health effects of aspects of cooking solutions.

However, almost 90% of household heads have never cooked for the family while less than 6% cook only occasionally (see Appendix G). Cooking is culturally performed by women and since the sample is dominated by over 90% male-headed households, the frequency of cooking among household heads is not unexpected. The challenge that may result however is that the majority of cooks in the households are not the drivers of critical household's decisions which could have stern adverse implications for the choice of cooking solutions and the underlying ultimate health repercussions.

Table 3.4: Control covariates

Variable	Obs.	Mean	Std. Dev.	Min	Max
Characteristics of Household Head					
Gender	3,240	0.952	0.212	0	1
Age	3,226	44.5	13.6	18	95
Marital status	3,240	1.10	0.429	1	3
Primary occupation	3,240	1.83	0.486	1	3
Characteristics of Household					
Household size	3,240	6.28	3.984	1	42
Cooking frequency	3,240	2.85	0.465	1	3
Total HH expenditure per capita	3,240	159.27	493.58	0	8,651.36
Total HH expenditure per capita (log)	3,240	12.0	1.02	5.52	16.67
Drinking water source	3,237	2.03	0.849	1	4
Toilet-in-dwelling (1=Yes)	3,240	0.056	0.230	0	1
Financial Characteristics of Household					
Formal finance access (1=Yes)	3,240	0.274	0.446	0	1
Informal finance access (1=Yes)	3,240	0.154	0.361	0	1
Credit access (1=Yes)	3,240	0.232	0.422	0	1

*Expenditures are expressed in US$ (US$1 = N359.25) for period of data collection: September 2017– March 2018.

Moving away from characteristics of the head, the study included three features of the household in general. These are the total household expenditure (annual), source of drinking water and the availability of toilet-in-dwelling. These are expected to control for the wealth and sanitation statuses of households. On the average, total annual household expenditure (per capita), stood at approximately $160 and ranges between $0 – 8,651. A detailed inspection shows that 25% of the households spent about $50 or less (in per capita terms) within a year while nearly 30% spent between $51-100 (in per capita terms) over the same period. There are about another 25% of households whose total expenditure ranges between $101-200 (in per capita terms). The percentages of households that spent between $201 – 500 and $501– 1,000 accounts respectively for only 14% and 2% of the sample. This shows that nearly 96% of households spent less than

$1,000 annually (in per capita terms). Actually, only about 4% of households incur annual expenditure (in per capita terms) exceeding $1,000. The narrative surrounding expenditure levels (in per capita terms) is clearly consistent with the high poverty rates as well as the highly unequal income distribution in the country reported by NBS (2019a)”.

As a result of the high levels of poverty and inequality, it is not surprisingly that there are more than half of the households whose sources of drinking water are unprotected water (28.5%) and bole-hole water (37.2%). Nevertheless, about a third incidentally drink from protected and piped water (31.1%) and sachet and bottled water (3.2%). Moreover, there are only 6% of the households with in-dwelling toilet facility. These characteristics of households unambiguously and unanimously suggest rather low wealth levels and poor sanitations among households in the zone with only rare notable exceptions.

Analysis of household’s financial characteristics shows that almost 72% do not have any formal financial services such as a bank account in a formal financial institution. Similarly, there are about 85% of households that do not use any informal saving groups. In the same way there are more than 76% of households that have no access to any form of credit. This demonstrates that households, generally, are financially excluded and face potential credit constraints.

Prevalence of cooking solutions

In Table 3.5, it is observed that household cooking is dominated by the use of three-stone/open fire stoves. This evidence is consistent with the general observation in many developing regions of the world including SSA and particularly at the nationwide level of Nigeria. With a generally lower level of access to electricity, coupled with incredibly high unreliability of electricity supply, it is not surprising that less than 0.3% of households from the zone use electric stoves. Perhaps, due to relatively better availability of LPG and natural gas in Nigeria, it is quite astounding that less than 4% of households in the zone use LPG/natural gas cookstoves as primary cookstove.

Table 3.5: Prevalence of cooking solutions

Type of Cookstove	Frequency	Percent
3-Stone/Open Fire Stove	2,642	81.54
Manufactured Stove Traditional	312	9.62
LPG/Natural Gas Stove	111	3.42
Kerosene Stove	151	4.66
Electric Stove	8	0.26
Total	**3,240**	**100.00**

3.4.2 Major Findings

The section presents and discusses the major findings emanating from estimating the various models of health outcomes as a function principally of the attributes of modern cooking solution while controlling for key household features and personal characteristics of the head. Given that the cough models are estimated using the probit model, we include the Pseudo R^2 and Hosmer-Lemeshow (H-L) test statistics. It is observed that the H-L results in all specifications, particularly, validate the null hypothesis which is a confirmation that the underlying models are valid.The total health expenditure per capita model on the other hand follows the Heckman model and thus the salient statistics included are the Rho (ρ), Sigma (σ), Lambda (λ), log-likelihood, likelihood ratio (LR test) and the number of selected observations. Both ρ and λ are found to be statistically significant in all health spending per capita models, along with σ and the LR test. In particular, the statistical significance of ρ is evidence of the interdependence of the decision to spend on health and the amount actually spent while statistical significance of λ is evidence of the presence of selection bias in the original data. Altogether, these statistics justify the appropriateness of the Heckman model. The Wald test of joint significance of a model in explaining the outcomes are also statistically significant all models. Consequently, in what follows, we proceed with the discussion of the results of each attribute and ends with the discussion of overall access based on all attribute information. The full results which show the control covariates are reported in Appendix E1 – E8. The results of the selection model component of the Heckman model which was estimated with probit are reported in Appendix E9. It is worth-mentioning that in all probit specifications, we report only the heteroscedastic-corrected marginal effects in models in which heteroscedasticity was detected, otherwise the reported marginal effects are estimated by the standard probit.

3.4.2.1 The health effects of the attributes of modern cooking solutions

Cooking efficiency attribute

In Table 3.6, it is evident that the cooking efficiency attribute, at lower tiers, tends to the incidence of cough in all specifications. In particular, the probability of any household member getting cough increases on average by 0.093 and 0.088 percentage points respectively if the household is located in Tier 2 and Tier 3 relative to households that are in Tier 1 of the cooking efficiency attribute. Also, the probability of a woman (child) getting cough increases on average by 0.056 (0.070) and 0.047 (0.090) percentage points if they live in a household with Tiers 2 and 3 efficiency rating respectively compared to their counterparts in households with Tier 1. Men (boys) also show higher cough incidence of 0.058 (0.122) percentage if they are residing in households with Tier 2 (Tier 3) ratings. The attribute has no effect on the incidence of cough among girls. Similarly, higher tiers of the attribute tend to have no statistically significant effect on cough incidence. Thus, being in Tiers 4 and 5 neither increase nor decrease the probability of cough incidence at the household level. In terms of the effect of the attribute on household’s total healthcare expenditure (per capita), it is observed that the coefficients are not statistically significant. However, those in Tier 2 of the attribute tend to spend 0.282% higher on healthcare (per capita) compared to counterparts in Tier 1 while those in Tier 5 spend and 0.145% lower on healthcare (per capita) compared to counterparts in Tier 1. Thus, households in lowest tier of the attribute (i.e., Tier 2) are more likely to experience adverse health outcomes in the form of increased healthcare spending (per capita) while a reduction in healthcare expenditure (per capita) is observed among households in the highest tier (i.e., Tier 5). Thus, improving the fuel combustion efficiency generates some desirable health outcomes such as reduced healthcare expenditure particularly for households in Tier 5. Undoubtedly, households trapped in the lowest tier of the cooking efficiency attribute are those using 3-stone/open fires as primary cooking stove. This could partly account for the relatively higher probability of cough incidence and health expenditure at the lowest tier. This is because the use of fuelwood in inefficient ways contributes to more IAP leading to respiratory infections and diseases such as cough which could also increase the total healthcare expenditure (per capita) of the household.

Table 3.6: The effects of cooking efficiency on household's health outcomes

Cooking Efficiency Attribute	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Tier 2	0.0931**	0.0561*	0.0584**	0.0514	-0.00054	0.0702**	0.282***
	(0.0367)	(0.0319)	(0.0269)	(0.0342)	(0.0359)	(0.0348)	(0.092)
Tier 3	0.0879*	0.0473**	0.0609	-0.0393	0.122**	0.0904*	0.210
	(0.0534)	(0.0053)	(0.0385)	(0.0465)	(0.0520)	(0.0514)	(0.443)
Tier 4	0.0470	-0.00906	0.0162	-0.0275	0.0354	0.0454	0.122
	(0.211)	(0.0177)	(0.0146)	(0.0185)	(0.208)	(0.203)	(0.559)
Tier 5	0.0769	-0.0263	0.0374	-0.0862	0.160	0.0719	-0.145***
	(0.0582)	(0.0498)	(0.0408)	(0.490)	(0.536)	(0.0546)	(0.047)
Pseudo R^2	0.0295	0.0402	0.0825	0.1932	0.0605	0.0952	
H-L (Prob)	0.8493	0.2381	0.4405	0.2826	0.2311	0.7240	
Prob > $\chi 2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test ($\chi 2$)							49.45 (0.000)
Log Likelihood							-4368.63
Rho (ρ)							0.6147***
							(0.0481)
Sigma (σ)							0.1540***
							(0.0253)
Lambda (λ)							0.0946**
							(0.0675)
Selected N							2,074
N	2,693	2,693	2,693	2,693	2,693	2,693	2,693

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Fuel Affordability Attribute

The health effect of the fuel affordability attribute of the access to modern cooking solution is reported in Table 3.7. The estimates suggest that fuel affordability generally is not associated with the incidence of cough given that the marginal effects in most specifications are not statistically despite being negative. The only exception is observed for households in Tier 5 of the attribute for whom greater fuel affordability tends to drive down the incidence of cough particularly among women, children and girls. For instance, the probability of any household member getting cough is, on average, 0.949 percentage points lower if the household is located in Tier 5 relative to households that are in Tier 1. Also, the probability of cough incidence among women (children) reduces on average by 0.183 (0.138) percentage points while that among girls declines on average by 0.093 percentage points if they are residing in households in Tier 5 compared to their counterparts in households ranked in Tier 1 of the attribute. However, the probability of a man or boy getting cough if he lives in a household with the same fuel affordability rating is not statistically significant. That notwithstanding, the attribute reduces health expenditure across almost all tiers relative to Tier 1. Particularly, households in Tiers 2, 4 and 5 spend 25.8%, 28.5% and 33.9% less on healthcare (per capita) relative to counterparts in Tier 1. These findings show that for affordability of cook fuel to translate into favourable health outcomes such as improved respiratory health and reduced health expenditure (per capita), then households must not just be using gas, LPG or electricity as primary cooking fuel but the expenditure on these fuels should necessarily not exceed 5% of household’s total expenditure.

Table 3.7: The effects of fuel affordability on household’s health outcomes

Fuel Affordability Attribute	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Tier 2	-0.083	0.0422	-0.0257	-0.0277	-0.00710	-0.0461	-0.258***
	(0.306)	(0.254)	(0.0204)	(0.0287)	(0.0283)	(0.0294)	(0.0795)
Tier 3	-0.00374	0.0182	0.0145	-0.0843	0.0156	-0.0201	0.0853
	(0.0600)	(0.0496)	(0.0410)	(0.500)	(0.0492)	(0.0566)	(0.364)
Tier 4	0.0416	-0.00869	0.0160	0.0154	0.0437	-0.00807	-0.285***

	(0.0335)	(0.0284)	(0.0231)	(0.0305)	(0.0301)	(0.0317)	(0.0864)
Tier 5	-0.949***	-0.183*	-0.0855	-0.093***	-0.103	-0.138	-0.339**
	(0.142)	(0.108)	(0.0765)	(0.0107)	(0.109)	(0.127)	(0.153)
Pseudo R^2	0.0350	0.0447	0.0805	0.1996	0.2148	0.0949	
H-L (Prob)	0.4540	0.7196	0.4275	0.2827	0.3179	0.1810	
Prob > $\chi2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test ($\chi2$)							49.96 (0.000)
Log Likelihood							-4414.51
Rho (ρ)							0.6099 ***
							(0.0480)
Sigma (σ)							0.1562 ***
							(0.0253)
Lambda (λ)							0.0952***
							(0.0373)
Selected N							2,083
N	2,717	2,717	2,717	2,717	2,717	2,717	2,717

Notes: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Fuel Availability Attribute

In Table 3.8, it is established that the fuel availability attribute generally has ambiguous effect on the incidence of cough. This is because while households in Tiers 4 and 5 largely tend to witness reduced cough incidence, the attribute generates marginal effects that are either positive or not statistically significant for those in Tier 2 and 3. Specifically, relative to households in Tier 1, those in Tier 4 the probability of any household member getting cough is, on average, 0.045 percentage points lower while men show 0.033 percentage points lower probability of experiencing cough if they live in a tier 4 rated household of the attribute. The marginal effects for the other gender-age groups are not statistically significant. However, for those in Tier 5 compared to households in Tier 1, the probability of any household member getting cough is, on average, 0.113 percentage points lower while women and girls respectively exhibit 0.144 and 0.116 percentage points lower probability of experiencing cough.

Table 3.8: The effects of fuel availability on household's health outcomes

Fuel Availability Attribute	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Tier 2	0.0370	-0.0336	0.0223	0.0402	-0.00152	0.0421	0.113
	(0.0385)	(0.0336)	(0.0285)	(0.0353)	(0.0351)	(0.0367)	(0.0972)
Tier 3	0.0304	-0.0271	0.0363	-0.0359	-0.0262	0.0960*	0.220
	(0.0569)	(0.0491)	(0.0430)	(0.0503)	(0.0488)	(0.0536)	(0.152)
Tier 4	-0.0450*	0.0291	-0.0333*	-0.0273	0.000697	-0.00231	-0.143**
	(0.0242)	(0.0207)	(0.0176)	(0.0209)	(0.0210)	(0.0231)	(0.0624)
Tier 5	-0.113*	-0.144**	-0.00660	-0.116**	-0.0187	0.0323	-0.359**
	(0.0609)	(0.0533)	(0.0422)	(0.0500)	(0.0501)	(0.0569)	(0.155)
Pseudo R^2	0.0290	0.0417	0.0840	0.1936	0.2169	0.0934	
H-L (Prob)	0.9536	0.2986	0.9233	0.2755	0.3625	0.4530	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							49.96 (0.000)
Log Likelihood							-4408.67
Rho (ρ)							0.6099 ***
							(0.0480)
Sigma (σ)							0.1562 ***
							(0.0253)
Lambda (λ)							0.0952***
							(0.0373)
selected N							2,093
N	2,719	2,719	2,719	2,719	2,719	2,719	2,719

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

In contrast, children residing in Tier 3 households show 0.096 percentage points higher probability of experiencing cough. These findings show that greater availability of biomass (i.e., Tiers 2 and 3) could contribute to cough while greater availability of modern cook fuel, gas, LPG and electricity (i.e., Tiers 4 and 5) is invariably linked to decline in cough incidence. This is because most of the households in Tiers 2 and 3 heavily rely on traditional biomass stoves while LPG and electric stoves are the main cookstoves for households in Tiers 4 and 5. At the level of healthcare expenditure, the findings are qualitatively the same as households in Tiers 4 and 5 spend 14.3% and 35.9% lower healthcare (per capita) compared to those in Tier 1 but the coefficients estimated for those in Tier 2 and 3 are not statistically significant.

Safety of Primary Cookstove Attribute

The results of the effect of the safety attribute of the primary cookstove, as reported in Table 3.9, suggest that safe cookstove largely reduces the incidence of cough given that the marginal effects in most specifications are negative and statistically significant. For instance, relative to households that are in Tier 1 of the safety attribute, the probability of a household member getting cough is, on average, 0.121, 0.200 and 0.152 percentage points lower if the household respectively is located in Tier 3, 4 and 5. Similarly, the probability of a woman getting cough is 0.060, 0.113 and 0.167 percentage points lower if she lives in a household with the same safety rating. Among men the probability of cough incidence declines on average by 0.082 and 0.073 percentage points while the probability of a girl reduces on average by 0.053 and 0.112 percentage points if they reside in households with Tiers 4 and 5 safety ratings compared to their counterparts in Tier 1 rated households. The probability of a child getting cough is 0.069 and 0.141 percentage points lower if he or she lives in a household ranked in Tier 4 and 5 respectively. For boys the probability of cough incidence reduces as far from Tier 2 with 0.209 lower likelihood and 0.060 and 0.116 lower likelihoods if he lives in Tier 4 and 5 households.

Since the safety of cookstove comprise a host of risk including risk of respiratory health, it is not surprising that households in higher tiers of the attribute display lower incidence of cough relative to their counterparts in lower tiers. It is also not surprisingly that the decline in the cough count is stronger among women and children compared to other gender/age group especially men. In addition, relative to being in Tier 1, households in Tiers 2 and 3 as well as those in Tiers 4 and 5 spend nearly 24.8%, 30.7%, 40.1% and 44.7% less on healthcare (per capita) respectively. This is intuitively straightforward because by the definition and measurement of the attribute, greater safety implies least or no occurrence of death or permanent damage, burns/fire/poisoning, severe or light cough/respiratory problem, minor injury, fire, itchy/watery eyes, injury/harm/damage experienced by member(s) of household in the last 12 months from the use of primary cookstove.

Table 3.9: The effects of safety of cookstove on household's health outcomes

Safety of Cookstove Attribute	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Tier 2	-0.121	0.0669	-0.0452	-0.0685	-0.209**	0.0709	-0.248***
	(0.0899)	(0.0775)	(0.0646)	(0.0857)	(0.0850)	(0.0845)	(0.023)
Tier 3	-0.121**	-0.060***	-0.0335	-0.0760	0.0576	8.33e-05	-0.307*
	(0.0591)	(0.0051)	(0.0427)	(0.0510)	(0.0569)	(0.0565)	(0.159)
Tier 4	-0.200***	-0.113***	-0.082***	-0.053**	-0.0601**	-0.069**	-0.401***
	(0.0290)	(0.0272)	(0.0234)	(0.0253)	(0.0285)	(0.0277)	(0.0760)
Tier 5	-0.152**	-0.167***	-0.0733*	-0.112**	-0.116**	-0.1406***	-0.447***
	(0.0646)	(0.0570)	(0.0424)	(0.0542)	(0.0582)	(0.0613)	(0.165)
Pseudo R^2	0.0413	0.0450	0.0858	0.2108	0.0628	0.0951	
H-L (Prob)	0.5757	0.5966	0.8573	0.2780	0.4167	0.2608	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							46.32 (0.000)
Log Likelihood							-4007.46
Rho (ρ)							0.6347***
							(0.0491)
Sigma (σ)							0.1694***
							(0.0274)
Lambda (λ)							0.1075 *
							(0.0610)
Selected N							1,886
N	2,472	2,472	2,472	2,472	2,472	2,472	2,472

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Cooking Convenience Attribute

The effect of convenience on the incidence of cough and health expenditure is reported in Table 3.10. Broadly, the probability of cough prevalence is upwardly driven by the convenience of cooking in most specifications. Perhaps, the only notable exception is observed among women for whom the attribute reduces the incidence of cough. It is worth-noting however that the incidence of cough among girls and boys is unaffected by cooking convenience as the estimated marginal effects are not statistically different from zero. In particular, it is found that relative to households ranked as Tier 1, the probability of any household member getting cough is, on average, 0.085, 0.063 and 0.139 percentage points higher if the household is located in Tiers 2, 3 and 5 respectively. Similarly, for men, the probability of cough incidence increases on average by 0.049, 0.069 and 0.070 percentage points. In contrast, among women the estimates suggest that cough incidences are 0.077, 0.097 and 0.125 percentage points lower if they reside in the same household. At the level of healthcare expenditure, the findings suggest that households tend to spend 18.4% and 22.5% higher if ranked in Tiers 2 and 3 respectively compared to those in Tier 1. Evidently, the health effect of cooking convenience is not only counterintuitive but also generally ambiguous. Given that the attribute is likely to influence household's allocation of time towards various productive, socio-cultural and other activities including healthcare, it was expected to contribute to improvement in health outcomes, if any effect at all. Hence, the precise reasonings behind these findings are not exactly clear. We suspect that the issue of potential endogeneity which is discussed at the end of this section could possibly account for the lack of precise reasonings behind these findings.

Table 3.10: The effects of cooking convenience on household's health outcomes

Cooking Convenience Attribute	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Tier 2	0.0850**	-0.077***	0.0497**	0.0239	0.0119	0.130***	0.184***
	(0.0381)	(0.0296)	(0.0240)	(0.0341)	(0.0342)	(0.0363)	(0.016)
Tier 3	0.0626*	-0.097***	0.0690***	-0.00374	-0.0264	0.130***	0.225**
	(0.0370)	(0.0291)	(0.0235)	(0.0335)	(0.0337)	(0.0354)	(0.113)
Tier 4	-0.0125	-0.0304	0.00625	-0.0220	-0.0285	0.110***	-0.177

	(0.0393)	(0.0305)	(0.0239)	(0.0358)	(0.0361)	(0.0380)	(0.120)
Tier 5	0.139**	-0.125***	0.0702*	0.0433	0.0253	0.198***	0.105
	(0.0557)	(0.0484)	(0.0396)	(0.0503)	(0.0492)	(0.0532)	(0.167)
Pseudo R^2	0.0286	0.0446	0.0760	0.1899	0.2066	0.0968	
H-L (Prob)	0.9456	0.8579	0.4635	0.2786	0.3300	0.2018	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							93.14 (0.000)
Log Likelihood							-4010.29
Rho (ρ)							-0.9564***
							(0.0103)
Sigma (σ)							0.3578***
							(0.0280)
Lambda (λ)							-0.3422***
							(0.0368)
Uncensored N							1,916
N	2,479	2,479	2,479	2,479	2,479	2,479	2,479

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Cooking Exposure Attribute

Table 3.11 reports the effect of cooking exposure on the incidence of cough and healthcare expenditure (per capita). Expectedly, it is observed that improvement in cooking exposure is accompanied by a consistently lower incidence of cough and healthcare expenditure (per capita) in all specifications. Explicitly, it is found that relative to households ranked as Tier 1, the probability of any household member getting cough is, on average, 0.089, 0.103 and 0.103 percentage points lower if the household is located in Tiers 3, 4 and Tier 5 respectively. For women (children) specifically, the probability of cough incidence decreases respectively on average by about 0.051 (0.019), 0.071 (0.021) and 0.102 (0.045) percentage points. Among girls (boys), the estimates suggest that cough incidences are 0.056 (0.099), 0.029 (0.010) and 0.038 (0.021) percentage points lower if the house hold is located in Tiers 3, 4 and Tier 5 respectively.

Table 3.11: The effects of cooking exposure on household's health outcomes

Cooking Exposure Attribute	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Tier 2	0.0570	-0.0659	0.0581	0.0500	-0.0399	0.124	-0.162***
	(0.0786)	(0.0607)	(0.0409)	(0.155)	(0.0317)	(0.0816)	(0.020)
Tier 3	-0.089***	-0.051**	-0.0523**	0.0556*	-0.099**	0.019***	-0.177*
	(0.0149)	(0.0133)	(0.0237)	(0.0385)	(0.0387)	(0.0039)	(0.091)
Tier 4	-0.103***	-0.071***	-0.080***	-0.029***	-0.010**	-0.021***	-0.184*
	(0.0344)	(0.0268)	(0.0196)	(0.0032)	(0.0032)	(0.0033)	(0.094)
Tier 5	-0.103***	-0.102***	-0.094***	-0.038***	-0.021**	-0.0448**	-0.205*
	(0.0385)	(0.0306)	(0.0235)	(0.0035)	(0.0035)	(0.0174)	(0.105)
Pseudo R^2	0.0292	0.0444	0.0866	0.1916	0.2165	0.0942	
H-L (Prob)	0.8804	0.3722	0.2160	0.2989	0.3240	0.3370	
Prob > $\chi2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test ($\chi2$)							53.52 (0.000)
Log Likelihood							-4433.06
Rho (ρ)							0.6219***
							(0.0466)
Sigma (σ)							0.1576***
							(0.0251)
Lambda (λ)							0.0980*
							(0.0596)
selected N							2,106
N	2,730	2,730	2,730	2,730	2,730	2,730	2,730

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Men also show about 0.052, 0.080 and 0.094 percentage points lower of incidence of cough if they live in a household with the same exposure rating. Similarly, households in Tiers 2 and 3 spend 16.2% and 17.7% lower healthcare expenditure relative to counterparts in Tier 1 while those in Tiers 4 and 5 are also 18.4% and 20.5% less health expenditure. Broadly, the results demonstrate that enhancing the extent to which household members get exposed to IAP is an important catalyst necessary to reducing cooking-related cough cases as well as household's overall healthcare expenditure (per capita). Since cooking exposure attribute is defined on the basis of the nature of the cooking area/space and cookstove then having a spacious kitchen as well as a well-ventilated kitchen and cookstove are non-negotiable in the quest to improve health outcomes.

Household's Overall Access to Modern Cooking Solutions

The estimates, as presented in Table 3.12, demonstrate that improvement in household's overall access to modern cooking solution is largely associated with a decline in the probability of cough prevalence in all specifications. The only notable exception is observed among households in Tier 2 of overall access to modern cooking solution. In addition, it could be observed that successively higher tiers are associated with successively greater reductions in health expenditure (per capita). For instance, at the aggregated level, the probability of cough occurrence is, on average, 0.097 and 0.277 percentage points lower if the household is located in Tier 3 and Tier 4 respectively relative to households that are in Tier 1. Among women (children), the probability of cough incidence decreases on average by 0.223 (0.142) and 0.313 (0.242) percentage points while for girls (boys) the probability of cough incidence, on average, is 0.087 (0.063) and 0.115 (0.164) percentage points lesser if they are residing in households whose overall access is rated as Tiers 3 and 4 ratings respectively compared to their counterparts in households rated as Tier 1. Likewise, men exhibit lower cough incidence of 0.115 and 0.140 percentage points if they live in a household with the same ratings regarding overall access to modern cooking solution. The healthcare expenditure (per capita) model also reveals that spending on healthcare is estimated to be 13.6%, 14.6% and 21.7% lower for households in Tiers 2, 3 and 4 compared to those in Tier 1. Thus, improvement in access to modern cooking solution drives the prevalence of cough and healthcare expenditure (per capita) consistently down especially among those in Tiers 3 and 4. This implies that, in general, improvement in access to modern cooking solution has the potential to contribute to a fall in the occurrence of respiratory health such as cough as well as healthcare spending.

Without accounting for the attributes to evaluate the effects of modern cooking solution, we would have been trapped in the conventional binary dichotomy of access which does not reveal the attributes responsible for the trends in health outcomes. This is because the binary dichotomy categorizes households into only two groups in which one group uses modern/clean cooking solution and the other group uses unclean cooking solution with no recognition of efficiency and safety of the underlying stove, level of exposure during cooking, convenience of cooking as well as the availability and affordability of the fuel/stove.

Table 3.12: The effects of multiple access to modern cooking on health outcomes

Household's Overall Access (Multi-tier)	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Tier 2	0.00114	0.000225	0.0129	0.0398	-0.00594	0.0402	-0.136**
	(0.0227)	(0.0192)	(0.0162)	(0.0384)	(0.0194)	(0.0351)	(0.0607)
Tier 3	-0.097***	-0.223***	-0.115***	-0.087***	-0.063**	-0.142**	-0.146***
	(0.0372)	(0.0298)	(0.059)	(0.0321)	(0.0316)	(0.0213)	(0.0976)
Tier 4	-0.277***	-0.313***	-0.140***	-0.115***	-0.1643**	-0.242***	-0.217*
	(0.0443)	(0.0365)	(0.0276)	(0.0201)	(0.0465)	(0.0437)	(0.115)
Pseudo R^2	0.0257	0.0416	0.0825	0.1922	0.2150	0.0925	
H-L (Prob)	0.7824	0.3732	0.1271	0.2889	0.3609	0.1659	
Prob > $\chi2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test ($\chi2$)							57.56 (0.000)
Log Likelihood							-4598.17
Rho (ρ)							0.6329***
							(0.0449)
Sigma (σ)							0.1641***
							(0.0249)
Lambda (λ)							0.1039*
							(0.0614)
Selected N							2,180
N	2,828	2,828	2,828	2,828	2,828	2,828	2,828

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

To compare the outcomes of both procedures, only as a way of checking the robustness of our main findings, we present the results of the binary approach in Appendix E8. Consistent with extant literature, it is unambiguously established that clean cooking solution reduces both health outcomes in all specifications. Nevertheless, some striking differences are observed when critically compared with the multi-tier approach adopted by the study which recognizes the attributes in scoping access to modern cooking solution. Foremost, the approach adopted by the study reveals the stern heterogeneous impact at different levels of access to modern cooking solution unlike the binary approach which compute a single marginal effect/coefficient for all households using modern cooking solution. As observed from Table 3.12 below, in most cases households in higher tiers of access experience greater reduction in cough incidence and total health expenditure (per capita). This heterogeneity in impact is not revealed by the binary approach as all households using modern cook fuel are grouped together in the same category even though they are likely to differ significantly with regards to the attributes as argued earlier in section 3.1.2. Consequently, the approach adopted by the study demonstrates how improvements in the various attributes of access to modern cooking solution could enable households to reach higher tiers in terms of overall access, even including households using clean cooking solutions. Furthermore, the approach adopted by the study affords us a rare opportunity of observing which attributes of modern cooking solution could be targeted by policy to improve the health-cooking solution nexus. By this, the approach adopted by the study further validates our overarching argument that, as far as health outcomes are concerned, having access to modern cooking solution does not end with the use of clean cooking fuel or stove but also has important connections with key attributes such as safety of the cooking solution, its availability and affordability as well as the extent to which household members are exposed to any harmful pollutants during cooking.

3.4.2.2 Other Findings

The study included some characteristics of the household and its head as additional covariates. Even though these were included explicitly only as control covariates, some of them reveal many important findings worth-highlighting. For instance, in the efficiency model, living in a household with a male head, unmarried head, cooking less frequently as well as having access to credit tend to generally improve health outcomes in most scenarios. Incidentally, many of the remaining covariates in the efficiency model had either ambiguous or no effect at all. Similarly, in the affordability and exposure models, living in a household with a male head, unmarried head, cooking less frequently, larger household size as well as having access to credit enhance the probability of experiencing reduced cough prevalence and total health expenditure (per capita). However, having aged household head age and borehole as main source of drinking water increases both health outcomes in most specifications while the other covariates are largely not statistically different from zero. Almost the same qualitative results established for affordability are observed for fuel availability as cough incidence declines in the presence of male head, unmarried head, less cooking frequency, larger household size and access to credit while the converse is observed for aged head and having borehole as main source of drinking water. The findings with respect to convenience and safety attributes are broadly similar to those earlier highlighted with only slight differences – the effects of male and unmarried head are rather ambiguous in the case of convenience while in the case of safety the ambiguity is found in such covariates as head's age, borehole as main source of drinking water and household size. Qualitatively, the same observations are found in the overall access model as those established for efficiency. Based on the behaviour of the control covariates, it is not unreasonable to assert that improvement in the two health outcomes could be, to some extent, driven by male heads, access to credit and lower cooking frequency as these are the only covariates that tend to improve both health outcomes with enough consistency across several specifications.

Finally, we perform diagnostics to check the extent to which households in the higher tiers – both of individual attributes and overall – are comparable (or otherwise) to those in lower tiers, based on characteristics that are both observed and controlled for by study, and ones that are unobserved. This is particularly important because the former may lead to bias if there is poor overlap between these groups (Imbens, 2000; Feng et al., 2011; McCaffrey et al., 2013) and the latter may result in endogeneity bias especially when the unobserved factors are also correlated with the health outcomes. Following Busso et al., (2013), we have utilized overlap plots (Kernel densities) to illustrate areas of common support based on the predicted probabilities (see Appendix H). Generally, in the case of individual attribute, the Kernel densities demonstrated sufficient overlap across households in Tiers 3, 4, 5 but are poorly overlapped with those in Tiers 1 and 2. The evidence is broadly the same in the case of overall access as sufficient overlap was observed across households in Tiers 2, 3, 4 but households in Tier 1 are entirely out of the overlapping zone. This shows that households in the higher tiers – both of individual attributes and overall – are comparable to each other but not comparable to those in lower tiers on observable characteristics. Consequently, the estimated results above are likely to have been biased by such contaminations. This is acknowledged as a major weakness of the analysis and thus, the results must be understood within this context. Nevertheless, by focusing on the attribute information of modern cooking solution rather than the cooking solution itself, this study has provided some valuable insights into potential effects of these attributes. In the process, the study has also revealed the attributes that could serve as critical catalyst in improving two major health outcomes which presents vital lessons on policies intended to improve household's health outcomes resulting from cooking. Obviously, this important evidence could not have been learnt if the attribute dimension of the nexus had not been evaluated.

3.5 Conclusions

There are a considerable number of households in many developing countries that suffer various forms of energy deprivations; prominent is the lack of access to modern cooking energy. In SSA, more than 800 million people still rely on biomass to meet household energy needs mainly for cooking. The situation is remarkably dire in Nigeria, as the estimated population lacking access to clean cooking equipment stands at 94% with over 72% relying on firewood for cooking purposes. In addition to adverse environmental and climate change outcomes, there are enormous reports and studies that consistently link several illness, diseases and deaths to IAP emitted during the combustion of biomass for household cooking.

Yet, there is little or no evidence regarding the specific aspects of the cooking process to blame so that effective targeting could be expected to contribute to improvement in health outcomes. Moreover, the literature has not adequately examined how the various aspects/attributes of access to modern cooking separately or jointly act to improve various health outcomes especially illnesses that are medically linked to IAP such as respiratory health notably cough. This chapter, which embraces some components of the SDGs 3 and 7, therefore conducts a comprehensive analysis into the attributes of modern cooking solution with an overarching objective of examining how they, individually and/or jointly, affect respiratory health particularly cough and total health expenditure (per capita) at the household level.

To achieve this, the study draws data from the World Bank MTF Global survey conducted in 2018 on Nigeria which solicited information from 3,668 representative households in its Northwest geopolitical zone. Utilizing the probit and Heckman models respectively to the analysis of the incidence of cough and health expenditure (per capita) the study observed that when attributes such as exposure and safety of primary cookstove are improved, they tend to be important catalyst to reducing both cough incidence and total health expenditure (per capita) of the households. At the positive limits of fuel availability and affordability attributes households experience declines in both cough incidence and total health expenditure (per capita). Similar qualitative findings are established for cooking convenience. Nevertheless, lower levels of fuel availability and cooking efficiency tend to increase both health outcomes. It is important to highlight that these implications are only indicative of the substantive policy recommendations which are thoroughly discussed in synchrony with other policy recommendations of the thesis (see chapter 5).

The study was limited in a number of ways. Foremost, it is important to mention that households' healthcare expenditure (per capita) could as well be driven by several other factors such as health status of the household members, the cost of health services, health insurance, public health financing etc. However, the World Bank MTF Global survey from which the study draws data does not have such health covariates. While this is acknowledged as a limitation of the study, the variable still provided a broader coverage of the notion of total household healthcare spending. Hence, the results and the eventual conclusions are relevant and could inform policy appropriately. Likewise, cough could also emanate from other causes as it is common to have cough in situations where one is not even suffering from indoor air pollution. Furthermore, as highlighted earlier, the cough variable utilized was an outcome of self-reporting and not a result of any medical laboratory test. Similarly, the health expenditures were those declared by the households during the survey without no supporting documents/receipts. In this way, both health outcome variables suffer from the subjectivity biases of the respondents. Another key limitation is that the exposure variable does not capture how clean the fuel and combustion is, while fuel availability, on the other hand, misses the time costs associated with procuring the household fuel. These limitations, together with the potential endogeneity, are admitted as potential weaknesses of the study and thus, the findings must be embraced with the needed caution. In chapter 5, these limitations are discussed in detail and suggestions for further research are consequently provided.

CHAPTER FOUR

One-off subsidies, credit regimes and households' willingness to pay for improved cookstoves

Abstract

Despite the well-documented benefits of clean cook-stoves and fuels, there are still about 94% of the population lacking access to any clean cooking equipment in Nigeria. Yet, there are several improved cook stoves (ICS) and other innovative cookstoves around the globe that have significant fuel combustion, emissions and thermal efficiencies. Moreover, there are enormous global, national and local improved cookstove programmes and interventions intended to enhance household's access. However, a growing body of literature shows that pricing of technology-related commodities with desirable environmental properties above marginal cost may result in inefficiently low adoption. This is particularly true when economic agents are generally poor, habitually short on cash, face persistent credit rigidities and/or are suffering from varied forms of chronic livelihood deprivations. Thus, to achieve some form of socially efficient level of adoption of ICS, some combinations of subsidies and credit payment regimes may be necessary even if not sufficient.

To this end, the study relies on data gathered through a World Bank survey that targeted only households without ICS or any clean cooking technology and for whom biomass is the primary cook fuel. The survey utilized the contingent valuation data elicitation approach to collect hypothetical responses on household's WTP for ICS in randomized bidding process characterized by one-shot subsidy and credit facilities. Using a heteroscedastic-corrected probit models, the results show that allowing households to pay over time coupled with a one-off subsidy of no less than 34% significantly increases the mean WTP to the extent that households are willing to pay even more than the subsidized price. Given that the regime mean WTP values are higher than the effective price of subsidized ICS, both WTP incentives (i.e., subsidy and credit regimes) are not likely to damage future pricing when ICS are eventually circulated through pure market mechanism. Furthermore, a 12-month payment instalment appears to be the maximum effective credit duration. This is because the estimated mean WTP declines after the 12-month credit regime.

4 Subsidy, credit regimes and households' WTP for ICS

4.1 Introduction

4.1.1 Background to the Study

In many developing countries biomass fuels often offer the most affordable, reliable and easily accessible source to meeting bulk of household's energy needs, especially household's cooking energy needs (Jan et al., 2017). Yet, overwhelming evidence suggests that reliance on traditional energy sources particularly biomass for cooking is accompanied by harmful repercussions that far outweigh the perceived benefits. For instance, there are several studies that link the use of biomass fuel to substantial environmental degradation mainly through unsustainable wood fuel harvesting practices (Arnold et al., 2006; Cheng and Urpelainen, 2014). It is also regarded as a principal contributor to greenhouse gases which eventually lead to climate change (Aboagye et al. 2020; Ramanathan and Carmichael, 2008; Bailis et al., 2015; Bond et al., 2007) and further account for about 4 million deaths annually through IAP (Lim et al., 2012; WHO, 2012). Indeed, the harmful effects of biomass have remained a key global problem for decades to the extent that energy sustainability is becoming increasingly central to major global development policies including the SDGs of the United Nations.

Incidentally, the biomass problem is further worsened by the use of inefficient traditional cookstoves in many developing countries. The widespread practice is that traditional biomass fuels such as fuelwood, dung cakes, twigs and leaves, among others are fed into the inefficient traditional cookstoves which are known for their typically low thermal efficiency, high fuelwood consumption and excessive emission of smoke, carbon monoxide (CO), particulate matter (PM) and other hazardous pollutants. In instances where cooking is done in the same room used for sleeping or close to the sleeping room or in a less spacious, poorly ventilated kitchen, which is a fairly common practice in many developing countries, the effects of these harmful pollutants on human health could be even dire. There is no doubt that the high emissions and poor ventilation properties of traditional cookstoves as well as their underlying combustion and heat transfer inefficiencies pose significant threat to the environment, quality of life and human health. The IAP emitted during the combustion of biomass in open fires and other traditional cookstoves is, for instance, ranked among the four topmost risk factors for morbidities worldwide (WHO, 2012). That notwithstanding, IEA (2017) expects the reliance on traditional inefficient stove fuelled with biomass to remain fairly constant in many developing countries until 2030. Indeed, this could even be expected to rise to keep up with the pace of population growth if pragmatic solutions are not rolled out as a matter of urgency. In fact, recent global estimates by IEA (2018) suggest that nearly 2.2 billion people will still lack access to clean cooking technologies by 2030, the year by which the world expects universal access to clean fuels including clean cook fuels. These predictions are consistent with the World Bank which in 2011 projected the rate of biomass use to increase in the coming years (World Bank, 2011). Consequently, providing access to affordable and sustainable modern energy services in developing countries is crucial. The World Bank (2019), United Nations (2012) have given further credence to the debate. In particular, both unequivocally argued extensively that the pursuit of health improvement, environmental sustainability, poverty reduction, economic growth and many other development goals is almost impossible without access to affordable and sustainable modern energy.

Undoubtedly, switching from traditional cookstoves to cookstove technologies such as liquefied petroleum gas (LPG) stoves and electric stoves is the most preferred solution to confronting the health and environmental dangers associated with traditional cookstoves (Grieshop et al., 2011; Siddiqui et al., 2009). This is because LPG and electric stoves do not only promise higher fuel combustion efficiency but also produces the least indoor air pollution. However, in developing countries these cleaner cooking technology alternatives are relatively expensive and often lack the necessary supply mechanisms especially in rural areas which often host the substantial share of the population. This makes these alternatives less economically attractive in many developing countries.

Hence, one of the readily available solutions entails strategies to improve the combustion and heat transfer of existing biomass stoves (Mobarak et al., 2012; Hutton et al., 2007) notably through the use of improved cookstoves (ICS). These ICS are biomass-fed stoves but are designed strategically to ensure better fuel combustion, enhanced thermal efficiency, greater fuel savings and cooking convenience relative to traditional cookstoves (Gebreegziabher et al., 2018). Therefore, depending on quality and construction, ICS can contribute to considerable declines in household air pollution (Ezzati and Kammen 2020; Bruce et al. 2014; Smith 2017; Naeher et al. 2000; 2007). Even though traditional stoves with chimneys may possibly reduce the level of smoke and emissions emitted by biomass, without improved combustion efficiency, they may do little to reduce the incidence of adverse human health outcome, environmental degradation and climate change (Armendáriz-Arnez et al., 2008; 2010). Indeed, ICS have been found to have the potential to improve household's health such as respiratory health, eye discomfort, lung cancer, infant mortality, pneumonia etc (Ezzati and Kammen 2020; Baumgartner et al., 2011, 2014; Smith et al., 2011; Pine et al. 2011; Kurmi et al., 2010; Smith-Siverstsen et al., 2009; Dherani et al., 2008; Mehta and Shahpar, 2004; Ezzati and Kammen, 2002; Bruce et al., 2000). As fuel-efficient cookstove, ICS can also ensure significant decline in biomass consumption which can ultimately contribute to the reduction of deforestation, greenhouse gases, climate change and environmental degradation (Bensch and Peters, 2013).

In these ways, ICS plays a crucial role in the attainment of the SDGs on health as well as energy and environmental sustainability. It must be emphasized that, even much of the recent push for widespread promotion of ICS in developing countries stem from concerns over the adverse role played by traditional cooking solutions in global climate change (Jeuland et al. 2015). The fuel savings potential of ICS further implies that using ICS as primary cookstove can reduce household expenditure on fuel and/or reduce time spent on the collection and preparation of fuel for cooking which can be rechannelled into productive activities. Fortunately, even though most ICS are built with relatively simple technologies, they are also able to meet a wide-range of user needs which further guarantees cooking convenience and often require only minor changes in the original cooking habits (Jeuland and Pattanayak, 2012; Mobarak et al., 2012).

Globally, there are several ICS programmes running concurrently in several developing countries (Ruiz-Mercado, 2011; Gifford, 2010). In most cases, the overarching aim of these ICS programmes is to create awareness of the diverse benefits of ICS while improving its accessibility, adoption and usage as first choice cookstove especially in households that hitherto relied on traditional inefficient cookstoves. To achieve this, up to about $1 billion is spent on various ICS programmes annually (Mobarak et al., 2012). Also, there are several stakeholders including programme implementing agencies, non-profit organizations, donor agencies, science institutions, investors and governments coordinating and collaborating at local, national and global scales. The remarkable diversity in the structure of the clean cookstove sector in recent years at the global level clearly underscores the broad appeal of ICS as a critical technology capable of minimizing and possibly eradicating the harmful repercussions of household air pollution, improving environmental sustainability and climate change as well as meeting many other development goals (Simon et al., 2014).

In 2010, the United Nations Foundation established the Global Alliance for Clean Cookstoves (GACC)[25] in order to avert the problems associated with using biomass and traditional cookstove for household cooking. It is arguably the largest public-private partnership committed to the manufacturing and distribution of clean and efficient cookstoves in developing countries (GACC, 2017). Since its inception in 2010, GACC has set out to empower 100 million households to adopt clean and efficient cookstoves by 2020 (Zhang et al. 2017) and a potential universal adoption of ICS by 2030 (Simon et al. 2014) by enabling the formation of a booming global market for clean and efficient household cooking solutions (Simon et al. 2014). To ensure the attainment of this highly ambitious goal, GACC has been working together with over 1,600 partners with primary target in eight developing countries including Nigeria as priority intervention points. Between 2010 and 2015, GACC (2016) reveals that about 53 million ICS have been distributed in these eight targeted developing countries.

It must be highlighted that there are various collaborations at the country-level and with other non-profits organizations and community stakeholders by the Alliance to develop suitable action plans for effective largescale market uptake. In the sub-region of the continent for instance, the West African Clean Cooking Alliance is also poised to supply ICS to 80% of the population by 2030 (NACOP, 2016). In Nigeria specifically, the government has also been persistently committed to maximizing the benefits of clean cooking energy access for its people. For instance, the Nigeria Cookstove Program was established in 2014 to promote the use of clean cooking solutions among households through market-based approach (World Bank, 2019). Additionally, there are other ongoing promotions of wood-based ICS in the country (for example, Save80 and Envirofit). With these efforts underway, the natural question that arises relates to the ability of policy to induce the needed largescale uptake.

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[25] In October 2018, GACC changed its name to the Clean Cooking Alliance (CCA); acknowledging the importance of increasing access to ‘clean’ cooking systems (CCS), rather than just stoves.

4.1.2 Problem Statement

It is remarkably puzzling that despite the well-documented benefits of clean cookstoves and fuels (Beltramo et al. 2015; Levine et al. 2018; Bensch and Peters 2015; Bensch, Grimm, and Peters 2015) coupled with several global and local interventions to promote adoption, there is still about 94% of the population lacking access to clean cooking equipment in Nigeria (World Bank, 2019). This low adoption has been the subject of significant debate (World Bank 2020). In 2018, only 5% of the country's population had access to any form of clean cooking solutions (IEA et al. 2018). The situation is even worse in the Northwest zone of the country as less than 3% of households in the zone uses clean cooking fuels (NBS, 2019b; World Bank, 2019). Interestingly, the IEA (2015) reports that the household cooking sector of the country is the largest consumer of energy, accounting for about 80% of the country's total energy consumption. Incidentally, nearly 90% of all the energy used by the household sector for its cooking activities is derived from biomass, with fuelwood accounting for over 80% (IEA, 2015). The widespread practice is that the biomass fuels are burnt in traditionally-made cookstoves with poor combustion and heat transfer efficiencies. This, as earlier highlighted, poses enormous challenge to the fight against climate change, environmental sustainability, human disease burden, living standards and other development goals. In the era where climate change and global warming are increasingly gaining attention in development agenda, ICS provides a better partial mitigating mechanism. There is, therefore, urgent need for more pragmatic interventions to stimulate its large-scale uptake.

Given that there already exist several ICS supply mechanisms, upon demand these cookstove could be made commercially available through a market-based approach. However, the high percentage of the population still lacking access to clean cook solutions in the country raises various concerns including demand side constraints and issues of willingness to pay (WTP). There are several evidences that demonstrate that only a limited number of interventions targeted at wide disseminations of ICS have shown success, at scale, over the long term (Hanna, et al., 2012; Martin et al., 2013). Indeed, most developing countries including Nigeria have reported very low adoption rates despite numerous stove dissemination projects (Pattanayak, 2019; Jan et al., 2017; Karekezi et al., 2014; Legros et al., 2009). Hence, one of the initial actions to unravelling the paradoxically low rates of adoption and usage of ICS is to determine the underlying mean WTP and examine the factors affecting households' WTP. When properly conducted, such analyses could usefully inform policy on the design of mechanisms and targeting strategies to ensure the success of this critical development intervention.

One peculiar demand mechanism that has gained rekindled attention in many developing countries relates to the use of subsidies and credit payment facilities to stimulate development interventions (Barnes et al., 1994; 2012). This follows from a shift of emphasis away from aid-based distribution models to more market-oriented approaches by the international development community as a means to ensuring the sustainability of interventions (Barnes et al., 1994; 2012). The assertion against subsidies is that they may not always yield sustainability of an intervention as subsidized interventions typically fail to ensure program cost recovery (Bailis et al., 2015). Nonetheless, subsidies could enhance the adoption of ICS by reducing the price paid. This potential gain could be improved further if complemented with flexible payment regimes that reduce even further the amount to be paid at regular periodic intervals. This is consistent with the evidence that credit regimes shift cost/payment to the future as they typically disperse one large payment across many periods (Berkouwer and Dean, 2022; Dertwinkel-Kalt et al., 2021; Gabaix and Laibson, 2017). Relative to free distribution, subsidy (especially, one-off subsidy) and some credit regimes deployed as WTP incentives are not likely to damage future pricing when ICS are eventually circulated through pure market mechanism (Dupas, 2014; Bensch and Peters, 2017).

4.1.3 Research Objectives

Generally, the chapter seeks to examine pathways to stimulate mass uptake of ICS based on households' WTP and socio-economic heterogeneity. The specific objectives are

i. To estimate household's WTP for improved cookstoves conditional on the availability of subsidy and credit regimes
ii. To evaluate the key socio-economic elements that could be effectively targeted to ensure initial public large-scale uptake of ICS

4.1.4 Organization of the chapter

The chapter is organized into five sections. The first section gives general background information and states problems motivating the study as well as the specific objectives of concern. This is followed by the second section which reviews the theoretical aspects of households' adoption behaviours as well as the various empirical evidence on household's WTP with special emphasis on the response dynamics within the contexts of subsidy and credit facility, the two main WTP hypothetical conditions of the study. The outcome of the literature review is the statement of novel scientific contribution. The third section discusses the strategies adopted to empirically model WTP and to estimate the underlying expectations which is perhaps the most important policy estimand. Section four brings out the findings which are discussed in consonance with the overarching objectives of the study. Finally, section five concludes the chapter.

4.2 Literature Review

The review of related literature commences with an appraisal of some theories that explain consumer choice. This is then followed by a review of empirical evidence which touches on the contingent valuation model since it is the main methodological underpinning for the data elicitation. We also review the determinants of WTP particularly for ICS and the role played by subsidy and credit regimes. However, it is important to mention that empirical evidence on subsidy and credit regimes in the context of WTP towards ICS is rather scanty.

4.2.1 Theoretical review

4.2.1.1 Theory of consumer behaviour

The decisions made by economic agents regarding WTP for ICS is firmly grounded in the microeconomic theory of consumer behaviour. In the theory, the consumer is assumed to be a utility maximiser and willing to acquire a commodity if only it does not reduce the original level of welfare. The behaviour is however constrained by a number of factors; prominent among them are commodity prices and consumer's income. The quantity of a commodity to be effectively demanded by the consumer is thus a function of own price, cross prices, disposable income among others. Factors such as product features and consumer's own socio-economic characteristics are other notable determinants of the consumer's behaviour. In the context of households' WTP for cooking technology such as ICS, the demand (i.e., hypothetical bid/WTP) function could, therefore arguably, include the hypothetical prices (i.e., randomized bids) of the ICS, market prices of firewood which the main intrinsic complementary fuel and income as well as consumer's preferences, cultural and belief system, socio-economic statuses among others.

The theory leads to a number of conventional predictions about the consumer's behaviour (Jehle and Reny, 2011) both in real and hypothetical markets. One of such predictions related to WTP for ICS in the context of subsidy and credit systems is that the consumer does not suffer from money illusion. This is the result of the zero-degree homogeneity of the consumer's ordinary demand function in prices and income. The major implication is that an equi-proportionate change in prices and income leaves the consumer's utility unchanged. An introduction or addition of ICS to the consumer's consumption basket could be regarded as a signal of an increase in prices (monetary value) of the new consumption basket relative to the consumption basket prior to the introduction/addition. In the same way, providing subsidy following the introduction of the ICS could also signify a rise in income level. While price/bid change and subsidy may not necessarily be equal to result in the absence of money illusion it is an effective mechanism that could ensure its realization by the consumer. This in turn could potentially provide the necessary incentive towards WTP.

Another related prediction is that the consumer's demand displays substitution and income effects. This implies the flexibility of the consumer modifying demand (i.e., WTP) in response to changes in prices and income. Credit regimes/systems that allow periodic instalment payments for a commodity indirectly increases the attractiveness of the commodity by making it look relatively cheaper compared to an upfront payment system. Thus, credit regimes can also induce demand (i.e., WTP) among consumers who hitherto could not have afforded. In this way, the credit system acts in mechanisms similar to price reduction which by the rationality assumption translates into higher WTP inclinations. Similarly, subsidy could be viewed as a rise in disposable income as it is a form of transfer payment. Invariably, the consumer is expected to demonstrate greater WTP in the face of increased income via subsidy. Consequently, credit systems and subsidy in the analysis of WTP for ICS are comparable to the conventional substitution and income effects predictions of the standard theory consumer behaviour.

4.2.1.2 Theories of household cooking energy choice and technology adoption

The decision to adopt a certain cooking technology such as ICS is inextricably intertwined with cooking energy choice. This is because a stove choice is effectively a fuel choice as well. In this way, the two theories of household's cooking energy choice discussed in the preceding chapter[26] could be utilized productively to understand adoption of cookstove as well. The overarching implication of both energy choice hypotheses (i.e., energy ladder hypothesis and the fuel stacking hypothesis) in the context of WTP towards ICS is that even if biomass/biomass-fuelled stove cannot be phased out completely by modern fuels/stoves, there is enough room for a transition towards cooking technologies/cookstoves that burn biomass more efficiently such that fuel and time savings are maximized while combustion and thermal efficiencies are also improved – this is precisely the important gap ICS contributes to fill.

Similarly, given that ICS are comparatively cleaner and advanced cooking technology relative to open-fire and 3-stone stoves, the theories governing the adoption and use of technologies could also be utilized to understand the critical factors underlying ICS adoption and hence the underlying WTP. In the literature, several theories, models and hypotheses have been postulated in support of technology adoption/acceptance/use behaviour. Prominent among them which also appears to have direct implication for ICS is the technology acceptance model (TAM) originally developed by Davis et al. (1989) and extended further by Venkatesh and Davis (2000) and Venkatesh and Bala (2008). In its original formulation, Davis et al. (1989) and Davis (1989, 1993) attempted to establish the general determinants of computer acceptance among end-users based on perceived usefulness and ease of use both of which were assumed to be ultimately influenced by other external factors. Later modifications extended the application beyond computer to a wide range of products though mainly technology-based products and services.

Subsequently, many other drivers of acceptance that account for individual differences and social characteristics as well as product features and facilitating conditions have been identified (Venkatesh and Davis, 2000; Venkatesh and Bala, 2008). ICS, even though not necessarily the outcome of any sophisticated technology is based on technologies capable of achieving better

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[26] Refer to section 3.2.1 of chapter 3 for more details of the energy choice hypotheses

combustion and thermal efficiency of the cookstove relative, at least, to open-fire and 3-stone stoves. Hence, the application of TAM to the understanding of WTP towards ICS is very apt. Following the adoption determinants of the TAM, the literature on ICS adoption and WTP has identified age, gender, education, marital status, occupation/source of income as key variables that can account for individual differences and social characteristics (see section 4.2.2). Likewise, based on TAM's postulations, product features that are likely to influence WTP for ICS could include stove usefulness, ease/convenience of use, safety, durability, affordability, availability, among others (again, refer to section 4.2.2). Similarly, the literature has identified variables such as access to credit, financial inclusion, preference for technological advancement, income, family size as other key facilitating conditions for adoption and hence WTP (see section 4.2.2). Thus, the technology acceptance theories particularly shed important light on the adoption behaviour of prospective users of new technology and it is realistically applicable to the understanding of economic agents' behaviour towards clean cooking technology such as ICS (also refer to section 4.3.2).

4.2.1.3 The role of subsidy and credit payments on choice and WTP

The microeconomic theory of consumer utility maximization, as discussed in section 2.1.1 of this chapter, revealed that market prices and income levels are the most critical constraints faced by consumers. Indeed, both of them act jointly to influence the purchasing power of prospective buyers of a good or service. Consequently, any interventions that alter prices and incomes in ways favourable to the consumer are essential catalysts to stimulate consumption. Subsidies and credit facilities are tools prominently utilized to achieve this appreciable improvement in purchasing power capable of encouraging demand and consumption. For instance, the use of instalment purchase regime is a notable mechanism to provide consumers with indirect credit for the purposes of encouraging the adoption and consumption of specific good or service without the need to go through the banking system to acquire loans. Firas (2016) describes an instalment purchase agreement as a contract used to finance the acquisition of assets in which the buyer commits to pay the seller the full purchase price by making a series of partial payments over an agreed period of time. This payment arrangement is provided in order to facilitate acquisition of the product by buyers who cannot afford to pay for purchases upfront in cash (Firas, 2016; Griebsch et al., 2007; Prelec and Loeweinstein, 1998). It is a popular sales arrangement utilized by several merchants and service providers in many commodity markets worldwide (Firas, 2016). Credit typically shifts cost/payment to the future and thus typically disperse one large payment across many periods and thus likely to incentivize adoption (Dertwinkel-Kalt et al., 2021; Berkouwer and Dean, 2022; Pattanayak et al., 2019; Gabaix and Laibson, 2017)

Subsidies on the other hand could be understood as the inverse of taxes (Ruffle 2005; Nagler et al. 2013) or positive taxes (Nechyba 2011) as they influence market prices, output and surpluses but in ways converse to taxes. Subsidies, when offered to consumers, are major mechanisms used to reduce the market prices of the commodities to make them affordable to buyers or consumers (Baffoe-Bonnie et al, 2021; Pattanayak et al., 2019) and to ultimately encourage consumption. The use of subsidies is frequently premised on the assertion that some critical development goals cannot be left in the hands of price mechanism as dictated by the principles of the market. For instance, in many developing countries poor households ordinarily cannot afford improve cooking technology even if desirable by them. Consequently, subsidies create a safety net that absorbs the part of prospective consumers abandoned by the market (Pattanayak et al., 2019). Subsidies could therefore be utilized effectively to address some of the problems resulting from market failures where prices are reduced to facilitate effective demand of critical welfare goods and services. Similarly, subsidies can be applied to respond to redistribution crisis by providing access to products which hitherto could not have been afforded by the poor and vulnerable. Thus, in the context of ICS, subsidies could be used to correct negative externalities resulting from emissions of IAP associated with the inefficient and incomplete combustion of biomass using traditional stove. Additionally, subsides obviously provide financial incentive to promote the adoption and use of a more sustainable and cleaner cooking technology which otherwise would not have been possible (Baffoe-Bonnie et al, 2021; Pattanayak et al., 2019). Komives et al. (2007) and Kumar et al. (2020) among others, for instance, have provided evidence in support of the use of subsidies to increase access to electricity and expansion of fishing activities in developing countries.

4.2.2 Empirical evidence on WTP for ICS

This study explores the role played by subsidy and credit regimes in household’s WTP for ICS utilizing the CVM. Thus, in reviewing the empirical literature, the focus is on subsidy, credit regimes, CVM and the evidences related to households’ WTP for energy-efficient technologies but with more emphasis on ICS. To put the review into productive perspective, we categorize the extant literature into three broad stands. The first strand of literature comprises studies that estimates WTP for ICS based on the attributes of the ICS rather than the ICS themselves while the second strand estimates WTP for the ICS as a whole rather than its attributes. The third strand deals with policy tools for enhancing adoption and use of ICS which include subsidy and credit facilities among others. However, it is important to reiterate that empirical evidence on subsidy and credit regimes in the context of WTP towards ICS is rather scanty.

In line with the first strand, Takama, et al (2011) applied a CVM to examine household-level WTP for ICS using household sample of 200 from Addis Ababa (Ethiopia), 564 from Dar es Salaam (Tanzania) and 402 from Maputo (Mozambique). The study emphasized the role of product-specific attributes such as indoor smoke, safety, usage cost and price of the stove along with socioeconomic factors. Utilizing a discrete choice estimation procedure to examine the trade-off between the attributes, the authors concluded that product-specific attributes were as important as households' socioeconomic characteristics in determining WTP for ICS.

Relatedly, Takama et al., (2012) with focus on the same four attributes in the same countries (i.e., Ethiopia, Tanzania and Mozambique) repeated the study in the subsequent year but on a sample categorized into income-groups. Again, using a discrete choice and CVM method, the authors found that low-income households in Ethiopia had a mean WTP of \$0.95 monthly while those in the middle and high-income groups were willing to pay \$1.16 and \$1.87 respectively. In Tanzania, the estimated mean WTP were \$1.16, \$0.92 and \$1.38 respectively for the low-income, middle-income and high-income households.

Jeuland et al. (2015) reported on preferences for ICS attributes in a large sample of 2,120 rural households in north India which is regarded as a global hotspot for biomass fuel use as well as its negative consequences. The authors observed that while preferences for stove attributes varied significantly across households and their socio-cultural and economic characteristics, strong preference for traditional stoves among the households was still evident. Consequently, households were willing to pay only about \$10 and \$5 respectively for realistic reductions in smoke emissions and fuel needs on average. These results suggest that households exhibit cautious interest in the promise of ICS, and that significant barriers to achieving widespread adoption remain profoundly. Mare and Annegarn (2017) focused on the number of burners/plates of the stove as the main attribute of interest. In particular, they examined household's WTP for four-plate LPG stove relative to multiple plate biomass stove in South Africa. They found that households are willing to pay a maximum of $259.88 for the four-plate LPG stove and $155.93 for the multiple plate biomass stove. This evidence was established in scenario where safety information about the cookstove is provided. Kooser (2014) also extracted data from a sample of 542 rural Ethiopian households through a CVM. The author observed that households were willing to pay as high as $20.74 if the ICS is durable but $12 for its time convenience attribute. Similarly, the estimated marginal WTP for ICS with fuel reduction attribute stood at $18.81 and $17.46 for the LPG and biomass stoves respectively. Like Takama et al. (2011), Kooser (2014) additionally showed that ICS adoption was influenced by various cookstove–specific attributes and socioeconomic characteristics. This specific conclusion is further corroborated by Bhojvaid et al. (2014) who conducted a thorough investigation into the determinants of households' WTP for ICS in rural India and observed the marginal WTP for ICS to vary significantly with respect to stove-related attributes.

Also, Rosenbaum et al. (2015) investigated avenues to accelerate the uptake of ICS as well as its consistent, exclusive and accurate use. To achieve this objective the authors conducted comprehensive assessment which included household ICS trials, fuel and stove use monitoring and consumers' perceived value of ICS as well as the underlying WTP. The trials successfully recruited 160 households that met the criteria for the study. Preliminarily, the authors found that while many preferred ICS over traditional stoves, this preference declined steadily over the 3-week trial period. This is because even though cooks appreciated and liked the ICS none of the models presented through the trials adequately met consumer's needs sufficiently enough to replace traditional biomass stoves. Also, while the trials further revealed smoke reduction it was relatively lower than expected by the households. Indeed, out of 105 households given the option to buy the stoves at market value, only one did so. Nonetheless, 80% of the households preferred to keep the ICS to the offer of receiving a cash buyout even at market value. This shows that users value ICS when acquisition barriers are removed emphasizing the need for better financing options.

Consistent with the second strand of literature, Bersisa, et al. (2021) applied a mix of double bounded dichotomous choice CVM technique and fractional factorial design choice experiment model (CEM) to examine households' WTP as well as preferences and determinants of adopting new gas stoves in rural Ethiopia. With estimated mean WTP ranging from about 150 Birr to 350

Birr which was lower than the market price of the ICS, the authors established that higher levels of education, higher incomes, non-farm employment, and having more livestock increased the probability of adopting the stoves. This was conditional on the fact that the households in the survey were aware of the effects of using traditional cookstoves as against ICS but were constrained by the availability of the new technology and discouraged by the low-quality of the products that they had previously used.

Furthermore, applying a discrete CEM on 383 households in rural Malawi, Jagger and Jumbe (2016) examined the underlying preferences and WTP for ICS by asking if households would choose a locally made ICS or a package of sugar and salt of roughly equal value. They established that having a larger share of crop residues in household, fuel supply, awareness of the environmental impacts of wood-fuel reliance, the time the primary cook devotes to collecting fuelwood and peer effects at the village-level increase the odds of choosing the ICS. The authors further established that households with large labour force for fuel wood collection and have a considerably low experience with non-traditional cooking facilities decreased the odds of choosing the ICS. In Nigeria, Onyekuru et al. (2021) similarly used a multistage random sampling procedure to survey 160 rural households in Enugu state of Nigeria with the objective of studying their WTP for ICS as well as the socio-economic covariates of households that affect their WTP. After a careful application of open-ended and closed-ended bid approach and the CVM to elicit the necessary data, a Tobit model was used to estimate the mean WTP due to the censoring nature of the data collected. The study found about 86% of the households were willing to pay for the use of ICS as a climate change mitigation strategy with a mean WTP of N2, 656.67 (~$8). Among other findings, education and farming experience of household head, as well as size and location of household were the factors that negatively influenced households' WTP, while age and gender of household head had positive effect on households' WTP for ICS. Surprisingly, income was found to lower households' WTP probability towards ICS.

Focusing on subsidy and credit regimes – the third strand of literature – Bensch and Peters (2017) used a randomized control trial (RCT) in rural Senegal to evaluate whether one-time free distribution of cookstoves affects households' WTP in the long run. The authors found that households who received a free stove six years back exhibit a higher WTP which suggests that one-time free distribution does not threaten future prices and might even be a stepping stone for a future market. Similarly, Berkouwer and Dean (2022), in an experimental study of 1,000 households in Nairobi observed that relative to a market price of $40, households were willing to pay as low as $12 for an energy-efficient charcoal cookstove despite its fuel-saving of nearly $240 and emission reduction of about $300 over the two-year of the stove. The authors were however quick to admit that the availability of an interest-embedded loan increases the underlying mean WTP by more than 200%. This demonstrates extent to which credit rigidities adversely affect adoption of privately optimal technologies (Berkouwer and Dean, 2022). Again, the authors argue that the loan facility is not likely to threaten future market-based distribution.

In India, Pattanayak et al., (2019) conducted an RCT of nearly 1,000 households in the Indian Himalayas to estimates demands for electric stoves relative to biomass stoves with intervention bundle which include incentive to ease their liquidity constraints. The experiment showed that, compared with zero purchase in control villages, more than 50% of households that received the intervention bundle bought an ICS, although demand was highly price-sensitive. In particular, the demand for the electric stoves was at least twice as high as biomass ICS. It was also observed that even among households that received a negligible price discount, the upgraded supply chain alone induced a 28 percentage-point increase in ICS ownership. This demonstrates that price discounts (along with the other interventions such as market analysis, robust supply chains etc.) are critical for ICS diffusion. The authors further argued that although the bundled intervention was resource-intensive, the full costs were still lower than the social benefits of ICS promotion. Also, Betralmo et al. (2015) conducted a second-highest bid auction of a fuel-efficient cookstove through an RCT to examine how WTP for an ICS varies with marketing messages and time payment plans. In particular, the time payment plans were such that 2,122 participants were willing to make payment within a week while another 2,135 opted for time payments within two weeks in a typical single bounded dichotomous choice CVM scenario. To ensure consistency with the tenets of RCTs the authors carried out the experiment in the southwestern region of Mbarara, Uganda where almost all of the households were using traditional three-stone open fires as cooking technology at the time of the trial and there were no active fuel-efficient cookstove interventions or fuel-efficient cookstoves for sale in the local markets. The experiment revealed that marketing messages about the ICS had no systematic effect on household’s WTP but time payment plan did. In particular, WTP was 40% higher with time payments than paying within a week. This shows the extent to which households generally prefer flexible payment plans even if short-termed.

Chindarkar et al. (2021) assessed household's WTP for a high-tech clean cooking solution in the form of exclusive use of LPG for cooking. The study was conducted in six most energy-deprived states in rural India. The study relied on a single-bounded dichotomous choice CVM-driven secondary data surveyed from 9,072 rural households. In the dataset, households had been hypothetically asked to make a binary choice regarding their WTP for a randomly assigned bid that potentially reflects the maximum monthly WTP for exclusive use LPG to meet all their cooking needs. These households included 4,021 non-LPG users and 1,866 non-primary LPG users. The mean monthly WTP was estimated at INR 453 and INR 471 for non-LPG households and non-primary LPG households respectively. Among the subsample of non-LPG households, a decomposition analysis revealed a mean monthly WTP of INR 466 for those that consider LPG to be better for their health than traditional biomass stove and INR 388 for households who think otherwise. Even though, relative to an effective equivalent monthly expenditure of INR 386–435 which is lower than the various estimated monthly mean WTP, estimates suggest that about 40–45% of the non-primary LGP users have a lower WTP than the current effective monthly cost of subsidized LPG. Consequently, the authors were quick to admit the need for policy to evaluate the payment schemes as households with irregular cash flows were found to be less likely to pay for exclusive use of LPG. Covariates such as LPG's health benefits, household size, availability of free biomass were established as the other determinants of the WTP for the exclusive use of LPG for cooking.

Hanna et al. (2012) however found some contrasting results when they estimated WTP for a relatively inexpensive ICS ran by an NGO in rural areas. Using random sampling technique to collect WTP and socio-economic data from 448 households, they found that even though the stoves were highly subsidized, essentially free, households reported a very low WTP and many households even refused to install them. This conclusion had previously been reported in a similar WTP study by Miller and Mobarak (2011) who argued that even a small cost discourages stove adoption.

In Nigeria, Nduka (2021) estimated WTP for ICS (and pico-PV system) from a sample of 218 rural households systematically sampled from the Ebonyi state. Households' hypothetical responses were collected using a single-bounded dichotomous CVM while estimation was carried with both parametric and non-parametric econometric methods. The study finds that an overwhelming 92% of respondents lack knowledge about ICS but have preference for sustainable cooking technologies. Based on the bids randomly declared to the respondents, the study estimated monthly mean WTP of ₦778.59 ($2.15) for ICS until the full payment is complete. In this way, the credit offer did not discriminate between wealthy households that can afford prompt payment and poor households that can only afford delayed payments. The study further shows that age, gender, marital status of household head as well as the income, current energy spending and size of the household generally drive WTP. Other specific results reveal that females are, perhaps, more risk-averse than males in adopting new technology and yet educated females are more likely to pay for cleaner energy than educated males.

4.2.4 Statement of contribution

The above review shows that even though the literature has examined various aspects of households' liquidity constraints in relation to WTP for improved cooking solutions, it often assesses each incentive (subsidy, credit regimes etc) separately at a time. Thus, despite the growing efficacy of both incentives, the literature has still not adequately examined how subsidy could be effectively *combined* with credit regimes *concurrently* to stimulate mass uptake even though either has been shown to be an important catalyst. Therefore, at the policy front, the study sheds light on how availing *both* subsidy and credit simultaneously impacts on WTP. This invariably has direct implications for the formulation of effective market-based pricing required for the establishment of sustainable ICS markets necessary to stimulate mass uptake. In terms of contribution to literature, the approach adopted in the study also attempts to demonstrate the dynamics of the mean WTP overtime – this is considered relatively novel especially in the context of ICS.

4.3 Methodology

4.3.1 The Valuation Approach – Contingent Valuation Method (CVM)

In the study, the CVM is utilized for estimating the mean WTP for the ICS. Even though, the method is conventionally applied to quantify values of environmental resources it has also been widely used to estimate values of several non-marketable goods and services that are not necessarily environmental resources (Kwak et al., 2013; Carson et al., 2001; Arrow et al., 1993; Mitchell and Carson, 1995; Diamond and Hausman, 1994). The CVM is a direct or stated preference technique in which economic agents are asked to respond to hypothetical questions as a way of ascertaining the values they assign to the underlying commodity. Since the questions are hypothetical, the responses are also hypothetical but are a useful mechanism of deducing preferences or WTP resulting from potential welfare changes (Dlamini et al., 2016). While the valuation approach is normally criticized as being overly simplistic in orientation and plagued with enormous biases and often regarded as the most controversial of all environmental valuation approaches, it remains one of the most widely used valuation technique (Obinna et al., 2018; Twerefou, 2014; Hanley et al., 2001; Kramer and Mercer, 1997).

One major merit of the CVM over the other valuation methods lies in its ability to measure both use and non-use values because in WTP decisions economic agents (i.e., the respondents) consider both use and non-use in quoting the maximum amount they are willing to pay for a good or service (Twerefou, 2014). The CVM-based WTP has been used diversely and widely in the literature to compute values of public goods, environmental goods as well as some private goods (Obinna et al., 2018; Kwak et al., 2013; Twerefou, 2014; Serra and Fierro, 1997). Furthermore, Lee and Heo (2016) and Segerson (2017) have shown that the technique can even be utilized productively to estimate various measures of welfare without making a general assumption about the utility function (also see Mitchell and Carson, 1995; Vaughan et al., 1999; MacMillian, 2004).

A closely related and applicable valuation technique is the choice experiment model (CEM). In particular, the CEM values specific attributes of a good or service rather than the good or service in its entirety (Obinna et al., 2018; Kwak et al., 2013; Twerefou, 2014; Lancaster, 1966; Louviere et al., 2000) by computing marginal WTP across attributes through the application of the traditional notion of marginal rate of substitution (see Kooser, 2014). Thus, even though both CEM and CVM can be used for the WTP analysis for ICS, the CEM estimates marginal WTP for some specific attributes while the CVM estimate mean WTP for the entire good. As the study focuses on estimating the mean WTP for the entire ICS rather than the marginal WTP of some specific attributes of the ICS, then CVM is therefore more appropriate relative to the CEM. The CVM only directly solicits WTP responses from economic agents and estimate the underlying mean WTP for the whole good (see Aklin et al., 2018; Yoon et al., 2016; Lensink et al., 2017; Roy and Jana, 1998).

4.3.1.1 The Contingent Valuation Scenario

In the datasets utilized for the study, households without ICS (or any clean cooking technology) and for whom firewood was their primary fuel were asked about their WTP for either Aspirational wood ICS available in country or popular Affordable wood ICS available in local market. The benefit of having ICS and the features of the assigned ICS is described and explained extensively to the respondent. For instance, respondents are informed that the cookstove (i.e., ICS) can reduce the smoke and fuel consumption significantly while cooking time per meal will be shortened since firepower of the cookstove is stronger than the traditional cookstove. After a type of these two ICS is randomly chosen, its price was assigned based on one of the three percentages of the reference price: 33%, 66% or 100%. Households then revealed their WTP by simply declaring a "Yes" or "No". Following a typical dichotomous choice, households that declare a "No" for upfront payment are then given a 6-month payment option and if they declare a "No", they are presented with a 12-month payment option and finally a 24-month instalments payment[27]. In all cases, the interviews ends once a "Yes" response is declared by the households. Thus, the underlying household choice is discrete in orientation. To ensure that the response reflects the household's

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[27] In the CVM literature there are formats that guide the sequence and repetitiveness of questions in a given scenario. For instance, in single-bounded formats, the valuation question is often one-off. However, double-bounded and triple-double formats are characterized by several follow-up (repeated) offers to assess respondent's precise valuation. These are acceptable formats that have guided several CVM studies in the literature. Thus, in principle, the CVM has been developed to accommodate/tolerate the repetitiveness of the questions or scenarios (Obinna et al., 2018; Kwak et al., 2013; Twerefou, 2014; Serra and Fierro, 1997). In this way, the repetitiveness of the questions or scenarios in itself does not bias the outcomes of the survey.

stove preferences as well as WTP, the questions were presented to and answered by a household member who most frequently cooks for the household or the household member who decides to purchase the cookstove. Respondents are also reminded to keep in mind the benefits of the ICS as well as the household's budget as they respond to the questions. The full CVM scenario presented to the households (respondents) during the World Bank MTF Global survey has been reported in Appendix I to provide additional information on the extent to which hypothetical, strategic and other CVM-inherent biases were controlled for as well as issues of consequentiality, payment vehicle, among others.

4.3.2 Conceptual Framework and Empirical Model

The conceptual framework for WTP analysis is rooted in the consumer choice problem (see section 4.2.1.1) which posits that a consumer may be willing to pay for ICS provided utility increases with the acquisition of the ICS, or at worse, the price does not lower utility beyond the original welfare level. As the choice of any of these solutions over their respective status quo has been known from the preceding section to be discrete, specifically binary, it is convenient to cast the choice within the random utility theory which is an extension of the consumer choice theory. A basic assumption of the random utility theory is that individuals know their preferences. These preferences are assumed to be well defined among alternative bundles of goods that could comprise of both market and non-market goods of varying quantities. Among many other important assumptions, the preferences are further assumed to possess some degree of substitutability among goods in a bundle. This implies that the individual has the capacity to acquire new products by reducing the consumption of other good(s) while maintaining his original utility level given prices and all else constant. This substitutability property is very fundamental to the analysis of WTP given its emphasis on the potential trade-off ratios among goods in a consumer basket. By trading-off some goods in favour of the other (e.g., ICS), the consumer gives an indication of how much value is placed on the ICS which could further reflect the underlying WTP (Aklin et al., 2018).

Generally, economists agree that the choice (trade-off) is contigent and that if an improvement or acqusition of a product translates into postive gains to the consumer, then the question of WTP is appropriate (Twerefou, 2014). The WTP concept is thus considered best approximations to evaluating the price underpinning the demand mainly for non-market goods but also for marketable goods for which the consumer has not yet made effective demand. Even though ICS are marketable goods in Nigeria as some previous interventions have made the technology publicly available in the market, the product is almost entirely missing among the sample utilized for the study. The underlying survey by the World Bank was a survey that intended to evaluate WTP for ICS among households without ICS.

The approach adopted by our study is to examine potential pathways to stimulating large-scale uptake of ICS by understanding household's WTP in the presence of a one-shot subsidy and flexible credit payment systems. Therefore, in this study, estimating the mean WTP becomes a better indicator of how much monetary resources a representative household is prepared to give up for an improved relatively cleaner cooking technology (i.e., ICS) rather than continuing cooking with inefficient traditional biomass cookstoves. Thus, estimating household's WTP for ICS starts with observing the choices made during the elicitation process since the associated valuation of the ICS are implicitly implied in the choices.

Following Hanemann (1994) and recent modifications by Jeuland et al. (2015) the economic agent could be assumed, within the random utility model, to have an indirect utility which is a function of household's income, vector of the various randomized bids of the ICS and other household and stove covariates. Essentially, the indirect utility only provides a deterministic component of the household's underlying utility function but the random utility model comprises both that deterministic component and a stochastic component. In its basic formulation the household's utility based on the random utility model could be given by equation (4.1)

$$V = v(Y, B, Q, Z) + \varepsilon \text{ --------------------------- } (4.1)$$

Where v(.) is the indirect utility function of the household which is deterministic but observable. Y is the level of income and B is the randomized bid values of the ICS capturing the upfront payment or stream of monthly payment instalments the household needs to make. Q represents the ICS associated with the randomized bids while Z is a catchall variable including but not limited to agent's socio-economic characteristics. ε is the random component which transforms the household's observable indirect utility to the actual unobservable utility based on the random utility theory. Suppose equation (4.1) is the initial indirect utility of the household, then its new indirect utility after acquiring the ICS could be written as given by equation (4.2)

$$V' = v'(Y', B, Q, Z) + \varepsilon \text{ --------------------------- (4.2)}$$

Where $Y' < Y$ is the remainder income of the household after honouring its financial payment obligation of the ICS. The alteration to the household's utility after the acquisition of the ICS could also occur via other channels including time and fuel saving, less IAP and its related diseases, reduced healthcare expenditure among others.

Typically, a household declaring a "Yes" is a direct reflection that the household considers the utility associated with the new cooking technology after deducting the instalment payments from income to be greater than the utility associated with using the traditional stoves. Simply put, $V' = v'(Y', B, Q, Z) + \varepsilon > V = v(Y, B, Q, Z) + \varepsilon$.

Given the binary structure of the WTP framework described above, the study, on the assumption that the random component of the household's utility function is identically and independently distributed with mean zero, subsequently utilizes the probit model to estimate the probability (as well as the underlying determinants) of a household responding "Yes or No" for each ICS. According to Paap and Franses (2000), a more general formulation of the probability of responding "Yes or No" to a specific WTP randomized bid values could be given by,

$$\Pr(\mathrm{y}_i = 1 | \mathrm{x}_i) = F(\mathrm{x}_i \beta) \text{------------ (4.3)}$$

where F is some function that returns values in the [0, 1] interval.

Following a latent variable formulation, we conceptualize that underlying the observed discrete outcome y (i.e., willing to pay for ICS) there is a continuous propensity y^* which changes a household from state of not willing to pay to a state of willing to pay once a certain critical level of utility y^* has been reached. Explicitly, this suggests that,

$$y_i^* = \mathrm{x}_i \beta + \varepsilon_i$$

$$y_i = 1(y_i^* > 0)$$

$$y_i = \begin{cases} 1 \; if \;\; y_i^* > 0 \\ 0 \; if \;\; y_i^* \leq 0 \end{cases}$$

Thus, empirically, our model could be of the form given in equation (4.4) below

$$y_i = \alpha + \delta Bid_i + X_i^{'}\beta + \varepsilon_i \text{ --------- (4.4)}$$

Where ***y*** is the probability of responding “Yes or No” to a specific WTP bid and takes the value 1 if the household responds with a “Yes” and 0 otherwise. ***X`*** is a vector of covariate including household’s income, size, access to credit, financial inclusion, head’s age, marital status, gender as well as stove features. It is important to reiterate that the Bid in all those equations and for that matter (4.4) is the price of the ICS that the respondents were asked to pay. However, at the point in the survey where it is being randomly assigned to the respondents, the bid then takes into account the one-off subsidy as well as amount of time a respondent takes to pay the originally proposed bid. This is because for each credit regime, there is a subsidy embedded. This is because the subsidy in the CVM scenario utilized by the World Bank in the survey was one-off which reduced the price of the ICS by 33.33% even before the households were given the opportunity/option to pay under various credit regimes. This implies the following: Option A = 33.33% subsidy + Upfront payment; Option B = 33.33% subsidy + 6-months instalment payment; Option C = 33.33% subsidy + 12-months instalment payment; Option D = 33.33% subsidy + 24-months instalment payment. In the results and discussions, for simplicity, option A is referred to as “Upfront” while option B is referred to as “6-month”. Also, option C is referred to as “12-month” and option D is referred to as “24-month”. Hence, the results and discussions ought to be understood in the light of these subsidy-credit regime combinations. The maximum likelihood methods are used to estimate the values of the marginal effects that maximize the likelihood that the choices of the households are observed in the sample of respondents. The study utilizes the Hosmer-Lemeshow test and McFadden’s pseudo R^2 to evaluate the goodness of fit of the models. Once equation (4.4) is estimated, the expected (mean) WTP are recovered using the following standard algorithm in equation (4.5) consistent with Haab and McConnell (2002) and Lopez-Feldman (2012)

$$E(WTP) = -\alpha/\delta \text{ ---- (4.5).}$$

Where α is the intercept of the WTP bid function in equation (4.4) and δ is the associated bid parameter.

4.3.3 Estimation strategy

The empirical strategy adopted by the study attempts to demonstrate the dynamics of the mean WTP for ICS over *time*. This is aimed at understanding how availing subsidies and credit concurrently can effectively impact WTP for ICS. Consequently, the main empirical strategy assumes that households willing to pay for the ICS at the upfront payment option are also willing to pay at the 6-month, 12-month and 24-month credit regimes. Similarly, those willing to pay at 6-month credit regime are presumably willing to pay at the 12-month and 24-month credit regimes and so forth. Following this strategy, each WTP sample comprises households who declared “Yes” to a particular subsidy-credit scheme plus those that declared "Yes" to the preceding subsidy-credit schemes (see Tables 4.1 and 4.2 for the case of the aspirational and affordable ICS respectively). However, it must be highlighted that the credit regime/period simply specifies the maximum amount of time within which a household/respondent has to settle the payment of the ICS. Hence, it does not preclude those who wants to settle the payment much earlier. This shows that the assumption does not alter the time preferences of the households in respect of the duration of the credit and repayment. It is only to demonstrate that households that prefer short-term credit regimes and would like to avoid longer ones are allowed to do so but also have the opportunity of long-term credit regimes if they so desire. Indeed, the assumption does not even eliminate the option of totally rejecting the credit. A key advantage of this behavioural assumption is that it allows the study to show how the entire sampled households in the survey value the ICS but at different subsidy-credit combinations. More importantly, it is this behavioural assumption that enables the study to demonstrate the dynamic behaviour of the underlying mean WTP i.e., how much each full-sample is distinctively willing to pay to acquire the ICS given those subsidy-credit combinations. In this way, estimations are always at the full-sample level and thus having the same distribution across all variables except for the outcome variable and the randomized bids. It is also emphasized that the credit regimes considered in the study does not involve any direct financial costs to households beyond the bid/price of the ICS.

We implement a second strategy, primarily to check for the robustness of the main empirical strategy. Here, rather than estimating our models at full-sample level like the main empirical strategy, estimations are done at the subsample levels with each subsample comprising only households to whom a particular subsidy-credit scheme was presented (see Tables 4.1 and 4.2 for the case of the aspirational and affordable ICS respectively). In this way, the unique behavioural assumption held for the main empirical strategy regarding household’s time preferences is relaxed for the robustness check estimations. Thus, contrary to the main empirical strategy which tells how the entire sample are willing to pay a certain amount for the ICS, the robustness check strategy only tells how different groups of households belonging to the different credit regimes are willing to pay a certain amount for the ICS. Thus, while the main empirical strategy is done at the full-sample level, the robustness check strategy is at the subsample level.

Consequently, in Tables 4.1 and 4.2 we report the bids that were presented to the households for the Aspiration wood ICS and the popular Affordable wood ICS respectively. It is observed that, as described in section 4.4.1.1, the upfront bid levels are respectively divided by 6, 12, and 24 to obtain bids for 6-month, 12-month and 24-month credit regimes. The Tables also show the number of households that accepted the various randomized bids at the different credit regimes – this is found in the second columns labelled as ‘Yes’. The corresponding ‘No’ responses are in the third columns. The figures in square parentheses ‘[ ]’ are the percentage of ‘Yes’ and ‘No’ responses at each credit regime. These percentages are obtained as ratios of ‘Yes’ and ‘No’ responses in parentheses ‘()’ to the total sample indicated in the last columns. For instance, the 33% and 67% ‘Yes’ and ‘No’ responses in the first row of Table 4.1 are obtained as 411/1,234 and 823/1,234 respectively. The distinction between the figures in parentheses and those before them is provided in the next section (i.e., 4.4.3) below.

Also, note that in the World Bank/ESMAP survey, the bid levels were derived from the full market price of the ICS and were pegged at 33%, 66% and 100% of the full market price of the ICS (which corresponded respectively to US$11.02, US$22.05 and US$33.40 for the Aspirational ICS and US$8.27, US$16.53 and US$25.05 for the Affordable ICS). During the interview, one of these reference prices is randomly assigned to a household after an ICS has been chosen randomly. Those who did not accept to pay this randomized bid at upfront are given the opportunity to pay the same bid in 6 months. This implies that the original bid is now divided by 6. Similarly, those did not accept the bid at 6 months (i.e., after the bid has been divided by 6) are giving the opportunity to pay the same/original bid in 12 months. This implies that the original bid is now divided by 12. The same analogy holds for 24 months too. This is succinctly presented in Tables 4.1 and 4.2. However, it must be highlighted that from the dataset, it appears the 100% reference price was either never assigned or completely unutilized. As a result, only the 33% and 66% reference prices are reported in the data by the World Bank.

Table 4.1: Bid determination and distribution of WTP Responses – Aspirational wood ICS

WTP Bids ($)	Yes	No	Total
Upfront price (Full sample 1)	**549 (411) [33%]**	**1,027 (823) [67%]**	**1576 (1,234) [100%]**
22.05=**66% (33.40)**	234 (169)	570 (452)	804 (621)
11.02=**33% (33.40)**	315 (242)	457 (371)	772 (613)
6-Month instalment (Full sample 2)	**695 (531) [43%]**	**881 (703) [57%]**	**1,576 (1,234) [100%]**
22.05=**22.05/1**	234 (169)	185 (118)	419 (287)
11.02=**22.05/1**	315 (242)	159 (112)	474 (354)
3.67=**22.05/6**	66 (50)	319 (284)	385 (334)
1.84=**11.02/6**	80 (70)	218 (189)	298 (259)
12-Month instalment (Full sample 3)	**856 (678) [55%]**	**720 (556) [45%]**	**1,576 (1,234) [100%]**
22.05=**22.05/1**	234 (169)	204 (133)	438 (302)
11.02=**11.02/1**	315 (242)	183 (132)	498 (374)
3.67=**22.05/6**	66 (50)	0 (0)	66 (50)
1.84=**22.05/12**	165 (149)	215 (190)	380 (339)
0.92=**11.02/12**	76 (168)	118 (101)	194 (169)
24-Month instalment (Full sample 4)	**938 (749) [61%]**	**638 (485) [39%]**	**1,576 (1,234) [100%]**
22.05=**22.40/1**	234 (169)	228 (157)	462 (326)
11.02=**11.02/1**	315 (242)	193 (141)	508 (383)
3.67=**22.40/6**	66 (50)	0 (0)	66 (50)
1.84=**22.05/12**	165 (149)	0 (0)	165 (149)
0.92=**22.05/24**	126 (110)	141 (124)	267 (234)
0.46=**11.02/24**	32 (29)	76 (63)	108 (92)

Table 4.2: Bid determination and distribution of WTP Responses – Affordable wood ICS

WTP Bids ($)	Yes	No	Total
Upfront price (Full sample 1)	**539 (425) [34%]**	**1,046 (835) [66%]**	**1,585 (1,260) [100%]**
16.53=**66% (25.05)**	191 (149)	581 (467)	772 (616)
8.27=**33% (25.05)**	348 (276)	465 (368)	813 (644)
6-Month instalment (Full sample 2)	**705 (566) [45%]**	**880 (694) [55%]**	**1,585 (1,260) [100%]**
16.53=**25.05/1**	191 (149)	195 (123)	386 (272)
8.27=**8.27/1**	348 (276)	150 (90)	498 (366)
2.26=**16.53/6**	69 (55)	317 (289)	386 (344)
1.38=**8.27/6**	97 (86)	218 (192)	315 (278)
12-Month instalment (Full sample 3)	**862 (709) [56%]**	**723 (551) [44%]**	**1,585 (1,260) [100%]**
16.53=**25.05/1**	191 (149)	219 (144)	410 (293)
8.27=**8.27/1**	348 (276)	185 (122)	533 (398)
2.26=**16.53/6**	69 (55)	0 (0)	69 (55)
1.38=**16.53/12**	187 (171)	203 (183)	390 (354)
0.69=**8.27/12**	67 (58)	116 (102)	183 (160)
24-Month instalment (Full sample 4)	**933 (774) [61%]**	**652 (486) [39%]**	**1,585 (1,260) [100%]**
16.53=**25.05/1**	191 (149)	234 (159)	425 (308)
8.27=**8.27/1**	348 (276)	196 (132)	544 (408)
2.26=**16.53/6**	69 (55)	0 (0)	69 (55)
1.38=**16.53/12**	187 (171)	0 (0)	187 (171)
0.69=**8.27/12**	118 (105)	137 (121)	255 (226)
0.34=**8.27/24**	20 (18)	85 (74)	105 (92)

4.4.1 Results and Discussions

It must be emphasized from the very outset that, as often encountered in many CVM surveys, quite a number of households indulged in hypothetical bias by failing to behave as realistically as expected in a real-world bidding scenario. In fact, there are more than 20% of households that indulged in the bias by declaring “Yes” to WTP randomized bids which were larger than their income. Interestingly, the difference between the bid and their income in some instance is even as large as 30 – 40% and yet they responded “Yes”. Incidentally, these households did not also have access to any credit. Thus, it is obvious that these responses are not real because there are no practical ways these households could honour the financial obligations associated with acquiring the ICS (Johnston et al., 2017). The effect of this specific hypothetical bias was that the implied mean WTP that were initially computed were negative mainly due to positive coefficient on bid, which is inconsistent with the conventional theory of demand.

To rectify this anomaly, these household responses were considered invalid and were thus dropped from the analysis so that households that made to the eventual WTP estimations comprises only valid samples i.e., households that declared “Yes” to WTP randomized bid and whose income is also larger than the randomized bids presented to them and/or have access to credit. While income is a highly variable and prone to response bias, such that it might not be measured well in the survey, the basis for dropping these households goes beyond that. This is because the study did not simply eliminate all households with low incomes. Indeed, there are some households with lower incomes that were not eliminated. The real problem was about the hypothetical bias exhibited by some of the low-income households. In fact, initial estimations included the entire sample of all households but the results were not sound. For instance, the coefficient on the bid (i.e., price of the ICS) variable was positive in most cases which is inconsistent with the negative relationship predicted by theory. As a result, the underlying mean WTP turn out to be negative in those cases. In subsequent estimations, while still using the entire sample of all households, several alternative specifications where attempted – these included the option of trying to estimate the WTP at lower and upper bounds. But again, the results were not sound as bid (price of the ICS) and WTP had the wrong signs.

This prompted a careful inspection of the data during which the hypothetical bias was discovered. Specifically, as highlighted earlier, there are households that had declared “Yes” to bids that were larger than their incomes. In fact, in some instances, the difference is as large as 30-40%. Even at this stage, the study would not have eliminated them if they had savings or access to credit because we could have assumed that, perhaps, they would finance the acquisition of the ICS from past savings or a credit facility. However, these households also did not have savings or access to any form of credit. Consequently, the estimations were conducted without these households that had exhibited the hypothetical bias. The results of these estimations were now consistent with theory. The sign on the bid variable becomes negative in all cases and the underlying mean WTP becomes both positive and generally consistent with the subsidized price of the ICS. Hence, it could be inferred that including data on households that exhibited the hypothetical bias clearly introduces noise into the analysis since their economic behaviour was simply inconsistent with the rationality assumption of utility maximization. Thus, the final estimated included only households who did not exhibit the hypothetical bias and are therefore considered to be our valid sample. In Tables 4.1 and 4.2 above, the valid samples for the aspirational and affordable wood ICS are shown in parentheses "()" beside their respective original samples while the percentage of "Yes" and "No" responses are those in the square parentheses "[]". It must be emphasized that it is a standard procedure to test for various biases in CVM and address/eliminate them before data collection and/or data analysis. The respondents in question were not behaving as economic agents as their behaviour was irrational in that they were indicating WTP that exceeded their budget which was compounded by the fact that they did not have access to credit. In this instance, one cannot infer economic reactions from these respondents and thus were dropped from the analysis. While we cannot necessarily rule out that some randomness has been hampered by this action, there is nothing we can pick up at the moment that seems to suggest that we hampered the randomness of the remaining data in any way (Lohr, 2021; Groves et al., 2009).

4.4.1.1 Descriptive Statistics

In this sub-section, we present a discussion on the key summary statistics of both outcomes and covariates reported in Appendix J. It is important to mention that the descriptive statistics are based, precisely, on the two empirical/estimation strategies of the study.

Outcome variable: WTP Response

The outcome variables are the "Yes" or "No" WTP responses declared by the households to the various randomized bid values of the ICS. The outcome variables are thus two binary variables which relates to the two ICS under examination (i.e., the Aspirational wood ICS and popular Affordable wood ICS). In each case, the outcome variable is coded one if household declares a "Yes" to a randomized bid of a randomly assigned ICS and zero otherwise.

The behaviour of the outcome variables as reported in Appendix J shows that the percentage of households stating a "Yes" for the aspirational wood ICS increases sharply from 33% to 43% if they have to pay for the ICS in six-month instalment instead of an upfront payment (see Appendix J1. Note that these are the same percentages reported in the square parentheses in Table 4.1). As the credit regime is extended to 12 months and 24 months, the percentage of households stating a "Yes" for the aspirational wood ICS increases accordingly to 55% and 61% respectively. Similar increases of 44%, 54% and 59% respectively are observed as the credit regime is extended to six months, 12 months and 24 months for the popular affordable wood ICS relative to the upfront response rate of 34% (see Appendix J2. Again, note that these are the same percentages reported in the square parentheses in Table 4.2). This observation has two main implications. Foremost, it unequivocally demonstrates the ability of subsidy, and more especially the credit system to induce households' WTP for improved cooking technologies. Secondly, the observation confirms the standard rationality behaviour of consumers (Entele, 2020) where lower prices (i.e., lower randomized bid values) are associated with higher quantity demanded (i.e., greater "Yes" responses).

4.4.1.2 Major Findings

The section presents and discusses the major findings emanating from estimating the two ICS probability models as a function principally of the randomized bids and household's income while controlling for the covariates listed in section 4.3.2 and whose descriptive statistics are reported in Appendix J. The results for the robustness check are reported in the succeeding sub-section. It is important to reiterate that the Bid (i.e., randomized bids), in all the equations above and for that matter the empirical model (4.4) that is eventually estimated and discussed here, is not just the price of the ICS but also incorporates both the subsidy and the credit regimes. This is to say that, for each credit regime, there is a subsidy embedded. This is because the subsidy was one-off which reduced the price of the ICS by at least 33.33% even before the households were given the opportunity/option to pay under various credit regimes. This implies the following: Option A = At least 33.33% subsidy + Upfront; Option B = At least 33.33% subsidy + 6-months; Option C = At least 33.33% subsidy + 12-months; Option D = At least 33.33% subsidy + 24-months. In the results and discussions, for simplicity, option A is referred to as "Upfront" while option B is referred to as "6-month". Also, option C is referred to as "12-month" and option D is referred to as "24-month". Hence, the results and discussions ought to be understood in the light of these subsidy-credit regime combinations. Given that all ICS models are estimated using the probit model, we include the Hosmer-Lemeshow (H-L) test statistics as a measure of model fit. In all specifications the H-L unambiguously validates the null hypothesis suggesting that the underlying ICS probability models are valid. The Pseudo R-squared and the Wald test are also included. In all specifications, we report only the heteroscedastic-corrected average partial effects in models in which heteroscedasticity were detected, otherwise the reported average partial effects are estimated by the standard probit. To avoid crowding of the result tables, we only reported covariates that are statistically significant while the full results reported in Appendix K.

4.4.1.2.1 Effects of one-off subsidy and credit regimes

The main objective of the study is to determine the mean WTP of the ICS within the context of one-off subsidy and credit payment systems. Hence, in what follows we compute various mean WTP for households to acquire the ICS under the four subsidy-credit payment regimes (see Tables 4.3 and 4.4). We subsequently discuss the effects of the various covariates included in the models. Generally, the implied mean WTP are statistically significant in all specifications and exhibit a consistently upward trend until after the 12-month credit payment regime.

Specifically, in respect of the aspirational ICS, the estimates suggest regime mean WTP of nearly \$26, \$30, \$35 and \$32 for upfront, 6-month, 12-month and 24-month credit regimes respectively. This translates into a monthly mean WTP of \$26, \$5, \$3 and \$1.3 over the same credit regimes. For the upfront bid acceptors, this represents almost 33% of their total monthly household income but represent less than 7%, 4% and 2% of monthly income in the case of the 6-month, 12-month and 24-month respectively.

Contextualizing the implied mean WTP with the full survey (subsidized) price of $22 for the aspirational ICS, it will take approximately 5, 8 and 18 months for 6-month, 12-month and 24-month bid acceptors to honour the entire subsidized price. Suppose there were no subsidies, then for 6-month, 12-month and 24-month bid acceptors to honour the full (non-subsidized) price of $33 it will take as many as 7, 12 and 26 months. This shows the beneficial effect of the one-off subsidy in facilitating WTP and thus a potential mass uptake. This is because, at the least, the one-off subsidy enables households to acquire the ICS within their preferred time/credit habitat or better still within a relatively shorter duration. Similar qualitative evidence is observed for the popular affordable wood ICS available in the local market. This is consistent with the assertion that both subsidy and credit regimes are important WTP incentives – whiles the subsidy reduces the original cost burden, the credit regimes shift the remainder cost burden/payment to the future as it typically disperses one large payment across many periods (Berkouwer and Dean, 2022). Consequently, the resulting attractiveness acts to incentivize adoption of the ICS (Dertwinkel-Kalt et al., 2021; Berkouwer and Dean, 2022; Gabaix and Laibson, 2017).

Accordingly, the underlying mean WTP demonstrates that a combination of subsidy (one-off) and credit regimes can be used to effectively stimulate initial large-scale uptake of ICS. Importantly, given that the regime mean WTP are higher than the effective price of subsidized ICS, then it is not unreasonable to assert that neither WTP incentive is likely to damage future pricing when ICS are eventually circulated through pure market mechanism. This conclusion is consistent with Berkouwer and Dean (2022), Dupas (2014) and Bensch and Peters (2017).

In particular, Bensch and Peters (2017) tested, in a related ICS study in Senegal, whether free technology distribution spoils the prospects of a self-sustaining market in the future[28]. Bensch and Peters (2017) unambiguously established that contrary to the fiscal burden predicted by the reference burden hypothesis, neither a free technology distribution nor a one-shot subsidy

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[28] The test by Bensch and Peters (2017) was against a long-standing reference dependence hypothesis (Köszegi and Rabin 2006). The hypothesis argues that a major adverse unanticipated consequence of a free distribution system is that consumers may anchor their future WTP to prices previously paid for the product.

systematically dampens future markets. Invariably, in this study it is the option to pay over-time and the subsidy that significantly increases the mean WTP to the extent that households are willing to pay even more than the full price (subsidized price) of the ICS. Consistent with Beltramo et al. (2015) and Berkouwer and Dean (2022), we find that credit payment specifically raises the mean WTP for ICS by nearly 35% relative to an upfront payment schedule.

The foregoing analysis demonstrates the dynamic behaviour of the underlying WTP for the full-sample. Explicitly, allowing households to pay within 6 months instead of immediately (i.e., Upfront) increases the (full-sample's) mean WTP by about \$4 which represents a growth of 19% over time. Similarly, allowing households to pay within 12 months instead of immediately increases the (full-sample's) mean WTP by approximately \$9 which represents a growth of about 35% over time. Hence, over time the underlying mean WTP grows dynamically from 0% to 19% and then to 35% from Upfront to 6-month and then to 12-month respectively. Both increases are quite significant and economically large; capable of providing a necessary platform for future ICS markets. This analysis of the dynamic behaviour of the underlying WTP stems from the assumption held in section 4.3.3 where it was emphasized that "a key advantage of this assumption is that it allows the study to show how the entire households in the survey value the ICS but at different subsidy-credit combinations. Accordingly, we are able to demonstrate the dynamic behaviour of the underlying mean WTP i.e., how much each full-sample is distinctively willing to pay to acquire the ICS given those subsidy-credit combinations".

Additionally, it is observed at almost every offer scenario that for households that declared "No" to the assigned randomized bids, the proportion of those who revealed the lack of money as the main reason for their response is strikingly definite. In respect of aspirational ICS for instance, out of the full sample of 1,575 that were originally presented with the upfront payment scheme, almost 85% out of the 1,027 that declared a "No" WTP indicated the lack of money as the main underpinning. Also, the remainder that were offered the 6-month, 12-month and 24-month credit facilities had about 93% of them attributed their "No" WTP responses to the lack of money. Only less than 3% of those who said "No" felt they did not need an ICS.

Thus, the credit regimes effectively allowed nearly 98% of those who had initially rejected the ICS to have an eventual positive WTP response. This signals the potential effectiveness of the credit mechanism to stimulate mass uptake although there are still 40% that declared "No" even up to the 24-month instalment plan. Therefore, altogether a 12-month credit regime can be considered to be generally “optimal” when augmented with a one-off subsidy of no less than 34%. These observations render considerable support that one-off subsidy and credit regimes could be utilized not only to stimulate initial mass uptake of ICS but also allow for the creation of self-sustaining ICS markets in the future.

Table 4.3: Determinants of WTP for Aspirational wood ICS (Abridged results)

Covariates	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	-0.0126***	-0.0166***	-0.0022*	-0.0063***
(Main slope)	(0.00213)	(0.00140)	(0.00125)	(0.00146)
Age	-0.211***	-0.243***	-0.185***	-0.205***
(log)	(0.0481)	(0.0483)	(0.0478)	(0.0466)
Households size	0.0163	0.0407	0.0591**	0.0608**
(log)	(0.0247)	(0.0248)	(0.0264)	(0.0258)
Monthly income	0.124***	0.0505***	0.0313**	0.0386***
(log)	(0.0145)	(0.0138)	(0.0140)	(0.0137)
Cookstove safety	-0.0489	-0.0854**	-0.113***	-0.109***
(1=Safe)	(0.0375)	(0.0380)	(0.0386)	(0.0372)
Cooking convenience	-0.0168	0.0451	-0.0903***	-0.0726**
(1=Convenient)	(0.0274)	(0.0282)	(0.0295)	(0.0290)
Grid electricity access	0.134***	0.156***	0.164***	0.143***
(1=Yes)	(0.0290)	(0.0295)	(0.0308)	(0.0300)
Access to credit	0.0196	0.0741**	0.0564*	0.0740**
(1=Yes)	(0.0312)	(0.0311)	(0.0325)	(0.0315)
Informal finance	0.0897**	0.0875**	0.0452	0.0567
(1=Yes)	(0.0378)	(0.0386)	(0.0405)	(0.0390)
Constant	0.323***	0.489**	0.0762**	0.0204**
(Intercept)	(0.0359)	(0.0357)	(0.0368)	(0.0156)

	PROBIT Statistics			
Observations	1,234	1,234	1,234	1,234
Pseudo R-squared	0.1173	0.1463	0.0606	0.0610
Prob > χ-squared	0.000	0.000	0.000	0.000
H-L (Prob)	0.5686	0.3871	0.0528	0.8480
	WTP Statistics			
Implied Mean WTP ($)	25.65**	29.50**	34.63*	32.32*
(Regime Level)	(17.45)	(13.35)	(17.91)	(21.74)
Mean WTP/Income	25.65/78.03	(29.50/6)/78.03	(34.63/12)/78.03	(32.32/24)/78.03
(Monthly Level)	=32.9%	=6.3%	=3.7%	=1.7%
Mean Bid/Income	16.67/78.03	10.42/78.03	10.32/78.03	10.59/78.03
(Monthly Level)	=21.2%	=13.4%	=13.2%	=13.6%

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4.4: Determinants of WTP for Affordable wood ICS (Abridged results)

Covariates	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	-0.0219***	-0.0173***	-0.00166***	-0.0107***
(Main slope)	(0.00272)	(0.00201)	(0.0009)	(0.00194)
Age	-0.0918**	-0.0331	-0.0405	-0.0614
(log)	(0.0456)	(0.0423)	(0.0411)	(0.0392)
Households size	-0.0139	0.00831	0.0138	0.0208
(log)	(0.0240)	(0.0252)	(0.0260)	(0.0254)
Monthly income	0.110***	0.0473***	0.0170***	0.0466***
(log)	(0.0139)	(0.0135)	(0.00133)	(0.00132)
Cookstove safety	-0.0180	-0.121***	-0.170***	-0.155***
(1=Safe)	(0.0355)	(0.0373)	(0.0362)	(0.0348)
Grid electricity access	0.110***	0.122***	0.164***	0.158***
(1=Yes)	(0.0292)	(0.0306)	(0.0312)	(0.0302)

Informal finance	0.136***	0.163***	0.151***	0.153***
(1=Yes)	(0.0354)	(0.0366)	(0.0362)	(0.0342)
Constant	0.325***	0.276***	0.0275	0.1829*
(Intercept)	(0.063)	(0.092)	(0.572)	(0.076)
	PROBIT Statistics			
Observations	1,260	1,260	1,260	1,260
Pseudo R-squared	0.1227	0.1146	0.0616	0.0651
Prob > χ-squared	0.000	0.000	0.000	0.000
H-L (Prob)	0.1146	0.0067	0.2467	0.0261
	WTP Statistics			
Implied Mean WTP ($)	14.87*	15.98**	17.21***	17.10*
(Regime Level)	(9.02)	(7.23)	(4.94)	(9.66)
Mean WTP/Income	14.87/80.81	(15.98/6)/80.81	(17.21/12)/80.81	(17.10/24)/80.81
(Monthly Level)	=18.4%	=3.3%	=1.8%	=0.9%
Mean Bid/Income	12.29/80.81	7.57/80.81	7.60/80.81	7.69/80.81
(Monthly Level)	=15.2%	=9.4%	=9.4%	=9.5%

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

4.4.1.2.2 Socio-economic drivers of WTP for ICS across credit payment systems

The main results in Tables 4.3 and 4.4 above which utilized the coefficients on the bid and intercepts to generate the salient WTP statistics also reports the average partial effects (as well as the corresponding robust standard errors corrected for heteroscedasticity where necessary). A major importance of these results is to show not only how the covariates affect the WTP probability but also how the effect of the various covariates changes as the subsidy-embedded credit facility is extended for longer duration. Thus, the discussion of the results emphasizes on the direction and the incremental effects of the covariates.

Predictably, the effect of income is positive and statistically significant in almost all specifications implying that higher income levels increase the WTP likelihood. For instance, a 1% increase in household's monthly income increases its WTP probability by about 12.4% (5.05%) and 3.86% (3.13%) respectively for upfront (6-month) and 12-month (24-month) subsidy-embedded credit options/scenarios. This demonstrates that the effect of income on WTP declines with subsidy-embedded credit duration extensions with the effect reducing sharply between upfront and 6-month and reducing further but only marginally in 12-month and 24-month for the aspirational ICS while reducing monotonically for the popular affordable ICS from 11% to 4.73% then to 1.7% in upfront (6-month) and 12-month credit regimes before rising only to 4.66% in the 24-month credit regime. This shows that directly increasing income does not necessarily induce a proportionate rise in WTP beyond 6 months.

Also, we observe an additional member of a household to contribute to a surge in the WTP probability of ICS by nearly 5.91% (6.08%) for 12-month (24-month) in the aspiration ICS case but has no statistically significant effect in its upfront and 6-month credit regime as well as in all four subsidy-embedded credit scenarios of the affordable ICS. This suggests that household size has a positive and increasing incremental effect (if any) on WTP with greater subsidy-embedded credit duration extensions for the aspirational ICS but for the popular affordable ICS, household size exerts no systematic effect on the WTP probability. Therefore, it could be asserted that household size has a limited effect on WTP for ICS and where it does, the effect is positive and increasing.

Having access to national grid electricity is also associated with a rise in the WTP probability of aspirational ICS by nearly 13.4 (15.6) and 16.4 (14.3) percentage points respectively for upfront (6-month) and 12-month (24-month) and 11.0 (12.2) and 16.4 (15.8) percentage points respectively for upfront (6-month) and 12-month (24-month) for the affordable ICS. This suggests that for both ICS, access to national grid electricity has an initial increasing positive incremental effect on WTP with greater subsidy-embedded credit duration extensions which peaks at 12-month and thereafter declines. Thus, the favourable effect of having access to national grid electricity on WTP for ICS rises over time until 12 months. Recall that access/connection to grid electricity was employed as a proxy for household's preference for modern energy as source of lighting – this is the motivation for including the variable in the regression analysis. Thus, the positive association between access to the grid and WTP demonstrates that household's preference for modern energy such as electricity also enhances its WTP for an "improved" version of biomass cookstove relative to the 'traditional' version". In other words, households that prefer modern energy such as electricity for lighting would also prefer modern cookstove such as ICS for cooking relative to traditional cookstove. This consequently enhances the underlying WTP for ICS.

In respect of household cooking solution characteristics, we observe that the average partial effects of both availability and affordability of firewood do not have systematic effect on households' WTP probability for either ICS regardless of the subsidy-credit combinations offered. In contrast, the safety of existing primary cookstove (i.e., 3-stove/open fire) and its cooking convenience are accompanied by a lower WTP probability for ICS. For instance, for households presented with the aspirational ICS, safety of their existing primary cookstove is associated with a lower WTP probability of approximately 8.54 and 11.3 (10.9) percentage points respectively for those willing to pay for 6-month and 12-month (24-month) relative to their counterparts with unsafe primary cookstove while that of the affordable ICS is 12.1 and 17.0 (15.5) percentage points respectively for those willing to pay for 6-month and 12-month (24-month). Also, for those willing to pay for 12-month (24-month) for the aspirational ICS, greater cooking convenience decreases the probability of households' WTP by almost 9.03 (7.26) percentage points relative to their counterparts that enjoy less cooking convenience. Clearly, WTP probability is adversely affected by safety and convenience of cooking with 3-stone/open fire stoves in the presence of extended subsidy-embedded credit regime particularly 12-month and 24-month. These findings generally render contrasting evidence in relation to the technology acceptance model as discussed in the theoretical literature section.

Two out the three variables included to control for household's financial inclusion and credit opportunities unambiguously exert positive effect on households' WTP probability. In respect of those presented with the aspirational ICS, access to credit exert about 7.41, 5.64 and 7.40 percentage points higher for households willing to pay 6-month, 12-month and 24-month while for informal financial inclusion, nearly 8.97 (8.75) percentage points higher was established for households willing to pay 12-month (24-month). Similarly, for households presented with the affordable ICS, those willing to pay upfront (6-month) and 12-month (24-month) and have some form of informal financial inclusion witness almost 13.6 (16.3) and 15.1 (15.3) percentage points higher WTP probability. Overall, informal finance and access to credit exhibit positive but decreasing incremental effect on WTP for aspirational ICS as subsidy-embedded credit duration extends while for the popular affordable ICS, an oscillatory movement is observed for both finance/credit variables starting with an expansive effect.

In contrast, households with older heads have a lower WTP probability relative to households with younger heads, particularly for those presented with the aspirational ICS. This shows that older heads are less willing to pay for aspirations ICS relative to younger heads. Explicitly, an additional age reduces the WTP probability by about 21.1 (24.3) and 18.5 (20.5) percentage points for those willing to pay respectively at upfront (6-month) and 12-month (24-month) subsidy-embedded credit systems. Age therefore exhibits an initial increasing positive incremental effect on WTP with credit duration extensions between upfront and 6-month and then declines at 12-month before picking up marginally in 24-month.

None of the statuses of marriage had any statistically significant influence on the probability of a household responding “Yes” to the WTP questions on both ICS across the four specifications of subsidy-embedded credit payment. Also, gender, enterprise ownership and primary occupation have no systematic effect on households’ WTP probability for ICS given that the associated average partial effects are not statistically significant even at 10% in all specifications.

Robustness checks

As a measure of robustness of our main results, we implement another WTP estimation that mirrors the main empirical strategy with the only distinction being that the estimation is performed at the subsample levels as discussed under the Estimation Strategy section (i.e., section 4.3.3). The methodological procedures are therefore similar to those utilized for the full-sample estimations and thus we do not consider it productive to repeat them here and rather focus on reporting the estimated results. The results as reported in Tables 4.5 and 4.6 show that most of the covariates have the same qualitative effects on the WTP probability in almost all specifications. Importantly, the implied mean WTP are not only statistically significant in all specifications of both ICS types but also grow dynamically at rates that mimics those of the main empirical strategy. More importantly, it is observed that the implied mean WTP also exhibit a consistently upward trend. The only notable exception, perhaps, is that the implied regime mean WTP rises monotonically through to the 24-month regime rather than peaking in the 12-month regime and turning in the 24-month subsidy-embedded credit payment regime.

Table 4.5: Determinants of WTP for Aspirational wood ICS (Robustness Check)

Covariate	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	-0.0126***	-0.0179***	-0.00386**	-0.00574***
(Main slope)	(0.00213)	(0.00149)	(0.00172)	(0.00162)
Gender	0.00789	-0.346	0.336***	-0.678***
(1=Male)	(0.132)	(0.247)	(0.0446)	(0.0448)
Age	-0.211***	-0.108*	-0.000244	-0.139
(logs)	(0.0481)	(0.0577)	(0.0666)	(0.0984)
Marital Status	-0.129	0.0545	-0.221*	0.720***
(2=Never married)	(0.0882)	(0.132)	(0.128)	(0.0302)
Marital Status	0.0305	-0.116	0.149	-0.146
(3=Divorced/Separated)	(0.118)	(0.0932)	(0.290)	(0.194)
Household size	0.0163	0.0579**	0.0782*	0.0737
(log)	(0.0247)	(0.0295)	(0.0439)	(0.0594)
Monthly income	0.124***	0.0169***	0.0798***	0.0200***
(log)	(0.0145)	(0.00137)	(0.0181)	(0.00238)
Cookstove safety	-0.0489***	-0.0589***	-0.0733***	-0.0413***
(1=Safe)	(0.00375)	(0.00497)	(0.00653)	(0.00846)
Cooking convenience	-0.0168	0.116***	0.158***	0.0292
(1=Convenient)	(0.0274)	(0.0371)	(0.0510)	(0.0677)
Grid electricity access	0.134***	0.0628*	0.0693	-0.0486***
(1=Yes)	(0.0290)	(0.0371)	(0.0508)	(0.00598)
Access to credit	0.0196	0.0945**	0.0111	0.109
(1=Yes)	(0.0312)	(0.0412)	(0.0540)	(0.0696)
Informal finance	0.0897**	0.0850	0.118*	0.0689
(1=Yes)	(0.0378)	(0.0560)	(0.0656)	(0.0963)
Constant	0.323***	0.473***	0.1024**	0.1552**
(Intercept)	(0.0359)	(0.0685)	(0.0603)	(0.0637)
	PROBIT Statistics			

Observations	1,234	593	438	258
Pseudo R-squared	0.1173	0.0878	0.0784	0.0796
Prob > χ-squared	0.000	0.001	0.016	0.000
H-L (Prob)	0.5686	0.3303	0.1100	0.7771
	WTP Statistics			
Implied Mean WTP ($)	25.65**	26.43***	26.55*	27.04*
(Regime Level)	(17.45)	(5.22)	(13.14)	(16.22)
Mean WTP/Income	25.65/78.03	(26.43/6)/78.30	(26.55/12)/74.11=	(27.04/24)/73.28
(Monthly Level)	=32.9%	=5.6%	3.0%	=1.5%
Mean Bid/Income	16.67/78.03	2.87/78.30	1.48/74.11	0.76/73.28
(Monthly Level)	=21.2%	3.6=%	2.0=%	1.0=%

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4.6: Determinants of WTP for Affordable wood ICS (Robustness Check)

Covariate	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	-0.0219***	-0.0922***	-0.0560***	-0.227***
(Main slope)	(0.00272)	(0.0228)	(0.00652)	(0.0160)
Gender	0.214**	0.0582	0.00912	-0.711
(1=Male)	(0.104)	(0.184)	(0.227)	(2.395)
Age	-0.0918**	0.0341	-0.0135	-0.0795
(logs)	(0.0456)	(0.0429)	(0.0555)	(0.0595)
Marital Status	-0.196**	0.0193	0.382*	
(2=Never married)	(0.0902)	(0.152)	(0.216)	
Marital Status	0.251	-0.139	-0.315***	-0.279
(3=Divorced/Separated)	(0.168)	(0.111)	(0.0607)	(0.733)
Monthly income	0.110***	0.0663*	0.0390**	0.0324*
(log)	(0.0139)	(0.0112)	(0.0156)	(0.0183)
Cookstove safety	-0.0180	-0.112**	-0.183***	-0.0620***

(1=Safe)	(0.0355)	(0.0482)	(0.0700)	(0.00900)
Cooking convenience	0.0218	0.0569	0.0174	0.00160
(1=Convenient)	(0.0278)	(0.0383)	(0.0525)	(0.0617)
Grid electricity access	0.110***	0.0974**	0.132**	0.0759***
(1=Yes)	(0.0292)	(0.0395)	(0.0541)	(0.00689)
Access to credit	-0.0257	0.0401	-0.00901	0.0855
(1=Yes)	(0.0305)	(0.0407)	(0.0539)	(0.0633)
Informal finance	0.136***	0.161***	-0.00142	0.0512
(1=Yes)	(0.0354)	(0.0554)	(0.0712)	(0.0887)
Formal finance	0.0419	0.000347	0.111	-0.0555
(1=Yes)	(0.0360)	(0.0485)	(0.0723)	(0.0877)
Constant	0.325***	0.1171	0.8602***	3.5434***
(Intercept)	(0.063)	(0.0786)	(0.0669)	(0.628)

	PROBIT Statistics		
Observations	640	432	261
Pseudo R-squared	0.0881	0.0810	0.0947
Prob > χ-squared	0.000	0.0012	0.093
H-L (Prob)	0.5771	0.1461	0.2646

	WTP Statistics		
Implied Mean WTP ($)	15.98**	17.21***	17.10*
(Regime Level)	(7.23)	(4.94)	(9.66)
Mean WTP/Income	(15.98/6)/79.87	(17.21/12)/77.9	(17.10/24)/81.5
(Monthly Level)	=3%	7=2%	=1%
Mean Bid/Income	2.13/79.87	1.11/77.97	0.57/81.50
(Monthly Level)	=2.7%	=1.4%	=0.7%

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

4.5 Conclusions

Despite the well-documented benefits of clean cookstoves and fuels, there are still about 94% of the population lacking access to clean cooking equipment in Nigeria. In addition to its adverse climate and environmental effects, traditional biomass cookstoves further exposes households to various IAP-related diseases. Yet, there are several improved "biomass" cookstoves (ICS) and other innovative cookstoves around the globe that have significant fuel combustion, emissions and thermal efficiencies. Globally, the GACC is a notable agent with the objective of manufacturing and distributing clean cookstoves to households in developing countries especially those with incredibly high levels of clean cookstove deprivations such as Nigeria. In the sub-region of the continent specifically, the West African Clean Cooking Alliance is also poised to supply ICS to 80% of the population by 2030. In Nigeria, government established the Nigeria cookstove program in 2014 intended to promote the use of clean cooking solutions among households through market-based approach. In addition, there are many ongoing promotions of wood-based ICS use in the country by various non-governmental organizations (for example, Save80 and Envirofit). Given these vibrant supply mechanisms, the high percentage of the population still lacking access to clean cook solutions raises various concerns including demand side constraints and WTP.

This chapter therefore evaluates the extent to which subsidies and credit payments could be utilized concurrently to stimulate mass adoption of improved cooking technologies like the ICS. This is premised on the evidence that a considerably growing body of literature shows that pricing of technology-related commodities with desirable environmental properties[29] above marginal cost may result in inefficiently low adoption. This is particularly true when economic agents are generally poor, habitually short on cash, face persistent credit rigidities and/or are suffering from varied forms of chronic livelihood deprivations. In such instances, society may not achieve socially efficient level of adoption. Thus, to achieve some form of socially efficient level of adoption of ICS, some combinations of subsidies and credit payment regimes may be imperative.

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[29] Undoubtedly, ICS adoption is desirable from a public-policy perspective because of the adverse (favourable) external effects of 3-stone stoves/open fires (ICS) on deforestation and climate change.

To this end, the study relies on data gathered through a survey by the World Bank in 2018 from a representative sample of 3,668 households from the Northwest geopolitical zone of the country. The zone is generally poorer compared to the rest of the country with the least levels of economic development, access to electricity and other forms of modern energy solutions such as ICS. The overarching objective of the study is to examine how policy on subsidy and credit payment systems could influence the WTP of ICS. The study consequently targeted only households in the dataset without ICS or any clean cooking technology and for whom firewood is the primary cook fuel. The survey had utilized the CVM valuation approach to collect hypothetical responses on household's WTP for ICS at various randomized bid values. A critical component of the bid system which is of central relevance to the study were the embedded one-shot subsidy and credit payment facilities.

The results show that a combination of subsidy (one-off) and credit regimes can be used to successfully stimulate a large-scale uptake of ICS. Furthermore, a 12-month payment instalment appears to be the maximum effective credit duration. This is because the estimated mean WTP declines after the 12-month credit regime. Additionally, we observe that income, household size, access to grid electricity, access to credit and informal financial inclusion are critical to interventions aimed at triggering WTP towards ICS. Quite surprisingly, firewood affordability and availability are scarcely related to the probability of a household willing to pay for ICS but in the extremely few instances where they do, they tend to increase household's WTP probability towards ICS. Other covariates such as marital status, cooking frequency, formal financial inclusion and primary occupation are not statistically significant in almost all specifications. It is also worth-emphasizing that our main results are robust to variation in sample compositions and WTP computation technique.

The most obvious policy action relates to the use of some subsidy and credit regime combinations to stimulate an initial public largescale uptake by government which is likely to be a win-win policy. Obviously, it is imperative that policy is well communicated and targeted to maximize the overall gains of these two WTP incentives and to create the necessary stepping foundations for future ICS markets. Additional details of these policy implications are comprehensively discussed in chapter 5. However, the study is not without some limitations. Foremost, as typical of many

CVM procedures, quite a lot of biases were found in the responses of many households, especially, those that declared “Yes” to the WTP bids that were larger than their income and yet did not have access to credit (this was discussed in detail in 4.4.1). It is not precisely clear the extent to which the World Bank attempted to address these biases prior to data collection. Even though, some actions have been taken by the study to address these biases during data analysis, it is important that the results and the eventual conclusions are understood within this context. Secondly, the survey as conducted by the World Bank did not collect data on households’ behaviour in the presence of no subsidies. Consequently, comparing a case of “no subsidy” with that of “subsidy” was simply impossible to allow for causal inferences. While alternative methods and procedures were adopted to address both issues, they acted as major limitations on the extent of innovations the study could perform. Thirdly, the time value of money was not considered by World Bank in the survey process. As a result, the study could not evaluate the extent to which the credit regimes offered to the households reflect in real term as compared to the upfront option or even the full market price of the ICS. While one can demonstrate the time value of the underlying credit once an appropriate discount rate is obtained, this is still regarded as a source of weakness of the survey process because it does not allow the for a direct evaluation of the underlying WTP in present value terms. Although these limitations are discussed in detail in the chapter 5 of the thesis with suggestions for future studies, they are highlighted here so that the findings/conclusions of this chapter are properly contextualized.

III. THE EPILOGUE

CHAPTER FIVE

5 Conclusions and Policy recommendations

5.1 Concluding the Thesis

In many developing countries the proportion of households without access to modern energy remains considerably large despite global efforts to achieving universal access to affordable and sustainable modern energy by 2030 as enshrined in the SDG 7. Nigeria's current level of access to both electricity and clean cooking solution does not signal potential achievement of many of the targets indicated in this SDG by the endline year. In this thesis, we examined various aspects of household's modern energy deprivation in Nigeria with focus on its Northwest zone, the most populous and yet least developed geopolitical zone which also inhabits the largest share of the country's population with no access to electricity and clean cooking technologies. Incidentally, Nigeria is also the largest economy as well as the biggest oil exporter and the largest natural gas reserves in Africa and yet saddled with enormous energy sector challenges particularly with respect to modern energy supply to households. These make the sample area critical for a study of this nature.

The thesis commenced its analytical chapters by focusing on evaluating the effect of the country's current level of access to electricity on the profits of households' non-farm enterprises as a potential pathway of improving households net income and possibly reducing the persistently high poverty rates of the country (see chapter 2). Specifically, it examined the causal impact of access to electricity on the profit (net income) of household's non-farm enterprise with special attention on the impact beyond connections to the national grid. This approach places emphasis on the intensity of access to electricity rather than access/connection itself. With this focus, our sample is categorized into at least two treatment groups and one control group. This eventually translated the analysis into a multiple treatment evaluation rather the traditional binary approach to treatment/impact evaluation. We utilized the GPS, an extension of the conventional PSM frequently applied to binary treatments, to match treated enterprises with comparable enterprises in the control group. Applying the IPTW to a reduced-from normalized profit model the evidence established based on the attributes of electricity access among users is quite remarkable and compelling. Specifically, the evidence demonstrates that the impact of access to electricity on profitability increases with steady improvement in the attributes of electrification. It was further demonstrated that the approach adopted by the study stands in sharps contrast to the binary approach which either underestimates the positive impact of access to electricity or annihilates the impact altogether.

In these ways, our approach, in addition to its contextual novelty and an improvement over the binary approach, it also creates more optimism about electrification investments towards livelihood improvement contrary to the near pessimism commonly created by the binary approach. These results are further subjected to quantile analysis to identify which enterprises tend to gain more from access to electricity. We find that without evaluating the QTE it was reasonable, based on the ATE/ATT/POM alone, to simply conclude that access to electricity has a uniform causal impact on profit. However, the QTE demonstrates that lower decile firms suffer while median and upper decile firms benefit from access to electricity. Here too, the gains increase with usage/attribute intensity. Thus, the QTE rejects the assertion that the benefits of electricity – a key socio-economic infrastructural intervention – are distributed favourably towards the vulnerable households' non-farm.

The thesis was further concerned about the nexus between modern cooking solutions and households' health outcome (see chapter 3). It was noted that even though Nigerian households also suffer from various cooking energy/stove deprivations, rather than evaluating the effects of the deprivations on health outcomes directly, the study focused on the attributes of modern cooking solutions due to the additional information they reveal about energy deprivations compared to the cook fuel and/or stove itself. Thus, similar to analytical chapter 1, we go beyond access to focus on the attributes of modern cooking solution which include stove safety, efficiency, cooking convenience and exposure as well as fuel availability and affordability.

As a result of data limitations, we included only two health outcomes – total health expenditure (per capita) and incidence of cough. The Heckman and probit models are applied for the estimation of the various nexuses. Expectedly, stove safety and cooking exposure tend to improve both health outcomes while only households in the positive limits of fuel availability, cooking convenience and cooking efficiency tend to experience improved health outcomes. Ultimately, improvements in household's overall access to modern cooking solution, on the basis of its attributes, is also associated with reduction in both cough incidence and total health expenditure (per capita). Consequently, it could be effectively concluded that, in general, higher tiers of most attributes of access to modern cooking solutions are associated with improved health outcomes. Thus, a move towards clean cookstoves such as LPG/natural gas stoves and electric stoves while ensuring households attain higher attribute tiers could be expected to generate significant improvement in household's overall health.

Even though, we did not seek to compare our results with the conventional binary approach in the literature which focuses simply on whether the underlying fuel for a cooking technology is clean or otherwise, it is also imperative to state that our main results are robust to the conventional binary approach. However, by focusing on attribute information the thesis further demonstrated the usefulness in isolating the independent effects of the various features of households' cooking solutions. This certainly uncovers important evidence hitherto concealed by the binary-dominated literature. Henceforth, analysis of the effects of access to modern cooking solutions on disease burden and other health outcomes could be bolstered by emphasizing not only on the cook fuel and the underlying cookstove but also on the distinctive features of the entire cooking process or solution. This would invariably improve public understanding on the broader scope of access to modern cooking solution and further assist policy on the specific aspects of modern solution that needs to be tackled in the quest to achieve SDG 7.1 and related SDG 3.

Thus, a major concluding remark relates to the amount of novel evidence revealed by focusing on the attributes of modern cooking solution. In the process, the study has revealed the attributes that could serve as critical catalyst in improving two major health outcomes. This presents vital lessons for policies intended to improve household's health outcomes resulting from cooking. Obviously, this important evidence could not have been learnt if the attribute dimension of the evidence had not been evaluated.

Finally, we overtly investigated potential pathways to alleviate households' modern energy deprivations. Unfortunately, the data contained enough information only capable of focusing on that of modern cooking energy deprivation by estimating the amount of money households are willing to offer in exchange for ICS. Thus, we evaluated the effectiveness of one-off subsidy, credit regimes in stimulating households' WTP for ICS in the last analytical chapter (i.e., chapter 4). The results show that allowing households to pay for the ICS over time does not only increase the mean WTP significantly but also make them willing to pay even more than the subsidized price if only there is an initial subsidy that reduces the market price by at least 34%. In all subsidy-credit scenarios, the underlying mean WTP values are higher than the effective price of subsidized ICS. This indicates that both WTP incentives (i.e., subsidy and credit facilities) when combined in ways suggested are not likely to harm future pricing when ICS are eventually circulated through pure market mechanism. Furthermore, a 12-month payment instalment appears to be the maximum effective credit duration. This is because the estimated mean WTP declines after the 12-month credit regime. For an effective targeting, we also highlight relatively richer households, those with larger household size and having access to grid electricity, cash credit, financial inclusion as important starting points for any initial public ICS circulation intervention.

5.2 Policy implications

The most obvious policy action emanating from the thesis is that modern energy projects/programmes – particularly, electricity and LPG – must go beyond connection and access. In respect of electricity and household's enterprises, we argue that electrification can indeed be used as an effective poverty reduction pathway given that some actual incremental gains accrue to household's incomes in the form of increased profit to their non-farm enterprises as electricity usage and attribute intensify. Hence, government should commit not only to extending the distribution lines of grid electricity but must also ensure electricity intensification. In the study, the aspects of electricity intensification that proved to require urgent policy attention are electricity availability and reliability. This is because an overwhelming majority – about 72% – of enterprises were trapped in lower tiers of electricity access as a result of attaining lower tiers in these two attributes. Explicitly, out of the possible 24 hours of daily available electricity, nearly 90% have not had more than 10 hours of electricity. Similarly, there are about 95% of the enterprises that have had only up to 5 hours of the 12 hours available during the night. These few and inadequate hours are also interrupted further by periodic irregular outages up to about 84 interruptions in a typical month. Indeed, there is no enterprise in the sample that has had electricity available for the entire 24 hours in a day. Altogether, these acted to impede the extent to which enterprises appropriate electricity access to productive uses. This invariably and ultimately limited the extent to which access to electricity exerted favourable causal effects on the profits of these firms. Needless to say, Tier 1 electricity-using enterprises were unsurprisingly cut off from the gains associated with electrification due to the woefully inadequate supply of electricity accessed by these enterprises and the enormous power interruptions they suffered.

Similarly, in progressing beyond access to modern cooking solution, we further recommend that as far as respiratory health and healthcare spending are concerned, the aspects of modern cooking that require the most urgent policy attention are the safety of cookstove and cooking exposure as each unambiguously improves both health outcomes consistently. Perhaps, the ultimate long-term aim of policy could be to make LPG/natural gas cookstove and electric cookstove or at least, ICS the primary cookstove of the greater majority of households. This is because the safety and smoke emissions (exposure levels) of these cookstoves are often superior and guaranteed relative to traditionally manufactured cookstoves. Until then however and as long as traditional biomass cookstoves remain the dominant cookstove, policy could be used to improve upon safety. This could be achieved by setting and possibly enforcing essential safety standards to guide the manufacturing and use of traditional biomass cookstoves. Policy could also, in a spirit similar to moral suasion, appeal to households to set up spacious and well-ventilated kitchens to minimize the extent of exposure and for their own health and safety. Again, policy must provide standardized guidelines in respect of kitchen space area and ventilation features so that households could factor them in the setup of kitchen spaces to maximize overall gains.

Nigeria, being the biggest oil exporter with considerable oil reserves and has the largest natural gas reserves in Africa is also strategically positioned to leverage its resource endowments which also include hydro, thermal and wind among others to improve upon the availability and affordability of electricity and LPG and even natural gas to meet household modern energy needs both for entrepreneurial activities and cooking. The country must consider exploiting this avenue as a critical catalyst to achieving major targets of SDGs 3, 7 while also reducing the extent of household's energy deprivations.

Moreover, the limited causal evidence in the ATT estimations further suggests that electricity may indeed be only necessary but not sufficient to the profitability of non-farm enterprises of households. The study therefore recommends that, in moving beyond connections, electrification programs in deprived and poorer areas such as those in the resemblance of the Northwest zone are also supported with other key socio-economic infrastructure as well as conducive business climate to complement the contribution of access to electricity.

Finally, given that ICS are desirable from the perspective of public policy, the most obvious policy action is for government to undertake the initial large-scale uptake. This could be done with a distribution strategy that combines a one-off subsidy of no less than 34% of the market price of the ICS with a credit regime not exceeding 12 months. However, an important caveat necessary to ensure that these initial uptake incentives do not jeopardize future distribution through a pure market mechanism is to communicate clearly to households that a one-time subsidy-credit offer today is, by no means, an entitlement tomorrow. An effective communication of this message could go a long way to safeguard future self-sustaining markets. In addition, an initial public distribution could be bolstered further with a carefully designed and effectively implemented targeting framework that focuses on household's characteristics that increase the probability of declaring "Yes" to WTP. In the study, covariates empirically demonstrated to contribute positively to the WTP inclination which can easily be targeted include income, access to grid electricity and finance. Thus, household's whose average monthly income exceeds the full market price of the ICS and has access to grid electricity and zero credit constraint could be targeted in the initial distribution by government. Recall that access/connection to grid electricity was employed as a proxy for household's preference for modern energy as source of lighting – this is the motivation for including the variable in the regression analysis. Thus, the positive association between access to the grid and WTP demonstrates that household's preference for modern energy such as electricity also enhances its WTP for an "improved" version of biomass cookstove relative to the 'traditional' version". In other words, households that prefer modern energy such as electricity for lighting would also prefer modern/improved cookstove such as ICS for cooking relative to traditional cookstove. This consequently enhances the underlying WTP for ICS. This justifies the need to target such households in any initial public distribution schemes.

5.3 Implications for Literature

Foremost, the conclusions emanating from the thesis implies that the empirical search for potential causal effect of access to electricity in particular, and any form of intervention, program, policy *inter alia*, must endeavour to examine its effectiveness along the salient distributions of the outcome of interest. As it became palpable in our estimations, it would have been easily concluded that access to electricity, whether based on connection, actual usage or attributes, had uniform and sometimes ambiguous causal impact on the profits of the enterprises if attention had not been paid to the dynamics along the profit distribution. Thus, from a methodological perspective, it is imperative that distributional effects are also examined when evaluating the efficacy of interventions, programs, policies among others.

The thesis has further demonstrated the urgent need for radical paradigm shift of emphasis away from access to modern energy towards the underlying attributes. Hitherto, bulk of the literature have focused merely on the headcount of households that have access to clean fuel or economic agents connected to the grid in scoping access to modern cooking energy and/or evaluating the impact thereof. Notable exceptions have also only focused on one attribute at a time. While these notable exceptions are also a commendable progress to the literature, they still fail to recognize that access to modern cooking solution and electricity goes beyond a single attribute. Henceforth, evaluation of access to modern cooking solution and the impact of electrification on firms or other economic agents such as communities, households, public sectors etc. should account for most, even if not all, of the policy-relevant attributes of access to modern cooking solution and electricity to improve the understanding of the scope of access to modern energy.

“The thesis, particularly in chapter 4 has also revealed an important aspect of the use of the CVM in generating WTP. However, until correcting for the extensive hypothetical bias in the responses of households, the coefficients of the randomized bids (i.e., price of the ICS) were positive which in inconsistent with the negative sign predicted by basic theory of demand. This is quite irrational in the given context of subsidy and credit facilities. Thus, in general, the study has provided further support for the use of the CVM to placing economic values on environmentally-friendly technology in particular and for that matter any other commodities. It is however incumbent on the researcher to deal with all observed and potential biases associated with the CVM so as to derive estimates that carry considerable accuracy, precision and stability capable of guiding policy.

5.4 Limitations of the thesis and Further Research

A major limitation relates to the lack of data on key variables such as input and output prices as well as other important control covariates. Consequently, our results must be interpreted within this context of missing key variables that make up an optimal profit function as well as other important control covariates. Similarly, there was limited amount of data on the use of electricity provided by the various technologies. As previously highlighted, there are various technology carriers by which access to electricity could be achieved by enterprises besides connection to the national grid (see section 2.1.2). For instance, the use of electric generators is a common avenue utilized by many households' enterprises to have access to back-up electricity in Nigeria. Elsewhere, enterprises also depend on local micro-grids and other off-grid technologies such as solar PV mini-grids, standalone systems and solar home systems (SHS) to meet their electricity needs. The study however had to concentrate exclusively on enterprises that use electricity from the national grid due to the limited data on alternative technology carriers from World Bank's dataset. This presents a compelling line of further research as sufficient data on the alternative technologies become available. Nonetheless, since the national grid continues to be the primary source of electricity as well as the most vibrant and commonly used technology carrier, the findings of the study remain largely relevant and insightful.

Another major limitation of the thesis relates to paucity of information about enterprise's behaviour on the use of electricity. For instance, there was no information on the extent to which electricity-using enterprises channel electricity into core business or production activities. The study could only infer the possible limited application of electricity in the core business or production activities on the basis of the empirical evidences obtained from the various estimations. Furthermore, at the level of grid electricity connection, there are 34% of enterprises that are connected to the grid but are not using the service. These enterprises are understood to may have previously used electricity in some form but have completely stopped using electricity in their current activities. The precise incentives or otherwise underpinning this behaviour is however not clear in the data. To some appreciable degree, this limited the extent to which the study could provide sufficient micro-foundations in support of some of the major findings. Thus, further studies that explore these aspects would be useful in giving additional clarity.

Even though the chapter on the health-cooking nexus was principally concerned with access to modern cooking solutions and its underlying attributes, it is acknowledged that most basic health theories nonetheless often require that some direct health covariates are included in our empirical health models as additional explicit control covariates. Additionally, both health outcomes could be driven by several other factors such as health status of the households, the cost of health services, health insurance, public health financing etc. However, the World Bank MTF Global survey from which the study draws data does not have such health covariates. Also, the cough variable utilized was an outcome of self-reporting and not a result of any medical laboratory test even though, cough could also be due to other causes as it is common to have them in situations where one is not even suffering from indoor air pollution or related problems. Similarly, household’s health expenditure that was captured during the survey is simply self-declared and not guided by any concrete evidential records or supporting documents/receipts. In this way, both health outcome variables suffer from the subjectivity biases of the respondents. Thus, the results must be appreciated within such a context. These limitations are admitted as a potential weakness of the study which provides a compelling consideration in future research. Furthermore, a key limitation of the exposure variable and general framework is that it does not capture how clean the fuel and combustion is, while fuel availability, on the other hand, misses the time costs associated with procuring the household fuel. Even though, there are adaptations from the World Bank dataset to incorporate the clean nature of the cooking fuel into attributes such as safety of primary cook, stove efficiency, fuel availability and fuel affordability, it is acknowledged that future research in which all attributes integrate the clean nature of the cooking fuel, particularly, could generate further precision in the underlying nexus. Notwithstanding, if nothing at all, the current study has given very important insights on the extent to which some salient attributes of modern cooking solutions could contribute separately or jointly to improving some health outcomes.

Another way to effectively evaluate the usefulness of subsidies in driving WTP for ICS is to compare a case of "no subsidy" with that of "subsidy". Such an approach typifies an impact evaluation similar to those deployed in the first analytical chapter. However, the survey as conducted by the World Bank did not collect data on households' behaviour in the presence of no subsidies. Consequently, comparing a case of "no subsidy" with that of "subsidy" was simply impossible. Thus, the study could only investigate what was available by utilizing other suitable methodologies. While the thesis eventually offered great insight and understanding on the potential gains that can accrue to society if subsidy is combined with credit payment facilities, further studies that explore "no subsidy" versus "subsidy" scenarios could help provide additional precision.

Also, quite a lot of biases were found in the responses of many households, especially, those that declared "Yes" to the WTP questions. Notably, as highlighted at the Results and Discussion section (section 4.4.1), there are more than 20% of households that declared "Yes" to randomized WTP bids which were larger than their income with the difference sometimes as large as 30-40%. Incidentally, these households did not also have access to any form of credit. It was thus unclear how these households intended to finance the acquisition of the ICS in a real-world situation. Secondly, we observe that more than 73% of households are either unemployed or retired. Even though, retirees and unemployed could rely on past savings to meet current and future expenditure including the acquisition of ICS, the evidence that the samples were overwhelmingly dominated by economically-inactive heads create suspicion around WTP as against ability to pay (ATP) especially as nearly 70% face considerable credit constraints. While the study has dealt with these biases, they acted as major limitations to the extent of innovations the study could perform. This is another aspect further studies could endeavour to circumvent to ensure even greater innovation. Additionally, the time value of money was not considered by World Bank in the survey process. As a result, the study is unable to evaluate the extent to which the credit regimes offered to the households reflect in real term as compared to the upfront option or even the full market price of the ICS. While one can demonstrate the time value of the underlying credit once an appropriate discount rate is obtained, this is still regarded as a source of weakness to the survey process because it does not allow for the evaluation of the underlying WTP in present value terms. Nonetheless, the empirical strategies and the associated robustness checks implemented by the study give considerable credence to the evidence provided by the study on the potential benefits a country stands to gain, in the form of increased ICS adoption, by combining subsidy with some credit payment regimes.

There is no doubt that using the attribute information is a superior way of understanding access to both electricity and modern cooking solution. In spite of this innovative contribution by the thesis, by relying on observational cross-sectional data, the only available data on Nigeria, the present study could only provide evidence at just a point in time (i.e., 2018). Thus, it would have been methodologically remarkable if over-time cross sectional (pooled/panel) data were available. This would invariably help account for unobservable heterogeneity across time and between households/enterprises belonging to different tiers of access to modern energy. This presents another interesting area of further interrogation which in turn could potentially enhance the empirical and methodological robustness of the evidence offered by the thesis.

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APPENDICES

Appendix A

A1: Classification of Profit

Profit category	Freq.	Percent
Subnormal Profit	377	35.67
Normal Profit	56	5.30
Supernormal Profit	624	59.04
Total	**1,057**	**100**

A2: Classification of Enterprise Age

Enterprise Age category	Freq.	Percent
<=1 year	107	10.13
Less than 10 years	611	57.86
Between 11-20 years	249	23.58
Older than 21 years	89	8.43
Total	**1,056**	**100**

A3: Classification of Number of employees

Labour force category	Freq.	Percent
Less than 5 employees	1,032	97.63
At least 5 employees	25	2.37
Total	**1,057**	**100**

A4: Classification of Enterprise ownership by gender

Gender	Freq.	Percent
Male	864	81.74
Female	193	18.26
Total	**1,057**	**100**

A5: Classification of Enterprise ownership by age

Age category	Freq.	Percent
15-35 years	543	51.37
36-40 years	180	17.03
41-54 years	218	20.62
55 years & above	116	10.98
Total	**1, 057**	**100**

A6: Classification of Enterprise ownership by finances

Financial Characteristics	Yes	No	Total
Formal Bank account	255 (24.15)	801 (75.85)	**1,056 (100)**
Informal Savings group	228 (21.59)	828 (78.41)	**1,056 (100)**
Credit access	251 (23.77)	805 (76.23)	**1,056 (100)**

Appendix B[30]

Appendix B1: Multinomial Probit regression (Connections and Actual Usage)

Regressors/ Covariates	Connected but not using Model	Connected and using Model
Enterprise Age	-0.00251	-0.0112
	(0.00683)	(0.00998)
Number of employees	-0.0161	0.0148
	(0.0473)	(0.0538)
Operating hours day	-0.0130	0.0602**
	(0.0182)	(0.0237)
Operating hours night	0.0274	0.125***
	(0.0290)	(0.0340)
Enterprise type: Cottage	0.412*	0.278
	(0.218)	(0.314)
Enterprise type: Shop/Trading	0.420***	0.552***
	(0.158)	(0.202)
Enterprise type: Services	1.103***	1.618***
	(0.235)	(0.276)
Enterprise type: Other	0.960***	0.269
	(0.347)	(0.468)
Enterprise Registration: Yes	0.725	1.539
	(0.949)	(0.962)
Gender: Male	0.370**	-0.383*
	(0.165)	(0.200)
Access to Credit: Yes	-0.269*	0.226
	(0.144)	(0.187)

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[30] Appendix B reports summaries of the predicted probabilities for each treatment level conditional on each treatment level.

A quick glance of Appendix B1 through to B8 shows that most of the predicted probabilities are not sufficiently close to either 0 or 1; otherwise, the parameters may not be identifiable (Khan and Tamer, 2010; Busso et al., 2013).

Formal Financial Service: Yes	1.147***	1.550***
	(0.144)	(0.180)
Informal Financial Service: Yes	0.244*	-0.0165
	(0.143)	(0.203)
Constant	-1.130***	-2.466***
	(0.224)	(0.298)
Observations	1,055	1,055

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix B2: Predicted probabilities of each treatment conditional on all treatments

Predicted conditional probabilities	Mean	Std. Dev.	Min	Max
Treatment = Unconnected	0.6316944	0.152347	0.101255	0.8469921
phat0: Unconnected	0.6316944	0.152347	0.101255	0.8469921
phat1: Connected but not using	0.2991329	0.1129769	0.1092539	0.7505802
phat2: Connected and using	0.0691727	0.0810823	0.0054543	0.5515795
Treatment = Connected but not using				
phat0: Unconnected	.4915637	.2158413	.0541694	.8136826
phat1: Connected but not using	.3900701	.1452541	.1096295	.8361771
phat2: Connected and using	.1183662	.1285436	.0058556	.6550356
Treatment = Connected and using				
phat0: Unconnected	.3705761	.2245187	.0128321	.8129589
phat1: Connected but not using	.3699809	.15409	.1202234	.8366445
phat2: Connected and using	.2594429	.1997852	.0163759	.8336758

Appendix B3: Multinomial Probit regression (Connections and Actual Usage)

Covariates	Tier 1 Model	Tier 2 Model	Tier 3 Model
Enterprise Age	-0.0118	-0.0141	-0.00343
	(0.0140)	(0.0138)	(0.0146)
Number of employees	0.0621	0.0133	-0.115
	(0.0550)	(0.0618)	(0.139)
Operating hours day	0.0114	0.0903***	0.116***
	(0.0305)	(0.0317)	(0.0351)
Operating hours night	0.132***	0.0937**	0.0949**
	(0.0414)	(0.0424)	(0.0450)
Enterprise type: Cottage	-0.0267	0.363	-0.225
	(0.455)	(0.385)	(0.574)
Enterprise type: Shop/Trading	0.197	0.265	0.551**
	(0.279)	(0.267)	(0.276)
Enterprise type: Services	0.879***	1.035***	1.208***
	(0.340)	(0.330)	(0.357)
Enterprise type: Other	-0.317	-0.150	-0.111
	(0.623)	(0.579)	(0.655)
Enterprise Registration: Yes	0.467	1.493*	0.805
	(1.026)	(0.774)	(0.985)
Gender: Male	-0.302	-0.670***	-0.687**
	(0.280)	(0.249)	(0.282)
Access to Credit: Yes	0.143	0.386	0.397
	(0.269)	(0.240)	(0.262)
Formal Financial Service: Yes	0.995***	0.613***	1.316***
	(0.232)	(0.231)	(0.246)
Informal Financial Service: Yes	-0.0996	0.140	-0.662**
	(0.273)	(0.252)	(0.330)
Observations	1,055	1,055	1,055

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix B4: Predicted probabilities of each treatment conditional on all treatments

Predicted conditional probabilities	Mean	Std. Dev.	Min	Max
Treatment = Tier 0				
phat0: Tier 0	.912651	.1033177	.3774022	.9946193
phat1: Tier 1	.0272078	.0319753	.0028044	.3645308
phat2: Tier 2	.0320097	.0395485	.001317	.4794369
phat3: Tier 3	.0281315	.0488734	.0000101	.3609535
Treatment = Tier 1				
phat0: Tier 0	.7836969	.167574	.328523	.9815232
phat1: Tier 1	.0753142	.0667292	.0095336	.2823823
phat2: Tier 2	.0717513	.0734925	.0059732	.3793198
phat3: Tier 3	.0692376	.0662067	.0012676	.2273302
Treatment = Tier 2				
phat0: Tier 0	.7588909	.2057023	.2277558	.982286
phat1: Tier 1	.0546334	.0525975	.007481	.3240851
phat2: Tier 2	.1004813	.1068761	.0092792	.5307517
phat3: Tier 3	.0859945	.10516	.0003928	.4473295
Treatment = Tier 3				
phat0: Tier 0	.6842184	.2231958	.1741017	.9686392
phat1: Tier 1	.0691578	.0507923	.0100378	.2633445
phat2: Tier 2	.0899076	.067376	.0128669	.3774102
phat3: Tier 3	.1567162	.1422219	.0042722	.5502034

Appendix C[31]: Conditional densities for evaluating the overlapping assumption

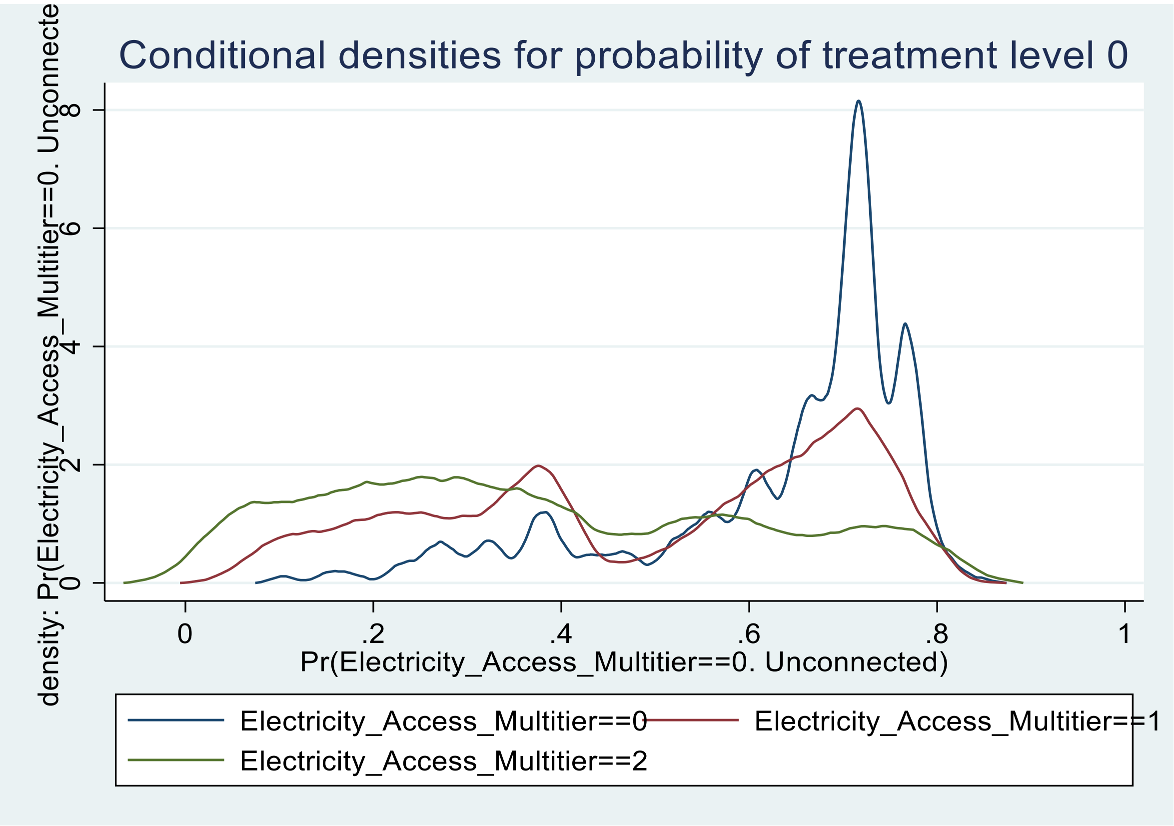

Figure C1: Kernel conditional densities for probability of the unconnected enterprises

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[31] Following Busso, DiNardo, and McCrary (2013), we have utilized overlap plots to illustrate areas of common support based on the predicted probabilities. Generally, the graphs demonstrated sufficient overlap and present only limited evidence that there is any mass of observations with predicted probabilities close to either 0 or 1.

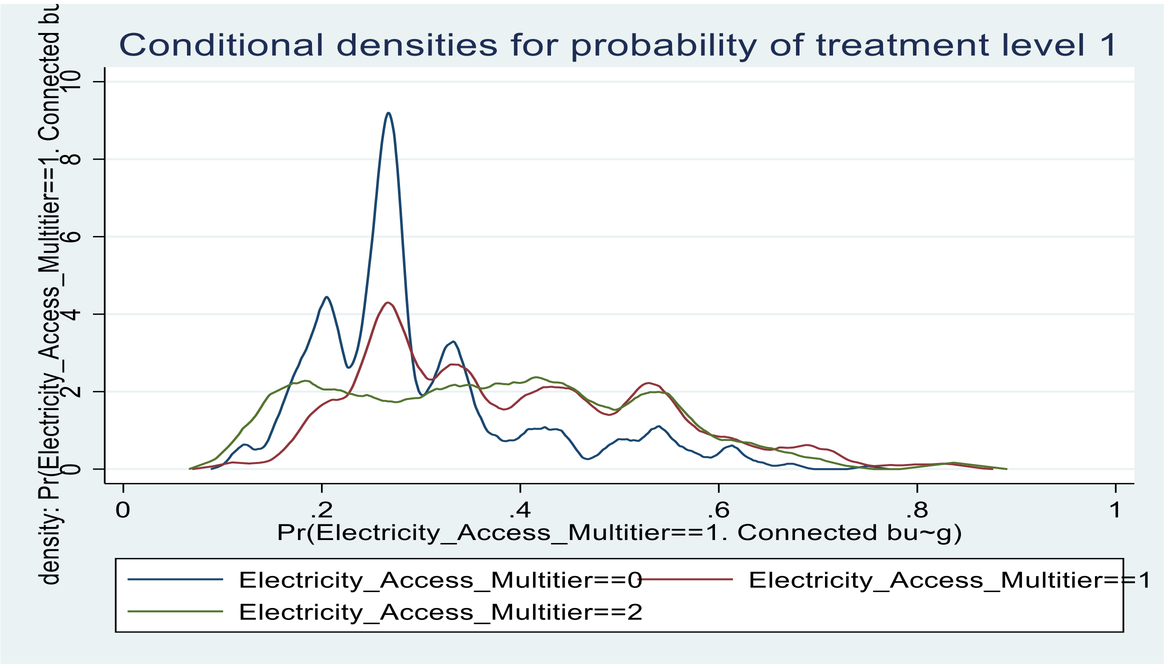

Figure C2: Kernel conditional densities for probability of the connected but not using

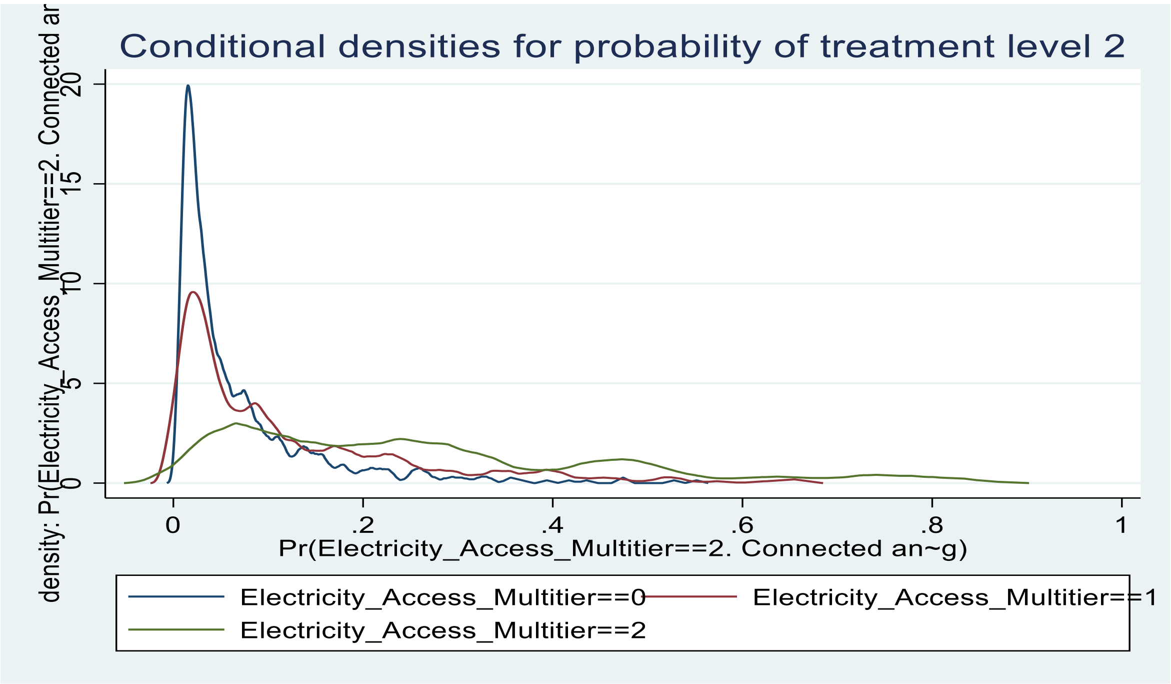

Figure C3: Kernel conditional densities for probability of the connected and using

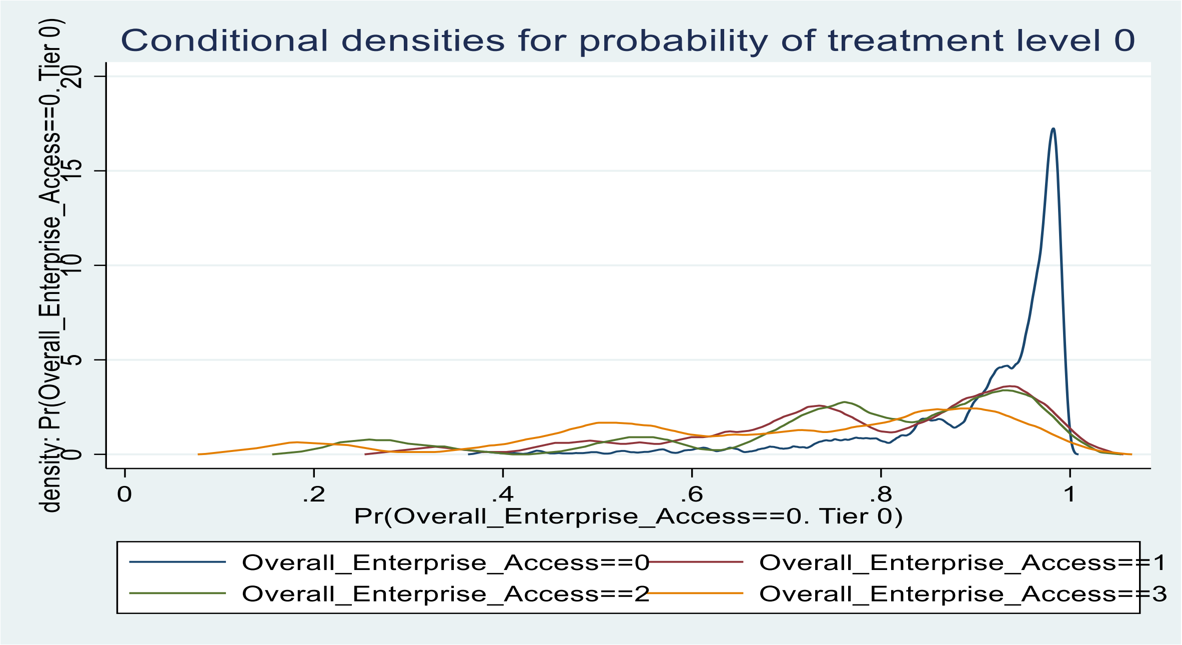

Figure C4: Kernel conditional densities for probability of Tier 0

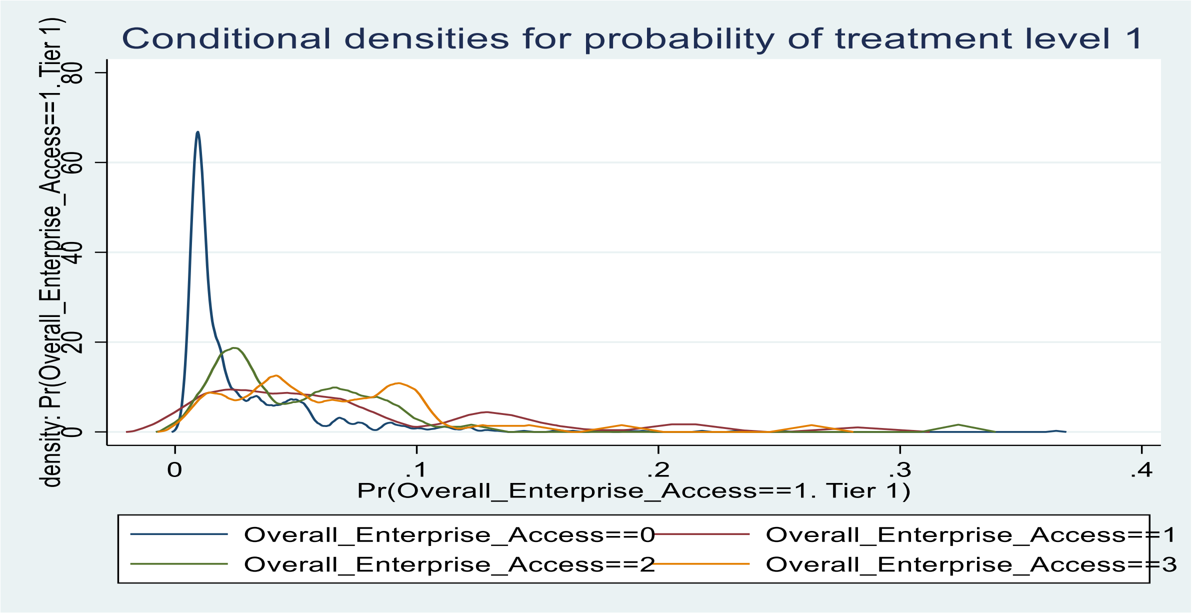

Figure C5: Kernel conditional densities for probability of Tier 1

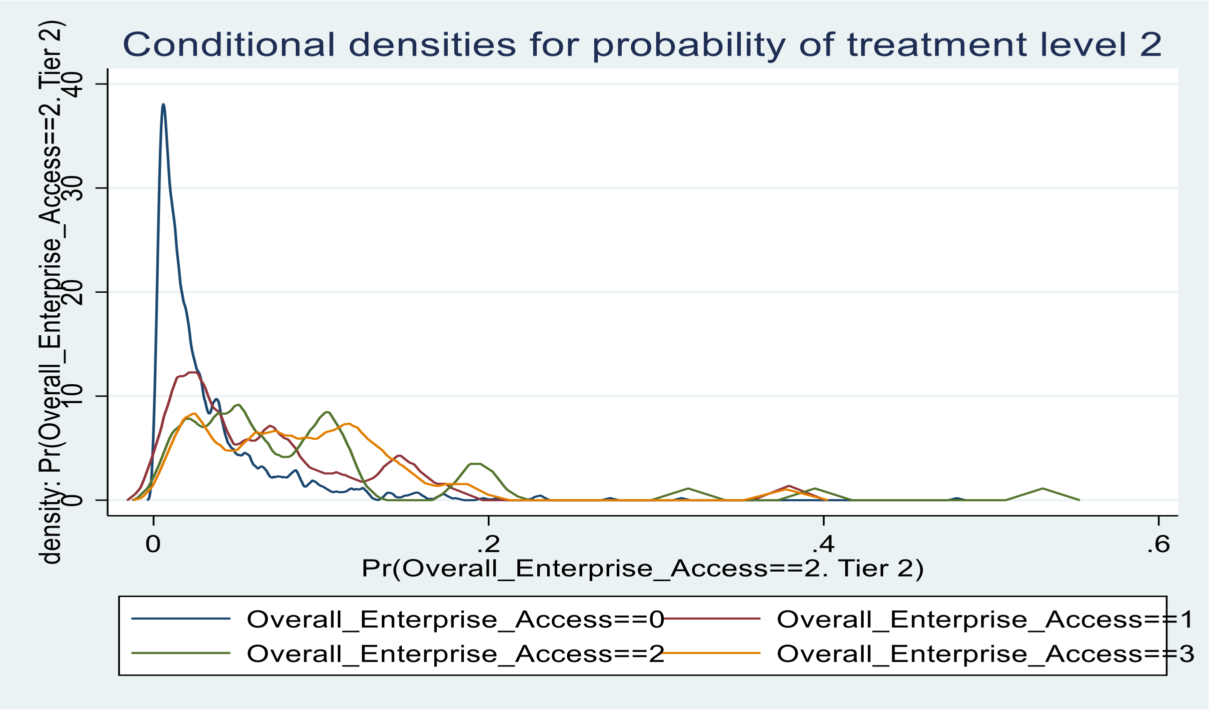

Figure C6: Kernel conditional densities for probability of Tier 2

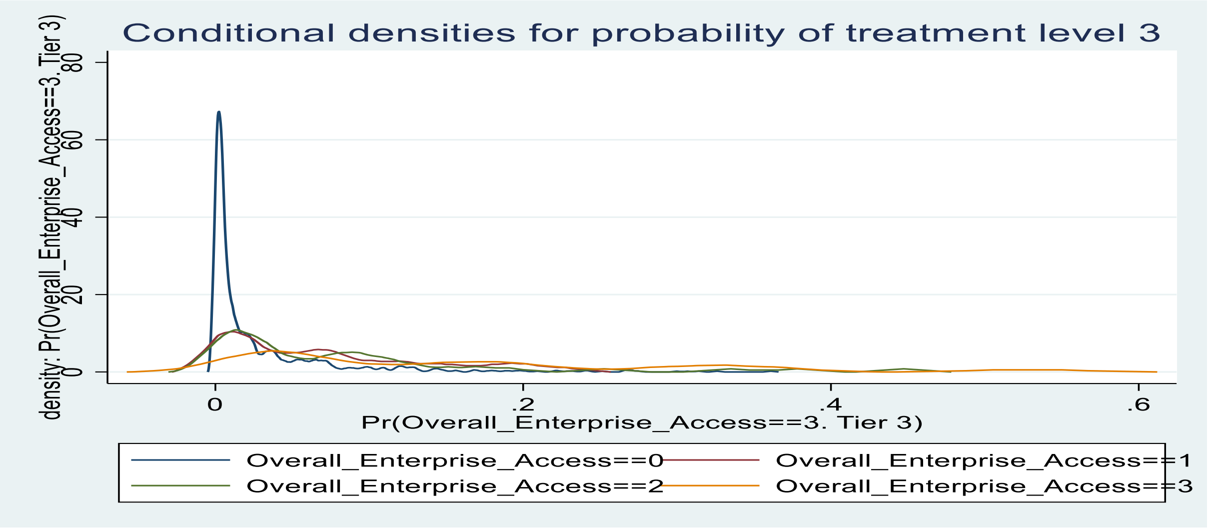

Figure C7: Kernel conditional densities for probability of Tier 3

Appendix D: Categorical entrepreneurial skill sets of non-farm enterprise owners.

Skill set	Frequency	Percentage
Highest education		
None	11	1.04
Non-Formal	625	59.12
Basic	186	17.60
Secondary	189	17.88
Tertiary	46	4.36
Total	**1,057**	**100.00**
Marital status		
Married	996	94.14
Never Married	10	0.95
Divorced	3	0.28
Separated	2	0.19
Widowed	47	4.44
Total	**1,057**	**100.00**

Appendix E: Full regression results of health-cooking nexus

Appendix E1: The effects of cooking efficiency on household's health outcomes (Full results)

Cooking Efficiency Attribute	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Tier 2	0.0931**	0.0561*	0.0584**	0.0514	-0.00054	0.0702**	0.282***
	(0.0367)	(0.0319)	(0.0269)	(0.0342)	(0.0359)	(0.0348)	(0.092)
Tier 3	0.0879*	0.0473**	0.0609	-0.0393	0.122**	0.0904*	0.210
	(0.0534)	(0.0053)	(0.0385)	(0.0465)	(0.0520)	(0.0514)	(0.443)
Tier 4	0.0470	-0.00906	0.0162	-0.0275	0.0354	0.0454	0.122
	(0.211)	(0.0177)	(0.0146)	(0.0185)	(0.208)	(0.203)	(0.559)
Tier 5	0.0769	-0.0263	0.0374	-0.0862	0.160	0.0719	-0.145***
	(0.0582)	(0.0498)	(0.0408)	(0.490)	(0.536)	(0.0546)	(0.047)
Gender	0.111	-0.195***	-0.278**	0.122	0.171*	0.0172	0.285
(Male)	(0.103)	(0.0294)	(0.116)	(0.0928)	(0.103)	(0.109)	(0.294)
Age	-0.0509	-0.0516*	0.0697***	-0.0491	-0.291***	0.409***	-0.0363
(logs)	(0.0357)	(0.0299)	(0.0249)	(0.0302)	(0.0318)	(0.0334)	(0.0913)
Education	-0.120	0.369***	0.0231	0.0582	0.0141	0.0605	-0.486
(Non-formal)	(0.147)	(0.140)	(0.109)	(0.118)	(0.139)	(0.123)	(0.423)
Education	-0.107	0.319**	0.0367	0.0683	-0.0353	0.0607	-0.492
(Basic)	(0.149)	(0.141)	(0.110)	(0.119)	(0.141)	(0.125)	(0.427)
Education	-0.150	0.378***	0.00295	0.0295	0.0146	0.0631	-0.211
(Secondary)	(0.148)	(0.141)	(0.109)	(0.119)	(0.140)	(0.125)	(0.425)
Education	-0.128	0.340**	0.0345	0.0597	0.0465	0.0547	-0.0243
(Tertiary)	(0.151)	(0.143)	(0.111)	(0.122)	(0.143)	(0.128)	(0.432)
Marital Status	-0.161**	-0.303***	0.0208	0.0535	0.117	0.351***	0.240
(Never married)	(0.0649)	(0.0702)	(0.0465)	(0.0599)	(0.0750)	(0.0408)	(0.194)
Marital Status	0.124	-0.381***	-0.00466	0.00110	0.102	0.110	0.231
(Div./Wid./Sep)	(0.0946)	(0.104)	(0.0565)	(0.0839)	(0.0957)	(0.0796)	(0.255)

Occupation	-0.0396	0.0242	-0.0206	-0.00699	0.0147	0.00845	0.0681
(Self-employed)	(0.0268)	(0.0228)	(0.0193)	(0.0241)	(0.0261)	(0.0254)	(0.0686)
Occupation	-0.0920*	0.0439	-0.00287	-0.0183	0.0748	0.00903	0.235*
(Unpaid)	(0.0505)	(0.0416)	(0.0365)	(0.0442)	(0.0495)	(0.0485)	(0.139)
Cooking Freq.	0.00631	-0.0683	-0.158**	0.0259	-0.0386	-0.0967	-0.164
(Sometimes)	(0.0865)	(0.0815)	(0.0805)	(0.0677)	(0.0781)	(0.0893)	(0.237)
Cooking Freq.	0.0130	0.124	-0.187**	-0.0310	-0.161**	-0.109	-0.523**
(Never)	(0.0879)	(0.0819)	(0.0848)	(0.0678)	(0.0788)	(0.0887)	(0.242)
HH Exp. per cap	0.0196*	-0.00234	0.00851	-0.0127	-0.049***	-0.0107	0.529***
(logs)	(0.0100)	(0.00821)	(0.00660)	(0.0091)	(0.0101)	(0.00940)	(0.0294)
Owns enterprise	0.0588	-0.0370	-0.0136	0.0253	0.0224	0.0626*	-0.0620
(Yes)	(0.0369)	(0.0327)	(0.0248)	(0.0358)	(0.0372)	(0.0360)	(0.0984)
Drinking Water	0.0440*	-0.0194	-0.00351	-0.0120	-0.0497**	0.0199	-0.0540
(Borehole)	(0.0232)	(0.0192)	(0.0165)	(0.0208)	(0.0227)	(0.0221)	(0.0610)
Drinking Water	-0.0313	-0.0216	-0.0237	-0.0119	0.0115	0.0217	-0.0799
(Unprotected)	(0.0264)	(0.0225)	(0.0185)	(0.0231)	(0.0257)	(0.0249)	(0.0702)
Drinking Water	0.0341	-0.00250	-0.00789	0.0442	-0.0272	-0.00887	0.161
(Mineralized)	(0.0590)	(0.0488)	(0.0393)	(0.0522)	(0.0590)	(0.0590)	(0.151)
Dwelling Type	-0.0502**	0.0369**	-0.051***	0.0161	0.0195	-0.00713	-0.0375
(Multi-occupants)	(0.0209)	(0.0179)	(0.0150)	(0.0186)	(0.0204)	(0.0198)	(0.0550)
Dwelling Type	-0.0191	0.0444*	-0.065***	-0.0511*	-0.0612*	0.0491	0.0290
(Multi-houses)	(0.0317)	(0.0262)	(0.0205)	(0.0290)	(0.0313)	(0.0302)	(0.0828)
Num. of Rooms	-0.00830*	0.000825	0.000177	0.008**	-0.00386	0.00323	-0.0340***
	(0.00424)	(0.00346)	(0.00247)	(0.0037)	(0.00395)	(0.00378)	(0.00985)
Roof Type	-0.148***	0.0167	0.0305	-0.0895*	-0.0907	-0.0760	-0.0833
(BSCB, Others)	(0.0540)	(0.0456)	(0.0413)	(0.0503)	(0.0571)	(0.0565)	(0.170)
Roof Type	0.0622**	-0.0457**	0.0347*	0.0123	0.00231	0.0202	0.136*
(Roofing sheet)	(0.0282)	(0.0229)	(0.0186)	(0.0249)	(0.0280)	(0.0271)	(0.0772)
Toilet	0.0214	0.0667**	-0.0159	-0.0685*	-0.0857**	-0.0299	0.129
(Yes)	(0.0434)	(0.0331)	(0.0297)	(0.0365)	(0.0421)	(0.0404)	(0.115)

Financial Service	-0.0568**	0.0544**	-0.0360**	0.0172	-0.0359	-0.00956	0.0995
(Formal=Yes)	(0.0278)	(0.0225)	(0.0183)	(0.0254)	(0.0276)	(0.0269)	(0.0718)
Financial Service	0.0414	-0.0170	-0.000281	-0.0109	-0.0213	0.0404	-0.00460
(Informal=Yes)	(0.0261)	(0.0226)	(0.0184)	(0.0241)	(0.0259)	(0.0247)	(0.0672)
Access to Credit	-0.00828	0.00479	0.00155	-0.0408*	-0.0176	-0.065**	-0.0810
(Yes)	(0.0231)	(0.0193)	(0.0162)	(0.0210)	(0.0229)	(0.0218)	(0.0614)
Household size	0.0128***	-0.00271	0.000364	-0.059**		-0.035**	0.427***
	(0.00282)	(0.00223)	(0.00186)	(0.0029)		(0.00307)	(0.0710)
Pseudo R^2	0.0295	0.0402	0.0825	0.1932	0.0605	0.0952	
H-L (Prob)	0.8493	0.2381	0.4405	0.2826	0.2311	0.7240	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							49.45 (0.000)
Log likelihood							-4368.63
Rho (ρ)							0.6147***
							(0.0481)
Sigma (σ)							0.1540***
							(0.0253)
Lambda (λ)							0.0946**
							(0.0675)
Selected N							2,074
N	2,693	2,693	2,693	2,693	2,693	2,693	2,693

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix E2: The effects of affordability on household's health outcomes (Full results)

Affordability Attribute	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Tier 2	-0.083	0.0422	-0.0257	-0.0277	-0.00710	-0.0461	-0.258***
	(0.306)	(0.254)	(0.0204)	(0.0287)	(0.0283)	(0.0294)	(0.0795)
Tier 3	-0.00374	0.0182	0.0145	-0.0843	0.0156	-0.0201	0.0853
	(0.0600)	(0.0496)	(0.0410)	(0.500)	(0.0492)	(0.0566)	(0.364)
Tier 4	0.0416	-0.00869	0.0160	0.0154	0.0437	-0.00807	-0.285***
	(0.0335)	(0.0284)	(0.0231)	(0.0305)	(0.0301)	(0.0317)	(0.0864)
Tier 5	-0.949***	-0.183*	-0.0855	-0.093***	-0.103	-0.138	-0.339**
	(0.142)	(0.108)	(0.0765)	(0.0107)	(0.109)	(0.127)	(0.153)
Gender	0.0934	-0.192***	-0.273**	0.0819	0.168*	0.0250	0.284
(Male)	(0.103)	(0.0294)	(0.116)	(0.0929)	(0.0862)	(0.111)	(0.294)
Age	-0.0642*	-0.0449	0.0630**	-0.0416	-0.0346	0.415***	-0.0755
(logs)	(0.0355)	(0.0296)	(0.0246)	(0.0299)	(0.0328)	(0.0332)	(0.0913)
Education	-0.0872	0.354**	0.0313	0.0625	0.130	0.0804	-0.461
(Non-formal)	(0.158)	(0.145)	(0.0993)	(0.118)	(0.120)	(0.126)	(0.424)
Education	-0.0664	0.306**	0.0548	0.0815	0.126	0.0882	-0.459
(Basic)	(0.159)	(0.147)	(0.101)	(0.120)	(0.122)	(0.128)	(0.428)
Education	-0.116	0.366**	0.0154	0.0420	0.112	0.0846	-0.210
(Secondary)	(0.159)	(0.146)	(0.0996)	(0.119)	(0.121)	(0.127)	(0.426)
Education	-0.0857	0.320**	0.0479	0.0450	0.106	0.0722	-0.0113
(Tertiary)	(0.161)	(0.148)	(0.101)	(0.122)	(0.124)	(0.130)	(0.432)
Marital Status	-0.147**	-0.329***	0.0342	0.0502	0.129**	0.362***	0.227
(Never married)	(0.0661)	(0.0694)	(0.0484)	(0.0594)	(0.0576)	(0.0378)	(0.194)
Marital Status	0.132	-0.400***	-0.00963	-0.00869	-0.0104	0.115	0.215
(Div./Wid./Sep)	(0.0943)	(0.104)	(0.0539)	(0.0863)	(0.0826)	(0.0810)	(0.255)
Occupation	-0.0216	0.0216	-0.0144	0.00472	0.00592	0.0124	0.0734
(Self-employed)	(0.0265)	(0.0225)	(0.0189)	(0.0237)	(0.0233)	(0.0251)	(0.0685)

Occupation	-0.0792	0.0502	-0.00877	-0.00858	0.0109	0.00118	0.185
(Unpaid)	(0.0500)	(0.0411)	(0.0356)	(0.0437)	(0.0425)	(0.0485)	(0.139)
Cooking Freq.	0.0185	-0.0733	-0.142*	0.0738	-0.0349	-0.109	-0.148
(Sometimes)	(0.0852)	(0.0818)	(0.0787)	(0.0673)	(0.0620)	(0.0888)	(0.236)
Cooking Freq.	0.00723	0.134*	-0.179**	0.00463	-0.0932	-0.112	-0.530**
(Never)	(0.0857)	(0.0816)	(0.0820)	(0.0664)	(0.0619)	(0.0869)	(0.237)
HH Exp. per cap	0.0168*	-0.000681	0.00794	-0.0113	-0.00434	-0.0126	0.537***
(logs)	(0.00993)	(0.00822)	(0.00648)	(0.0089)	(0.0088)	(0.00931)	(0.0291)
Owns enterprise	0.0764**	-0.0474	-0.00701	0.0338	0.0636*	0.0527	-0.0904
(Yes)	(0.0369)	(0.0329)	(0.0251)	(0.0356)	(0.0355)	(0.0362)	(0.0988)
Drinking Water	0.0278	-0.0101	-0.00647	-0.0199	-0.0270	0.0112	-0.0782
(Borehole)	(0.0229)	(0.0191)	(0.0163)	(0.0208)	(0.0207)	(0.0220)	(0.0609)
Drinking Water	-0.0462*	-0.0120	-0.0270	-0.0191	0.0124	0.0202	-0.0939
(Unprotected)	(0.0261)	(0.0222)	(0.0181)	(0.0231)	(0.0230)	(0.0248)	(0.0699)
Drinking Water	0.0221	-0.00885	0.00414	0.0245	0.0112	0.0110	0.163
(Mineralized)	(0.0580)	(0.0490)	(0.0413)	(0.0521)	(0.0530)	(0.0578)	(0.149)
Dwelling Type	-0.0618***	0.0391**	-0.057***	0.00450	-0.0174	-0.0144	-0.0235
(Multi-occupants)	(0.0207)	(0.0177)	(0.0147)	(0.0183)	(0.0187)	(0.0197)	(0.0550)
Dwelling Type	-0.0325	0.0544**	-0.073***	-0.069**	-0.072**	0.0398	0.0643
(Multi-houses)	(0.0315)	(0.0256)	(0.0200)	(0.0290)	(0.0284)	(0.0303)	(0.0832)
Num. of Rooms	-0.00905**	0.000802	-0.000642	0.007**	0.009**	0.00221	-0.0300***
	(0.00420)	(0.00339)	(0.00252)	(0.0036)	(0.0043)	(0.00377)	(0.00984)
Roof Type	-0.121**	0.00282	0.0398	-0.0771	-0.0800*	-0.0782	-0.0775
(BSCB, Others)	(0.0566)	(0.0469)	(0.0426)	(0.0506)	(0.0480)	(0.0565)	(0.170)
Roof Type	0.0572**	-0.0438*	0.0317*	0.00973	0.00816	0.0135	0.123
(Roofing sheet)	(0.0282)	(0.0227)	(0.0184)	(0.0248)	(0.0252)	(0.0270)	(0.0775)
Toilet	0.0220	0.0623*	-0.0132	-0.0673*	-0.084**	-0.0307	0.114
(Yes)	(0.0436)	(0.0333)	(0.0295)	(0.0365)	(0.0366)	(0.0405)	(0.115)
Financial Service	-0.0370	0.0454**	-0.0252	0.0404	0.0291	0.00424	0.0937
(Formal=Yes)	(0.0275)	(0.0223)	(0.0182)	(0.0248)	(0.0254)	(0.0266)	(0.0715)

Financial Service	0.0324	-0.0106	-0.000817	-0.0214	-0.00777	0.0366	-0.00608
(Informal=Yes)	(0.0258)	(0.0221)	(0.0180)	(0.0240)	(0.0239)	(0.0245)	(0.0669)
Access to Credit	-0.00136	0.00165	0.00170	-0.0333	-0.0180	-0.065**	-0.0823
(Yes)	(0.0229)	(0.0192)	(0.0160)	(0.0210)	(0.0208)	(0.0218)	(0.0613)
Household size	0.0125***	-0.00299	-0.000597	-0.061**	-0.064**	-0.036**	0.336***
	(0.00278)	(0.00220)	(0.00186)	(0.0029)	(0.0044)	(0.00308)	(0.0712)
Pseudo R^2	0.0350	0.0447	0.0805	0.1996	0.2148	0.0949	
H-L (Prob)	0.4540	0.7196	0.4275	0.2827	0.3179	0.1810	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							49.96 (0.000)
Log likelihood							-4414.51
Rho (ρ)							0.6099 ***
							(0.0480)
Sigma (σ)							0.1562 ***
							(0.0253)
Lambda (λ)							0.0952***
							(0.0373)
Selected N							2,083
N	2,717	2,717	2,717	2,717	2,717	2,717	2,717

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix E3: The effects of fuel availability on household's health outcomes (Full results)

Fuel Availability Attribute	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Tier 2	0.0370	-0.0336	0.0223	0.0402	-0.00152	0.0421	0.113
	(0.0385)	(0.0336)	(0.0285)	(0.0353)	(0.0351)	(0.0367)	(0.0972)
Tier 3	0.0304	-0.0271	0.0363	-0.0359	-0.0262	0.0960*	0.220
	(0.0569)	(0.0491)	(0.0430)	(0.0503)	(0.0488)	(0.0536)	(0.152)
Tier 4	-0.0450*	0.0291	-0.0333*	-0.0273	0.000697	-0.00231	-0.143**
	(0.0242)	(0.0207)	(0.0176)	(0.0209)	(0.0210)	(0.0231)	(0.0624)
Tier 5	-0.113*	-0.144**	-0.00660	-0.116**	-0.0187	0.0323	-0.359**
	(0.0609)	(0.0533)	(0.0422)	(0.0500)	(0.0501)	(0.0569)	(0.155)
Gender	0.101	-0.193***	-0.291**	0.115	0.166**	0.00925	0.273
(Male)	(0.104)	(0.0300)	(0.117)	(0.0926)	(0.0845)	(0.109)	(0.294)
Age	-0.0513	-0.0506*	0.0664***	-0.0443	-0.0252	0.411***	-0.0505
(logs)	(0.0356)	(0.0296)	(0.0249)	(0.0301)	(0.0328)	(0.0332)	(0.0907)
Education	-0.0971	0.361**	0.0340	0.0592	0.139	0.0727	-0.413
(Non-formal)	(0.152)	(0.142)	(0.102)	(0.119)	(0.119)	(0.124)	(0.424)
Education	-0.0857	0.316**	0.0466	0.0659	0.124	0.0739	-0.414
(Basic)	(0.154)	(0.143)	(0.103)	(0.121)	(0.121)	(0.126)	(0.427)
Education	-0.133	0.374***	0.0114	0.0302	0.126	0.0734	-0.138
(Secondary)	(0.153)	(0.143)	(0.102)	(0.120)	(0.120)	(0.125)	(0.426)
Education	-0.104	0.334**	0.0450	0.0537	0.134	0.0634	0.0700
(Tertiary)	(0.156)	(0.145)	(0.104)	(0.123)	(0.123)	(0.128)	(0.432)
Marital Status	-0.144**	-0.313***	0.0187	0.0592	0.0926	0.357***	0.281
(Never married)	(0.0652)	(0.0692)	(0.0458)	(0.0598)	(0.0563)	(0.0387)	(0.190)
Marital Status	0.125	-0.384***	-0.0109	-0.00823	-0.00619	0.108	0.234
(Div./Wid./Sep)	(0.0950)	(0.105)	(0.0544)	(0.0844)	(0.0800)	(0.0808)	(0.254)
Occupation	-0.0389	0.0247	-0.0218	-0.00550	0.00251	0.0108	0.0632
(Self-employed)	(0.0266)	(0.0227)	(0.0193)	(0.0240)	(0.0233)	(0.0253)	(0.0682)

Occupation	-0.0948*	0.0452	-0.00536	-0.0150	0.00120	0.0133	0.240*
(Unpaid)	(0.0500)	(0.0410)	(0.0360)	(0.0441)	(0.0421)	(0.0481)	(0.138)
Cooking Freq.	0.0112	-0.0695	-0.148*	0.0325	-0.0371	-0.0907	-0.139
(Sometimes)	(0.0866)	(0.0811)	(0.0795)	(0.0673)	(0.0621)	(0.0893)	(0.237)
Cooking Freq.	0.0263	0.115	-0.176**	-0.0268	-0.0798	-0.0911	-0.515**
(Never)	(0.0882)	(0.0817)	(0.0840)	(0.0675)	(0.0625)	(0.0886)	(0.241)
HH Exp. per cap	0.0198**	-0.00172	0.00908	-0.0128	-0.00308	-0.0103	0.533***
(logs)	(0.00998)	(0.00821)	(0.00661)	(0.0089)	(0.00888)	(0.00939)	(0.0293)
Owns enterprise	0.0596	-0.0382	-0.0118	0.0287	0.0588*	0.0589	-0.0637
(Yes)	(0.0369)	(0.0326)	(0.0248)	(0.0356)	(0.0357)	(0.0360)	(0.0979)
Drinking Water	0.0445*	-0.0190	-0.00186	-0.0125	-0.0293	0.0203	-0.0435
(Borehole)	(0.0231)	(0.0192)	(0.0165)	(0.0208)	(0.0207)	(0.0221)	(0.0609)
Drinking Water	-0.0331	-0.0190	-0.0238	-0.0134	0.0136	0.0222	-0.0708
(Unprotected)	(0.0261)	(0.0222)	(0.0183)	(0.0230)	(0.0230)	(0.0247)	(0.0696)
Drinking Water	0.0406	0.00221	-0.00740	0.0474	0.0222	0.00157	0.246*
(Mineralized)	(0.0579)	(0.0471)	(0.0384)	(0.0513)	(0.0530)	(0.0575)	(0.147)
Dwelling Type	-0.0500**	0.0379**	-0.052***	0.0153	-5.14e-05	-0.00713	-0.0337
(Multi-occupants)	(0.0208)	(0.0177)	(0.0149)	(0.0184)	(0.0187)	(0.0197)	(0.0544)
Dwelling Type	-0.0225	0.0457*	-0.066***	-0.0540*	-0.0600**	0.0475	0.0217
(Multi-houses)	(0.0316)	(0.0260)	(0.0204)	(0.0289)	(0.0282)	(0.0301)	(0.0821)
Num. of Rooms	-0.00869**	0.000890	9.33e-05	0.008**		0.00274	-0.036***
	(0.00415)	(0.00340)	(0.00243)	(0.0037)		(0.00379)	(0.00975)
Roof Type	-0.140**	0.0115	0.0374	-0.0833*	-0.100**	-0.0751	-0.0608
(BSCB, Others)	(0.0545)	(0.0463)	(0.0426)	(0.0504)	(0.0477)	(0.0567)	(0.170)
Roof Type	0.0622**	-0.0450**	0.0340*	0.0129	0.00855	0.0205	0.133*
(Roofing sheet)	(0.0281)	(0.0227)	(0.0185)	(0.0249)	(0.0253)	(0.0271)	(0.0770)
Toilet	0.0218	0.0646*	-0.0160	-0.0670*	-0.0858**	-0.0292	0.121
(Yes)	(0.0435)	(0.0332)	(0.0297)	(0.0365)	(0.0364)	(0.0404)	(0.115)
Financial Service	-0.0642**	0.0592***	-0.0371**	0.0213	0.00964	-0.0171	0.110
(Formal=Yes)	(0.0274)	(0.0220)	(0.0179)	(0.0250)	(0.0253)	(0.0266)	(0.0709)

Financial Service	0.0421	-0.0125	0.00247	-0.0135	0.00717	0.0439*	0.00236
(Informal=Yes)	(0.0258)	(0.0223)	(0.0183)	(0.0239)	(0.0239)	(0.0245)	(0.0663)
Access to Credit	-0.00694	0.00186	0.000406	-0.0368*	-0.0191	-0.066**	-0.0918
(Yes)	(0.0230)	(0.0192)	(0.0161)	(0.0210)	(0.0206)	(0.0218)	(0.0611)
Household size	0.0126***	-0.00285	0.000357	-0.059**	-0.064***	-0.035**	0.294***
	(0.00280)	(0.00220)	(0.00184)	(0.0029)	(0.00437)	(0.00305)	(0.0706)
Pseudo R^2	0.0290	0.0417	0.0840	0.1936	0.2169	0.0934	
H-L (Prob)	0.9536	0.2986	0.9233	0.2755	0.3625	0.4530	
Prob > $\chi2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test ($\chi2$)							49.69 (0.000)
Prob. > $\chi2$							0.000
Log likelihood							-4408.67
Rho (ρ)							0.6076***
							(0.0481)
Sigma (σ)							0.1521***
							(0.0249)
Lambda (λ)							0.9242*
							(0.0507)
Selected N							2,093
N	2,719	2,719	2,719	2,719	2,719	2,719	2,719

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix E4: The effects of convenience on household's health outcomes (Full results)

Cooking convenience Attribute	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Tier 2	0.0850**	-0.077***	0.0497**	0.0239	0.0119	0.130***	0.184***
	(0.0381)	(0.0296)	(0.0240)	(0.0341)	(0.0342)	(0.0363)	(0.016)
Tier 3	0.0626*	-0.097***	0.0690***	-0.00374	-0.0264	0.130***	0.225**
	(0.0370)	(0.0291)	(0.0235)	(0.0335)	(0.0337)	(0.0354)	(0.113)
Tier 4	-0.0125	-0.0304	0.00625	-0.0220	-0.0285	0.110***	-0.177
	(0.0393)	(0.0305)	(0.0239)	(0.0358)	(0.0361)	(0.0380)	(0.120)
Tier 5	0.139**	-0.125***	0.0702*	0.0433	0.0253	0.198***	0.105
	(0.0557)	(0.0484)	(0.0396)	(0.0503)	(0.0492)	(0.0532)	(0.167)
Gender	0.132	-0.180***	-0.264**	0.174*	0.253***	-0.0184	-0.121
(Male)	(0.104)	(0.0346)	(0.119)	(0.0955)	(0.0812)	(0.107)	(0.336)
Age	-0.0469	-0.0424	0.0726***	-0.0616*	-0.0530	0.432***	-0.322***
(logs)	(0.0374)	(0.0308)	(0.0259)	(0.0319)	(0.0354)	(0.0349)	(0.105)
Education	-0.0537	0.334**	0.0127	0.0931	0.185	0.110	-1.118**
(Non-formal)	(0.164)	(0.155)	(0.119)	(0.121)	(0.115)	(0.132)	(0.491)
Education	-0.0357	0.292*	0.0263	0.104	0.181	0.113	-1.210**
(Basic)	(0.166)	(0.156)	(0.121)	(0.124)	(0.117)	(0.134)	(0.496)
Education	-0.0789	0.352**	-0.00890	0.0651	0.171	0.111	-0.929*
(Secondary)	(0.165)	(0.156)	(0.120)	(0.123)	(0.116)	(0.133)	(0.493)
Education	-0.0563	0.306*	0.0153	0.0655	0.168	0.0891	-0.727
(Tertiary)	(0.168)	(0.158)	(0.121)	(0.126)	(0.119)	(0.136)	(0.500)
Marital Status	-0.0992	-0.322***	0.0336	0.0812	0.114*	0.351***	0.326
(Never married)	(0.0744)	(0.0753)	(0.0530)	(0.0648)	(0.0618)	(0.0426)	(0.221)
Marital Status	0.110	-0.356***	0.00333	0.0277	0.0138	0.154**	-0.0605
(Div./Wid./Sep)	(0.0972)	(0.109)	(0.0583)	(0.0869)	(0.0820)	(0.0768)	(0.290)
Occupation	-0.0339	0.0263	-0.0127	0.00077	0.00533	0.0315	0.0608
(Self-employed)	(0.0279)	(0.0238)	(0.0199)	(0.0252)	(0.0247)	(0.0263)	(0.0804)

Occupation	-0.101*	0.0685	-0.0173	-0.0243	-0.0160	0.00465	0.229
(Unpaid)	(0.0547)	(0.0435)	(0.0392)	(0.0481)	(0.0460)	(0.0518)	(0.166)
Cooking Freq.	-0.0452	-0.0401	-0.0944	0.0136	-0.0985	-0.0175	0.0664
(Sometimes)	(0.0904)	(0.0856)	(0.0794)	(0.0719)	(0.0651)	(0.0895)	(0.270)
Cooking Freq.	-0.0149	0.121	-0.143*	-0.0171	-0.118*	-0.0168	-0.464*
(Never)	(0.0905)	(0.0852)	(0.0819)	(0.0702)	(0.0640)	(0.0880)	(0.269)
HH Exp. per cap	0.0155	0.00639	0.00822	-0.0160*	-0.00262	-0.020**	0.252***
(logs)	(0.0105)	(0.00859)	(0.00681)	(0.0096)	(0.00936)	(0.00982)	(0.0326)
Owns enterprise	0.0682*	-0.0441	-0.00326	0.0260	0.0772**	0.0625	-0.190
(Yes)	(0.0404)	(0.0355)	(0.0271)	(0.0395)	(0.0390)	(0.0395)	(0.120)
Drinking Water	0.0541**	-0.0211	0.00203	-0.0162	-0.0327	0.0181	-0.252***
(Borehole)	(0.0241)	(0.0199)	(0.0170)	(0.0218)	(0.0218)	(0.0230)	(0.0708)
Drinking Water	-0.0134	-0.0157	-0.0149	-0.00867	0.0180	0.0273	-0.135*
(Unprotected)	(0.0276)	(0.0230)	(0.0191)	(0.0244)	(0.0245)	(0.0260)	(0.0817)
Drinking Water	0.0316	-0.0127	0.00427	0.0262	0.0271	0.0117	0.0835
(Mineralized)	(0.0626)	(0.0522)	(0.0418)	(0.0544)	(0.0535)	(0.0600)	(0.176)
Dwelling Type	-0.0522**	0.0326*	-0.048***	0.00521	-0.0197	-0.0155	-0.0314
(Multi-occupants)	(0.0218)	(0.0182)	(0.0155)	(0.0194)	(0.0197)	(0.0205)	(0.0637)
Dwelling Type	-0.0257	0.0334	-0.067***	-0.0584*	-0.0632**	0.0507	0.0201
(Multi-houses)	(0.0338)	(0.0280)	(0.0216)	(0.0310)	(0.0302)	(0.0319)	(0.0988)
Num. of Rooms	-0.00289	0.000181	0.00113	0.013**	0.0110**	0.00405	-0.0214*
	(0.00425)	(0.00363)	(0.00258)	(0.0043)	(0.00483)	(0.00417)	(0.0119)
Roof Type	-0.103*	-0.0344	0.0510	-0.0603	-0.0793	-0.0286	0.151
(BSCB, Others)	(0.0614)	(0.0526)	(0.0477)	(0.0546)	(0.0515)	(0.0601)	(0.196)
Roof Type	0.0658**	-0.0482**	0.0273	0.0145	0.00207	0.0283	-0.00814
(Roofing sheet)	(0.0294)	(0.0233)	(0.0193)	(0.0261)	(0.0265)	(0.0281)	(0.0891)
Toilet	0.0449	0.0490	-0.0232	-0.0632	-0.101**	0.00105	0.146
(Yes)	(0.0457)	(0.0365)	(0.0314)	(0.0388)	(0.0395)	(0.0424)	(0.135)
Financial Service	-0.0431	0.0430*	-0.0257	0.0387	0.00882	0.0322	0.0793
(Formal=Yes)	(0.0284)	(0.0230)	(0.0190)	(0.0257)	(0.0265)	(0.0270)	(0.0826)

Financial Service	0.0581**	-0.0139	0.0110	-0.0253	-0.00197	0.0404	-0.204***
(Informal=Yes)	(0.0275)	(0.0236)	(0.0197)	(0.0258)	(0.0256)	(0.0259)	(0.0791)
Access to Credit	-0.00558	-0.00139	0.00492	-0.0439*	-0.0184	-0.084**	0.00403
(Yes)	(0.0244)	(0.0203)	(0.0170)	(0.0224)	(0.0220)	(0.0231)	(0.0725)
Household size	0.0115***	-0.00323	0.000389	-0.058**	-0.062***	-0.035**	0.235***
	(0.00291)	(0.00231)	(0.00191)	(0.0031)	(0.00468)	(0.00321)	(0.0803)
Pseudo R^2	0.0286	0.0446	0.0760	0.1899	0.2066	0.0968	
H-L (Prob)	0.9456	0.8579	0.4635	0.2786	0.3300	0.2018	
Prob > $\chi2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test ($\chi2$)							93.14 (0.000)
Log likelihood							-4010.29
Rho (ρ)							-0.9564***
							(0.0103)
Sigma (σ)							0.3578***
							(0.0280)
Lambda (λ)							-0.3422***
							(0.0368)
Selected N							1,916
N	2,479	2,479	2,479	2,479	2,479	2,479	2,479

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix E5: The effects of cook exposure on household's health outcomes (Full results)

Cooking exposure Attribute	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Tier 2	0.0570	-0.0659	0.0581	0.0500	-0.0399	0.124	-0.162***
	(0.0786)	(0.0607)	(0.0409)	(0.155)	(0.0317)	(0.0816)	(0.020)
Tier 3	-0.089***	-0.051**	-0.0523**	0.0556	-0.099**	0.0191	-0.177*
	(0.0149)	(0.0133)	(0.0237)	(0.0385)	(0.0387)	(0.0397)	(0.091)
Tier 4	-0.103***	-0.071***	-0.080***	-0.029***	-0.010**	-0.021***	-0.184*
	(0.0344)	(0.0268)	(0.0196)	(0.0032)	(0.0032)	(0.0033)	(0.094)
Tier 5	-0.103***	-0.102***	-0.094***	-0.038***	-0.021**	-0.0448**	-0.205*
	(0.0385)	(0.0306)	(0.0235)	(0.0035)	(0.0035)	(0.0174)	(0.105)
Gender	0.106	-0.184***	-0.306**	0.106	0.175**	0.0138	0.262
(Male)	(0.106)	(0.0351)	(0.123)	(0.0957)	(0.0867)	(0.110)	(0.302)
Age	-0.0517	-0.0455	0.0720***	-0.0426	-0.0340	0.406***	-0.0288
(logs)	(0.0356)	(0.0298)	(0.0248)	(0.0299)	(0.0327)	(0.0332)	(0.091)
Education	-0.115	0.371***	0.0270	0.0574	0.119	0.0687	-0.399
(Non-formal)	(0.144)	(0.135)	(0.108)	(0.119)	(0.119)	(0.126)	(0.424)
Education	-0.106	0.325**	0.0395	0.0673	0.111	0.0685	-0.388
(Basic)	(0.145)	(0.136)	(0.109)	(0.120)	(0.121)	(0.128)	(0.428)
Education	-0.146	0.380***	0.00846	0.0309	0.102	0.0685	-0.0881
(Secondary)	(0.145)	(0.135)	(0.108)	(0.120)	(0.120)	(0.127)	(0.426)
Education	-0.112	0.334**	0.0486	0.0390	0.110	0.0562	0.109
(Tertiary)	(0.147)	(0.138)	(0.110)	(0.123)	(0.123)	(0.130)	(0.432)
Marital Status	-0.120*	-0.345***	0.0293	0.0722	0.0801	0.354***	0.283
(Never married)	(0.0681)	(0.0697)	(0.0478)	(0.0613)	(0.0579)	(0.0399)	(0.192)
Marital Status	0.159*	-0.385***	-0.00384	-0.00095	0.0173	0.127	0.178
(Div./Wid./Sep)	(0.0947)	(0.104)	(0.0582)	(0.0854)	(0.0814)	(0.0781)	(0.259)
Occupation	-0.0364	0.0243	-0.0183	-0.00367	0.00439	0.0137	0.0774
(Self-employed)	(0.0266)	(0.0227)	(0.0191)	(0.0238)	(0.0232)	(0.0251)	(0.0680)

Occupation	-0.0923*	0.0445	0.00102	-0.0178	-0.00021	0.00666	0.219
(Unpaid)	(0.0502)	(0.0413)	(0.0367)	(0.0442)	(0.0422)	(0.0486)	(0.139)
Cooking Freq.	0.0300	-0.0897	-0.118	0.0321	-0.0315	-0.0846	-0.172
(Sometimes)	(0.0863)	(0.0810)	(0.0796)	(0.0697)	(0.0633)	(0.0908)	(0.238)
Cooking Freq.	0.0304	0.108	-0.159*	-0.0172	-0.0732	-0.0912	-0.610**
(Never)	(0.0880)	(0.0817)	(0.0832)	(0.0696)	(0.0637)	(0.0902)	(0.242)
HH Exp. per cap	0.0200**	-0.00341	0.00899	-0.0133	-0.00486	-0.0120	0.526***
(logs)	(0.00996)	(0.00826)	(0.00648)	(0.0089)	(0.00878)	(0.00934)	(0.0291)
Owns enterprise	0.0476	-0.0377	-0.0149	0.0280	0.0562	0.0493	-0.0799
(Yes)	(0.0370)	(0.0329)	(0.0247)	(0.0355)	(0.0358)	(0.0364)	(0.0988)
Drinking Water	0.0379*	-0.0129	-0.00403	-0.0143	-0.0242	0.0258	-0.00081
(Borehole)	(0.0230)	(0.0192)	(0.0164)	(0.0206)	(0.0205)	(0.0220)	(0.0607)
Drinking Water	-0.0394	-0.0131	-0.0241	-0.0148	0.0183	0.0222	-0.0777
(Unprotected)	(0.0262)	(0.0224)	(0.0183)	(0.0230)	(0.0230)	(0.0248)	(0.0700)
Drinking Water	0.0731	-0.0265	0.00863	0.0161	0.00322	0.0163	0.368**
(Mineralized)	(0.0569)	(0.0487)	(0.0398)	(0.0518)	(0.0516)	(0.0559)	(0.144)
Dwelling Type	-0.0494**	0.0340*	-0.051***	0.0106	-0.00679	-0.0140	-0.0314
(Multi-occupants)	(0.0208)	(0.0177)	(0.0148)	(0.0184)	(0.0187)	(0.0197)	(0.0546)
Dwelling Type	-0.0212	0.0464*	-0.065***	-0.069**	-0.064**	0.0411	0.0280
(Multi-houses)	(0.0316)	(0.0259)	(0.0203)	(0.0290)	(0.0282)	(0.0301)	(0.0824)
Num. of Rooms	-0.00925**	0.00163	-0.000125	0.007**	0.0102**	0.00344	-0.037***
	(0.00428)	(0.00353)	(0.00259)	(0.0035)	(0.00426)	(0.00382)	(0.00984)
Roof Type	-0.138**	0.0120	0.0285	-0.0918*	-0.0877*	-0.0680	-0.0850
(BSCB, Others)	(0.0546)	(0.0455)	(0.0405)	(0.0503)	(0.0475)	(0.0565)	(0.169)
Roof Type	0.0629**	-0.0465**	0.0351*	0.0116	0.00976	0.0235	0.148*
(Roofing sheet)	(0.0282)	(0.0228)	(0.0183)	(0.0248)	(0.0251)	(0.0270)	(0.0771)
Toilet	0.0222	0.0644*	-0.0151	-0.0649*	-0.087**	-0.0355	0.0928
(Yes)	(0.0434)	(0.0335)	(0.0298)	(0.0363)	(0.0362)	(0.0403)	(0.115)
Financial Service	-0.0409	0.0438**	-0.0289	0.0201	0.00967	0.00264	0.154**
(Formal=Yes)	(0.0272)	(0.0223)	(0.0182)	(0.0247)	(0.0250)	(0.0261)	(0.0702)

Financial Service	0.0391	-0.0113	0.00286	-0.0178	0.00211	0.0382	-0.0117
(Informal=Yes)	(0.0259)	(0.0223)	(0.0183)	(0.0241)	(0.0240)	(0.0245)	(0.0668)
Access to Credit	-0.00402	-0.00486	0.00631	-0.0327	-0.0195	-0.069**	-0.0773
(Yes)	(0.0231)	(0.0196)	(0.0164)	(0.0211)	(0.0208)	(0.0220)	(0.0614)
Household size	0.0129***	-0.00322	0.000531	-0.057**	-0.063**	-0.035**	0.266***
	(0.00280)	(0.00221)	(0.00184)	(0.0029)	(0.00431)	(0.00299)	(0.0715)
Pseudo R^2	0.0292	0.0444	0.0866	0.1916	0.2165	0.0942	
H-L (Prob)	0.8804	0.3722	0.2160	0.2989	0.3240	0.3370	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							53.52 (0.000)
Log likelihood							-4433.06
Rho (ρ)							0.6219***
							(0.0466)
Sigma (σ)							0.1576***
							(0.0251)
Lambda (λ)							0.0980*
							(0.0596)
Selected N							2,106
N	2,730	2,730	2,730	2,730	2,730	2,730	2,730

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix E6: The effects of stove safety on household's health outcomes (Full results)

Safety of primary stove Attribute	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Tier 2	-0.121	0.0669	-0.0452	-0.0685	-0.209**	0.0709	-0.248***
	(0.0899)	(0.0775)	(0.0646)	(0.0857)	(0.0850)	(0.0845)	(0.023)
Tier 3	-0.121**	-0.060***	-0.0335	-0.0760	0.0576	8.33e-05	0.307*
	(0.0591)	(0.0051)	(0.0427)	(0.0510)	(0.0569)	(0.0565)	(0.159)
Tier 4	-0.200***	-0.113***	-0.082***	-0.053**	-0.0601**	-0.069**	-0.401***
	(0.0290)	(0.0272)	(0.0234)	(0.0253)	(0.0285)	(0.0277)	(0.0760)
Tier 5	-0.152**	-0.167***	-0.0733*	-0.112**	-0.116**	-0.140***	-0.447***
	(0.0646)	(0.0570)	(0.0424)	(0.0542)	(0.0582)	(0.0613)	(0.165)
Gender	0.165*	-0.205***	-0.300**	0.125	0.158	-0.0499	0.224
(Male)	(0.0992)	(0.0248)	(0.124)	(0.0927)	(0.109)	(0.109)	(0.313)
Age	-0.0630*	-0.0541*	0.0674***	-0.0470	-0.301***	0.391***	-0.0344
(logs)	(0.0368)	(0.0307)	(0.0252)	(0.0309)	(0.0327)	(0.0349)	(0.0962)
Education	-0.0659	0.342**	0.0423	0.0641	0.0292	0.0865	-0.433
(Non-formal)	(0.152)	(0.144)	(0.0890)	(0.120)	(0.142)	(0.125)	(0.428)
Education	-0.0664	0.307**	0.0550	0.0744	-0.0282	0.0814	-0.462
(Basic)	(0.154)	(0.146)	(0.0904)	(0.122)	(0.143)	(0.127)	(0.432)
Education	-0.102	0.342**	0.0197	0.0595	0.0376	0.0876	-0.156
(Secondary)	(0.154)	(0.145)	(0.0894)	(0.121)	(0.143)	(0.126)	(0.430)
Education	-0.0777	0.301**	0.0477	0.0474	0.0541	0.0835	0.0632
(Tertiary)	(0.157)	(0.148)	(0.0917)	(0.125)	(0.146)	(0.130)	(0.438)
Marital Status	-0.158**	-0.340***	0.0241	-0.00454	0.0922	0.335***	0.165
(Never married)	(0.0704)	(0.0756)	(0.0489)	(0.0646)	(0.0828)	(0.0477)	(0.215)
Marital Status	0.190*	-0.415***	0.0281	-0.0310	0.0950	0.133	0.300
(Div./Wid./Sep)	(0.0985)	(0.110)	(0.0668)	(0.0877)	(0.102)	(0.0835)	(0.274)
Occupation	-0.0410	0.0236	-0.0201	-0.0157	0.0129	0.00136	0.101
(Self-employed)	(0.0280)	(0.0237)	(0.0199)	(0.0253)	(0.0276)	(0.0269)	(0.0740)

Occupation	-0.0981*	0.0391	-0.0208	-0.0316	0.0806	-0.0139	0.243
(Unpaid)	(0.0524)	(0.0434)	(0.0362)	(0.0458)	(0.0516)	(0.0508)	(0.148)
Cooking Freq.	-0.00515	-0.0489	-0.119	0.0219	-0.0256	-0.0127	-0.0816
(Sometimes)	(0.0887)	(0.0863)	(0.0775)	(0.0657)	(0.0823)	(0.0954)	(0.258)
Cooking Freq.	0.00538	0.120	-0.132	-0.0480	-0.158*	-0.0495	-0.453*
(Never)	(0.0887)	(0.0848)	(0.0818)	(0.0655)	(0.0819)	(0.0932)	(0.260)
HH Exp. per cap	0.0222**	-0.000105	0.00949	-0.0109	-0.044***	-0.00755	0.524***
(logs)	(0.0104)	(0.00849)	(0.00678)	(0.0092)	(0.0104)	(0.00973)	(0.0313)
Owns enterprise	0.0619	-0.0446	-0.0159	0.0439	0.0283	0.0640*	-0.0661
(Yes)	(0.0378)	(0.0343)	(0.0250)	(0.0369)	(0.0387)	(0.0374)	(0.103)
Drinking Water	0.0405*	-0.0148	-0.00380	-0.00972	-0.0505**	0.00449	-0.0730
(Borehole)	(0.0242)	(0.0201)	(0.0171)	(0.0217)	(0.0240)	(0.0234)	(0.0657)
Drinking Water	-0.0318	-0.0218	-0.0220	-0.0116	0.0122	0.0140	-0.0681
(Unprotected)	(0.0266)	(0.0227)	(0.0184)	(0.0236)	(0.0261)	(0.0254)	(0.0726)
Drinking Water	0.0366	0.00575	0.0196	0.0385	-0.0701	-0.0101	0.0798
(Mineralized)	(0.0640)	(0.0513)	(0.0464)	(0.0585)	(0.0642)	(0.0652)	(0.167)
Dwelling Type	-0.0455**	0.0343*	-0.047***	0.00726	0.0138	-0.00529	-0.0487
(Multi-occupants)	(0.0217)	(0.0185)	(0.0155)	(0.0191)	(0.0213)	(0.0208)	(0.0585)
Dwelling Type	-0.0113	0.0388	-0.057***	-0.0552*	-0.0612*	0.0491	0.0192
(Multi-houses)	(0.0326)	(0.0269)	(0.0209)	(0.0294)	(0.0324)	(0.0313)	(0.0863)
Num. of Rooms	-0.00827*	-0.000114	0.000302	0.0067*	-0.00397	0.00368	-0.030***
	(0.00429)	(0.00342)	(0.00241)	(0.0035)	(0.00401)	(0.00391)	(0.0102)
Roof Type	-0.131**	0.00172	0.0403	-0.0826*	-0.0608	-0.0867	-0.0119
(BSCB, Others)	(0.0552)	(0.0470)	(0.0429)	(0.0499)	(0.0587)	(0.0582)	(0.178)
Roof Type	0.0653**	-0.0510**	0.0349*	0.0121	0.00332	0.0159	0.148*
(Roofing sheet)	(0.0280)	(0.0223)	(0.0180)	(0.0250)	(0.0281)	(0.0272)	(0.0788)
Toilet	0.0131	0.0667**	-0.0189	-0.071**	-0.0904**	-0.0371	0.114
(Yes)	(0.0438)	(0.0327)	(0.0284)	(0.0364)	(0.0422)	(0.0407)	(0.117)
Financial Service	-0.0475	0.0627***	-0.0301	0.0184	-0.0476	-0.00786	0.0894
(Formal=Yes)	(0.0292)	(0.0234)	(0.0189)	(0.0270)	(0.0296)	(0.0287)	(0.0778)

Financial Service	0.0186	-0.00576	-0.0123	-0.0156	-0.0347	0.0310	-0.0305
(Informal=Yes)	(0.0272)	(0.0232)	(0.0182)	(0.0251)	(0.0270)	(0.0260)	(0.0716)
Access to Credit	0.00808	0.00328	0.00394	-0.0424*	-0.0237	-0.058**	-0.112*
(Yes)	(0.0242)	(0.0203)	(0.0168)	(0.0217)	(0.0242)	(0.0230)	(0.0661)
Household size	0.0122***	-0.00252	-0.000503	-0.063**		-0.037**	0.229***
	(0.00290)	(0.00230)	(0.00196)	(0.0030)		(0.00341)	(0.0738)
Pseudo R^2	0.0413	0.0450	0.0858	0.2108	0.0628	0.0951	
H-L (Prob)	0.5757	0.5966	0.8573	0.2780	0.4167	0.2608	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							46.32 (0.000)
Log likelihood							-4007.46
Rho (ρ)							0.6347***
							(0.0491)
Sigma (σ)							0.1694***
							(0.0274)
Lambda (λ)							0.1075 *
							(0.0610)
Selected N							1,886
N	2,472	2,472	2,472	2,472	2,472	2,472	2,472

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix E7: The effects of overall access on household's health outcomes (Full results)

Overall Access (Multi-tier)	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Tier 2	0.00114	0.000225	0.0129	0.0398	-0.00594	0.0402	-0.136**
	(0.0227)	(0.0192)	(0.0162)	(0.0384)	(0.0194)	(0.0351)	(0.0607)
Tier 3	-0.097***	-0.223***	-0.115***	-0.087***	-0.063**	-0.142**	0.146***
	(0.0372)	(0.0298)	(0.059)	(0.0321)	(0.0316)	(0.0213)	(0.0976)
Tier 4	-0.277***	-0.313***	-0.140***	-0.115***	-0.1643**	-0.242**	-0.217*
	(0.0443)	(0.0365)	(0.0276)	(0.0201)	(0.0465)	(0.0437)	(0.115)
Gender	0.102	-0.195***	-0.296**	0.118	0.179**	0.0397	0.204
(Male)	(0.101)	(0.0273)	(0.116)	(0.0913)	(0.0825)	(0.107)	(0.288)
Age	-0.0632*	-0.0375	0.0659***	-0.0427	-0.0330	0.420***	-0.0754
(logs)	(0.0349)	(0.0289)	(0.0241)	(0.0294)	(0.0322)	(0.0324)	(0.0896)
Education	-0.109	0.365***	0.0276	0.0579	0.125	0.0692	-0.390
(Non-formal)	(0.150)	(0.140)	(0.105)	(0.117)	(0.118)	(0.123)	(0.426)
Education	-0.0940	0.319**	0.0427	0.0689	0.115	0.0720	-0.393
(Basic)	(0.152)	(0.142)	(0.106)	(0.119)	(0.120)	(0.125)	(0.429)
Education	-0.144	0.383***	0.00748	0.0300	0.105	0.0785	-0.111
(Secondary)	(0.151)	(0.141)	(0.105)	(0.118)	(0.119)	(0.124)	(0.427)
Education	-0.107	0.344**	0.0413	0.0389	0.105	0.0818	0.0724
(Tertiary)	(0.154)	(0.143)	(0.106)	(0.121)	(0.122)	(0.127)	(0.433)
Marital Status	-0.119*	-0.332***	0.0373	0.0743	0.104*	0.363***	0.288
(Never married)	(0.0655)	(0.0677)	(0.0476)	(0.0591)	(0.0565)	(0.0358)	(0.189)
Marital Status	0.132	-0.411***	-0.00465	0.0181	0.00388	0.131*	0.155
(Div./Wid./Sep)	(0.0921)	(0.102)	(0.0548)	(0.0813)	(0.0777)	(0.0758)	(0.249)
Occupation	-0.0287	0.0224	-0.0170	-0.00421	0.00541	0.0224	0.0519
(Self-employed)	(0.0260)	(0.0220)	(0.0186)	(0.0232)	(0.0228)	(0.0245)	(0.0670)
Occupation	-0.0783	0.0459	-0.00190	-0.0121	0.00596	0.0285	0.167
(Unpaid)	(0.0494)	(0.0401)	(0.0353)	(0.0432)	(0.0412)	(0.0473)	(0.137)

Cooking Freq.	0.00736	-0.0678	-0.128*	0.0527	-0.0399	-0.0979	-0.134
(Sometimes)	(0.0835)	(0.0805)	(0.0764)	(0.0673)	(0.0611)	(0.0851)	(0.230)
Cooking Freq.	0.0114	0.135*	-0.170**	-0.00246	-0.0906	-0.114	-0.584**
(Never)	(0.0844)	(0.0810)	(0.0798)	(0.0670)	(0.0614)	(0.0841)	(0.232)
HH Exp. per cap	0.0205**	-0.00306	0.0109*	-0.0123	-0.00387	-0.0140	0.547***
(logs)	(0.00986)	(0.00814)	(0.00637)	(0.00881)	(0.0087)	(0.00922)	(0.0288)
Owns enterprise	0.0552	-0.0383	-0.0163	0.0315	0.0634*	0.0408	-0.101
(Yes)	(0.0369)	(0.0323)	(0.0238)	(0.0353)	(0.0353)	(0.0360)	(0.0982)
Drinking Water	0.0446**	-0.0173	-0.000103	-0.0130	-0.0256	0.0227	-0.0326
(Borehole)	(0.0226)	(0.0187)	(0.0159)	(0.0203)	(0.0201)	(0.0215)	(0.0598)
Drinking Water	-0.0324	-0.0122	-0.0225	-0.0144	0.0165	0.0228	-0.105
(Unprotected)	(0.0256)	(0.0216)	(0.0177)	(0.0226)	(0.0227)	(0.0243)	(0.0687)
Drinking Water	0.0556	-0.0266	0.00498	0.0308	0.0231	0.0154	0.336**
(Mineralized)	(0.0550)	(0.0470)	(0.0377)	(0.0480)	(0.0483)	(0.0534)	(0.140)
Dwelling Type	-0.0532***	0.0371**	-0.052***	0.0109	-0.00806	-0.0103	-0.0121
(Multi-occupants)	(0.0204)	(0.0173)	(0.0144)	(0.0180)	(0.0183)	(0.0192)	(0.0537)
Dwelling Type	-0.0221	0.0460*	-0.065***	-0.0659**	-0.063**	0.0446	0.0406
(Multi-houses)	(0.0311)	(0.0255)	(0.0200)	(0.0283)	(0.0277)	(0.0297)	(0.0816)
Num. of Rooms	-0.00741*	0.00129	-9.22e-05	0.0097***	0.011**	0.00293	-0.03***
	(0.00403)	(0.00331)	(0.00235)	(0.00365)	(0.0043)	(0.00366)	(0.0095)
Roof Type	-0.127**	0.00474	0.0361	-0.0821	-0.0872*	-0.0689	-0.0544
(BSCB, Others)	(0.0549)	(0.0457)	(0.0409)	(0.0501)	(0.0473)	(0.0565)	(0.169)
Roof Type	0.0679**	-0.0452**	0.0350*	0.0161	0.00775	0.0272	0.160**
(Roofing sheet)	(0.0279)	(0.0224)	(0.0179)	(0.0246)	(0.0250)	(0.0269)	(0.0769)
Toilet	0.0200	0.0679**	-0.0210	-0.0638*	-0.089**	-0.0302	0.0936
(Yes)	(0.0433)	(0.0324)	(0.0285)	(0.0363)	(0.0364)	(0.0402)	(0.115)
Financial Service	-0.0490*	0.0429**	-0.0340*	0.0330	0.0187	0.00159	0.157**
(Formal=Yes)	(0.0265)	(0.0216)	(0.0174)	(0.0239)	(0.0245)	(0.0255)	(0.0688)
Financial Service	0.0360	-0.00617	0.00357	-0.0242	-0.00361	0.0391	-0.0145
(Informal=Yes)	(0.0253)	(0.0215)	(0.0178)	(0.0234)	(0.0234)	(0.0238)	(0.0654)

Access to Credit	-0.00706	-0.00296	0.00207	-0.0401*	-0.0208	-0.067**	-0.0689
(Yes)	(0.0227)	(0.0190)	(0.0158)	(0.0207)	(0.0205)	(0.0216)	(0.0606)
Household size	0.0131***	-0.00321	0.000488	-0.059***	-0.064**	-0.034**	0.345***
	(0.00276)	(0.00216)	(0.00178)	(0.00283)	(0.0042)	(0.00291)	(0.0702)
Pseudo R^2	0.0257	0.0416	0.0825	0.1922	0.2150	0.0925	
H-L (Prob)	0.7824	0.3732	0.1271	0.2889	0.3609	0.1659	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							57.56 (0.000)
Log likelihood							-4598.17
Rho (ρ)							0.6329***
							(0.0449)
Sigma (σ)							0.1641***
							(0.0249)
Lambda (λ)							0.1039*
							(0.0614)
Selected N							2,180
N	2,828	2,828	2,828	2,828	2,828	2,828	2,828

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix E8: The effects of binary access on household's health outcomes (Full results)

Overall access (Binary Approach)	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Stove type	-0.123***	-0.0869**	-0.0556*	-0.0779*	-0.0148**	-0.1244**	-0.126***
(Clean)	(0.0549)	(0.0457)	(0.0368)	(0.0457)	(0.0044)	(0.0517)	(0.0217)
Gender	0.114	-0.196***	-0.272**	0.112	0.165*	0.0220	0.602
(Male)	(0.102)	(0.0295)	(0.115)	(0.0933)	(0.0850)	(0.110)	(0.459)
Age	-0.0508	-0.0528*	0.0711***	-0.0470	-0.0282	0.408***	0.390***
(logs)	(0.0358)	(0.0300)	(0.0250)	(0.0302)	(0.0330)	(0.0334)	(0.139)
Education	-0.103	0.362***	0.0279	0.0558	0.139	0.0749	0.303
(Non-formal)	(0.150)	(0.140)	(0.107)	(0.119)	(0.119)	(0.124)	(0.647)
Education	-0.0934	0.314**	0.0398	0.0649	0.128	0.0724	0.404
(Basic)	(0.152)	(0.142)	(0.108)	(0.121)	(0.121)	(0.126)	(0.651)
Education	-0.130	0.369***	0.0107	0.0308	0.124	0.0794	0.642
(Secondary)	(0.151)	(0.141)	(0.107)	(0.120)	(0.120)	(0.125)	(0.647)
Education	-0.107	0.329**	0.0444	0.0544	0.136	0.0736	0.773
(Tertiary)	(0.154)	(0.143)	(0.109)	(0.123)	(0.123)	(0.128)	(0.655)
Marital Status	-0.150**	-0.315***	0.0345	0.0515	0.103*	0.356***	-0.0560
(Never married)	(0.0652)	(0.0691)	(0.0486)	(0.0604)	(0.0571)	(0.0390)	(0.311)
Marital Status	0.133	-0.385***	0.000244	0.00102	-0.00087	0.120	0.386
(Div./Wid./Sep)	(0.0944)	(0.104)	(0.0578)	(0.0848)	(0.0806)	(0.0795)	(0.390)
Occupation	-0.0414	0.0244	-0.0210	-0.00598	0.00158	0.00666	0.0240
(Self-employed)	(0.0268)	(0.0228)	(0.0194)	(0.0241)	(0.0234)	(0.0253)	(0.0964)
Occupation	-0.0940*	0.0436	-0.00269	-0.0163	-0.00277	0.00797	-0.0698
(Unpaid)	(0.0505)	(0.0416)	(0.0367)	(0.0445)	(0.0423)	(0.0484)	(0.210)
Cooking Freq.	0.00840	-0.0709	-0.155*	0.0340	-0.0394	-0.0959	-0.429
(Sometimes)	(0.0862)	(0.0824)	(0.0800)	(0.0683)	(0.0625)	(0.0889)	(0.374)
Cooking Freq.	0.0102	0.129	-0.194**	-0.0234	-0.0749	-0.112	-0.626*
(Never)	(0.0871)	(0.0827)	(0.0837)	(0.0678)	(0.0624)	(0.0879)	(0.380)

HH Exp. per cap	0.0199**	-0.00285	0.00882	-0.0120	-0.00292	-0.0104	0.756***
(logs)	(0.0100)	(0.00823)	(0.00657)	(0.00904)	(0.00890)	(0.00942)	(0.0443)
Owns enterprise	0.0567	-0.0347	-0.0157	0.0234	0.0567	0.0602*	0.000780
(Yes)	(0.0371)	(0.0326)	(0.0247)	(0.0358)	(0.0359)	(0.0361)	(0.143)
Drinking Water	0.0479**	-0.0218	-0.000597	-0.00995	-0.0280	0.0227	0.157*
(Borehole)	(0.0232)	(0.0193)	(0.0166)	(0.0208)	(0.0207)	(0.0221)	(0.0850)
Drinking Water	-0.0352	-0.0183	-0.0265	-0.0157	0.0167	0.0190	-0.0774
(Unprotected)	(0.0263)	(0.0223)	(0.0182)	(0.0232)	(0.0231)	(0.0249)	(0.0992)
Drinking Water	0.0512	-0.0128	0.00433	0.0416	0.00854	0.00840	0.392*
(Mineralized)	(0.0584)	(0.0491)	(0.0412)	(0.0512)	(0.0534)	(0.0571)	(0.219)
Dwelling Type	-0.0485**	0.0370**	-0.050***	0.0121	-0.00238	-0.00483	-0.0136
(Multi-occupants)	(0.0209)	(0.0178)	(0.0150)	(0.0185)	(0.0188)	(0.0198)	(0.0772)
Dwelling Type	-0.0180	0.0455*	-0.065***	-0.057**	-0.0629**	0.0514*	0.0437
(Multi-houses)	(0.0317)	(0.0261)	(0.0205)	(0.0289)	(0.0283)	(0.0302)	(0.119)
Num. of Rooms	-0.0088**	0.00111	-0.000155	0.0079**		0.00268	-0.0369**
	(0.00422)	(0.00346)	(0.00247)	(0.00366)		(0.00381)	(0.0158)
Roof Type	-0.143***	0.0134	0.0353	-0.0876*	-0.102**	-0.0714	-0.325
(BSCB, Others)	(0.0544)	(0.0457)	(0.0416)	(0.0505)	(0.0475)	(0.0569)	(0.245)
Roof Type	0.0660**	-0.0488**	0.0380**	0.0173	0.00964	0.0232	0.272**
(Roofing sheet)	(0.0281)	(0.0226)	(0.0183)	(0.0249)	(0.0252)	(0.0270)	(0.113)
Toilet	0.0182	0.0690**	-0.0188	-0.0701*	-0.0867**	-0.0327	0.0733
(Yes)	(0.0435)	(0.0329)	(0.0294)	(0.0365)	(0.0364)	(0.0406)	(0.165)
Financial Service	-0.0510*	0.0487**	-0.0304*	0.0214	0.00572	-0.00505	0.175*
(Formal=Yes)	(0.0275)	(0.0224)	(0.0182)	(0.0251)	(0.0255)	(0.0266)	(0.0961)
Financial Service	0.0421	-0.0165	-0.00110	-0.0129	0.0103	0.0413*	0.134
(Informal=Yes)	(0.0262)	(0.0226)	(0.0184)	(0.0242)	(0.0241)	(0.0247)	(0.0927)
Access to Credit	-0.00845	0.00390	0.00212	-0.0381*	-0.0225	-0.065***	-0.0932
(Yes)	(0.0231)	(0.0194)	(0.0162)	(0.0211)	(0.0207)	(0.0219)	(0.0848)
Household size	0.0125***	-0.00258	0.000228	-0.05***	-0.063***	-0.035***	-0.045***
	(0.00280)	(0.00222)	(0.00185)	(0.00291)	(0.00431)	(0.00306)	(0.00934)

Pseudo R^2	0.0350	0.0447	0.0805	0.1996	0.2148	0.0949	
H-L (Prob)	0.4540	0.7196	0.4275	0.2827	0.3179	0.1810	
Prob > χ2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LR test (χ2)							50.54 (0.000)
Log likelihood							-4380.57
Rho (ρ)							0.6142***
							(0.0475)
Sigma (σ)							0.1598***
							(0.0253)
Lambda (λ)							0.0981***
							(0.0167)
Selected N							
N	2,717	2,717	2,717	2,717	2,717	2,717	2,717

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix E9: Effects of attributes of modern cooking solution of health spending per capita (Probit model – Selection equation component of the Heckman model)

Covariates	Efficiency	Availability	Affordability	Safety	Convenience	Exposure	Overall
Tier 2	0.0658**	-0.0482**	0.0273	-0.145**	0.00207	-0.283**	-0.185**
	(0.0294)	(0.0233)	(0.0193)	(0.0961)	(0.0265)	(0.0281)	(0.044)
Tier 3	-0.0522**	0.0326*	-0.048***	-0.152**	-0.0197	-0.155**	-0.651**
	(0.0218)	(0.0182)	(0.0155)	(0.0794)	(0.0197)	(0.0205)	(0.170)
Tier 4	-0.0992	-0.322***	0.0336	-0.181**	0.114*	-0.351***	-0.662**
	(0.0744)	(0.0753)	(0.0530)	(0.0648)	(0.0618)	(0.0426)	(0.164)
Tier 5	-0.0537	0.334**	0.0127	0.193**	0.185	-0.410***	
	(0.164)	(0.155)	(0.119)	(0.0921)	(0.115)	(0.032)	
Gender	-0.00558	-0.00139	0.00492	-0.0439*	-0.0184	-0.084**	-0.617**
(Male)	(0.0244)	(0.0203)	(0.0170)	(0.0224)	(0.0220)	(0.0231)	(0.199)
Age	0.110	-0.356***	0.00333	0.0277	0.0138	0.154**	0.0428
(logs)	(0.0972)	(0.109)	(0.0583)	(0.0869)	(0.0820)	(0.0768)	(0.789)
Education	0.0658**	-0.0482**	0.0273	0.0145	0.00207	0.0283	0.0185
(Non-formal)	(0.0294)	(0.0233)	(0.0193)	(0.0261)	(0.0265)	(0.0281)	(0.244)
Education	-0.00289	0.000181	0.00113	0.013**	0.0110**	0.00405	-0.0240
(Basic)	(0.00425)	(0.00363)	(0.00258)	(0.0043)	(0.00483)	(0.00417)	(0.0349)
Education	0.0449	0.0490	-0.0232	-0.0632	-0.101**	0.00105	1.564***
(Secondary)	(0.0457)	(0.0365)	(0.0314)	(0.0388)	(0.0395)	(0.0424)	(0.347)
Education	0.0541**	-0.0211	0.00203	-0.0162	-0.0327	0.0181	0.313*
(Tertiary)	(0.0241)	(0.0199)	(0.0170)	(0.0218)	(0.0218)	(0.0230)	(0.188)
Marital Status	0.0850**	-0.077***	0.0497**	0.0239	0.0119	0.130***	1.961***
(Never married)	(0.0381)	(0.0296)	(0.0240)	(0.0341)	(0.0342)	(0.0363)	(0.338)
Marital Status	0.0581**	-0.0139	0.0110	-0.0253	-0.00197	0.0404	0.972***
(Div./Wid./Sep)	(0.0275)	(0.0236)	(0.0197)	(0.0258)	(0.0256)	(0.0259)	(0.199)
Occupation	0.0115***	-0.00323	0.000389	-0.058**	-0.062***	-0.035**	0.156***
(Self-employed)	(0.00291)	(0.00231)	(0.00191)	(0.0031)	(0.00468)	(0.00321)	(0.0216)
Occupation	-0.0485**	0.0370**	-0.050***	0.0121	-0.00238	-0.00483	-0.583**
(Unpaid)	(0.0209)	(0.0178)	(0.0150)	(0.0185)	(0.0188)	(0.0198)	(0.170)

Cooking Freq.	-0.00845	0.00390	0.00212	-0.0381*	-0.0225	0.065***	-0.454**
(Sometimes)	(0.0231)	(0.0194)	(0.0162)	(0.0211)	(0.0207)	(0.0219)	(0.193)
Cooking Freq.	-0.130	0.369***	0.0107	0.0308	0.124	0.0794	2.285*
(Never)	(0.151)	(0.141)	(0.107)	(0.120)	(0.120)	(0.125)	(1.206)
HH Exp. per cap	0.132	-0.180***	-0.264**	0.174*	0.253***	-0.0184	0.426
(logs)	(0.104)	(0.0346)	(0.119)	(0.0955)	(0.0812)	(0.107)	(0.925)
Owns enterprise	-0.103	0.362***	0.0279	0.0558	0.139	0.0749	1.759
(Yes)	(0.150)	(0.140)	(0.107)	(0.119)	(0.119)	(0.124)	(1.198)
Drinking Water	0.0679**	-0.0452**	0.0350*	0.0161	0.00775	0.0272	0.181
(Borehole)	(0.0279)	(0.0224)	(0.0179)	(0.0246)	(0.0250)	(0.0269)	(0.238)
Drinking Water	0.0102	0.129	-0.194**	-0.0234	-0.0749	-0.112	-1.142
(Unprotected)	(0.0871)	(0.0827)	(0.0837)	(0.0678)	(0.0624)	(0.0879)	(0.727)
Drinking Water	-0.0414	0.0244	-0.0210	-0.00598	0.00158	0.00666	0.116
(Mineralized)	(0.0268)	(0.0228)	(0.0194)	(0.0241)	(0.0234)	(0.0253)	(0.219)
Dwelling Type	-0.0125	-0.0304	0.00625	-0.0220	-0.0285	0.110***	1.264***
(Multi-occupant)	(0.0393)	(0.0305)	(0.0239)	(0.0358)	(0.0361)	(0.0380)	(0.356)
Dwelling Type	0.0552	-0.0383	-0.0163	0.0315	0.0634*	0.0408	-0.539
(Multi-houses)	(0.0369)	(0.0323)	(0.0238)	(0.0353)	(0.0353)	(0.0360)	(0.331)
Num. of Rooms	-0.0940	0.319**	0.0427	0.0689	0.115	0.0720	1.956
	(0.152)	(0.142)	(0.106)	(0.119)	(0.120)	(0.125)	(1.247)
Roof Type	0.0316	-0.0127	0.00427	0.0262	0.0271	0.0117	1.194**
(BSCB, Others)	(0.0626)	(0.0522)	(0.0418)	(0.0544)	(0.0535)	(0.0600)	(0.483)
Roof Type	-0.0452	-0.0401	-0.0944	0.0136	-0.0985	-0.0175	-0.922
(Roofing sheet)	(0.0904)	(0.0856)	(0.0794)	(0.0719)	(0.0651)	(0.0895)	(0.711)
Toilet	0.0155	0.00639	0.00822	-0.0160*	-0.00262	-0.020**	0.790***
(Yes)	(0.0105)	(0.00859)	(0.00681)	(0.0096)	(0.00936)	(0.00982)	(0.0920)
Financial Service	-0.0469	-0.0424	0.0726***	-0.0616*	-0.0530	0.432***	1.735***
(Formal=Yes)	(0.0374)	(0.0308)	(0.0259)	(0.0319)	(0.0354)	(0.0349)	(0.304)
Financial Service	0.139**	-0.125***	0.0702*	0.0433	0.0253	0.198***	0.620
(Informal=Yes)	(0.0557)	(0.0484)	(0.0396)	(0.0503)	(0.0492)	(0.0532)	(0.530)

Access to Credit	0.0626*	-0.097***	0.0690***	-0.00374	-0.0264	0.130***	1.790***
(Yes)	(0.0370)	(0.0291)	(0.0235)	(0.0335)	(0.0337)	(0.0354)	(0.335)
Household size	-0.0257	0.0334	-0.067***	-0.0584*	-0.0632**	0.0507	-0.0266
	(0.0338)	(0.0280)	(0.0216)	(0.0310)	(0.0302)	(0.0319)	(0.272)
N	2,693	2,719	2,717	2,472	2,479	2,730	2,828

Appendix F: VIF test for Multicollinearity in respect of health-cooking energy nexus

Appendix F1: VIF test for Multicollinearity in the cooking efficiency model

Covariate	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Efficiency (Tier 2)	6.72	5.68	6.93	7.38	7.40	6.38	5.37
Efficiency (Tier 3)	8.67	7.33	8.94	9.51	9.53	8.22	6.92
Efficiency (Tier 4)	8.04	6.80	8.29	8.82	8.84	7.63	6.42
Efficiency (Tier 5)	6.12	5.18	6.31	6.72	6.74	5.81	4.89
Gender (Male)	18.58	16.17	21.45	19.55	21.60	16.59	18.75
Age (logs)	6.56	6.48	8.92	6.66	7.62	6.65	7.80
Education (Non-formal)	1.26	1.11	1.47	1.06	1.47	1.14	1.28
Education (Basic)	3.79	3.49	4.86	3.74	4.41	3.58	4.25
Education (Secondary)	2.90	2.97	2.40	2.02	2.04	2.99	2.22
Education (Tertiary)	2.71	2.72	2.99	2.22	2.83	2.74	2.87
Marita status (Never married)	1.74	1.86	2.83	3.26	2.02	1.91	2.47
Marita status (Div./Separated)	2.94	3.91	6.33	5.45	3.42	4.01	5.54
Main occupation (S&S.)	1.28	1.78	2.33	1.73	1.49	1.83	2.04
Main occupation (Unpaid-R&U)	1.44	1.61	2.56	2.54	1.67	1.65	2.24
Cooking Freq. (Sometimes)	2.99	2.95	2.33	2.97	2.15	2.97	2.17
Cooking Freq. (Never)	1.72	1.77	2.55	2.03	2.00	1.82	2.23
HH expenditure per capita (logs)	3.15	3.22	5.04	3.94	3.66	3.30	4.40
Drinking water (Borehole)	4.70	4.65	7.57	7.42	5.47	4.78	6.62
Drinking water (Unprotected)	6.98	7.98	7.34	6.02	7.14	7.01	7.17
Drinking water (Mineralized)	1.51	1.37	1.83	1.44	1.76	1.41	1.60
Dwelling (Multi-occupants)	2.96	2.04	2.50	2.13	2.12	2.06	2.32
Dwelling (Multi-houses)	2.89	2.85	2.17	2.85	2.03	2.87	2.02
Number of rooms	1.30	1.20	1.60	1.18	1.51	1.23	1.40
Roof type (BSCB, Others)	1.74	1.86	2.83	3.26	2.02	1.91	2.47
Roof type (Roofing sheet)	2.94	3.91	6.33	5.45	3.42	4.01	5.54

Toilet-in-dwelling (Yes)	1.28	1.78	2.33	1.73	1.49	1.83	2.04
Formal finance (Formal)	1.44	1.61	2.56	2.54	1.67	1.65	2.24
Formal finance (Informal)	1.99	1.95	1.33	1.97	1.15	1.97	1.17
Access to credit (Yes)	1.72	1.77	2.55	2.03	2.00	1.82	2.23
Household size (logs)	3.15	3.22	5.04	3.94	3.66	3.30	4.40
Mean VIF	**3.84**	**3.71**	**4.75**	**4.38**	**4.14**	**3.84**	**4.10**

Appendix F2: VIF test for Multicollinearity in the fuel affordability model

Covariate	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Affordability (Tier 2)	8.17	6.57	7.12	8.12	6.74	7.78	8.00
Affordability (Tier 3)	9.15	7.36	7.98	9.10	7.55	8.71	8.96
Affordability (Tier 4)	9.34	7.51	8.14	9.29	7.70	8.89	9.14
Affordability (Tier 5)	7.57	6.08	6.60	7.52	6.24	7.20	7.41
Gender (Male)	25.58	23.33	20.61	23.49	21.68	21.18	20.62
Age (logs)	9.03	9.34	8.57	8.00	7.65	8.48	8.58
Education (Non-formal)	1.74	1.60	1.41	1.27	1.47	1.45	1.41
Education (Basic)	5.22	5.04	4.67	4.50	4.42	4.57	4.67
Education (Secondary)	1.24	1.40	1.35	1.23	1.05	1.27	1.35
Education (Tertiary)	0.98	1.04	0.95	1.46	0.83	0.95	0.95
Marita status (Never married)	2.39	2.68	2.72	3.92	2.02	2.43	2.72
Marita status (Div./Separated)	4.05	5.64	6.09	6.55	3.43	5.12	6.09
Main occupation (S&S.)	1.77	2.57	2.24	2.08	1.50	2.33	2.24
Main occupation (Unpaid-R&U)	1.98	2.32	2.46	3.05	1.67	2.10	2.46
Cooking Freq. (Sometimes)	1.36	1.37	1.28	1.16	1.15	1.24	1.28
Cooking Freq. (Never)	2.37	2.56	2.45	2.44	2.01	2.32	2.45
HH expenditure per capita (logs)	4.34	4.64	4.84	4.73	3.67	4.21	4.84
Drinking water (Borehole)	6.48	6.71	7.27	8.92	5.49	6.10	7.28

Drinking water (Unprotected)	1.35	1.42	1.29	1.23	1.15	1.29	1.29
Drinking water (Mineralized)	2.08	1.98	1.76	1.73	1.76	1.80	1.76
Dwelling (Multi-occupants)	1.32	1.50	1.45	1.36	1.12	1.36	1.45
Dwelling (Multi-houses)	1.22	1.22	1.13	1.03	1.03	1.11	1.13
Number of rooms	1.79	1.73	1.54	1.42	1.52	1.57	1.54
Roof type (BSCB, Others)	2.39	2.68	2.72	3.92	2.02	2.43	2.72
Roof type (Roofing sheet)	4.05	5.64	6.09	6.55	3.43	5.12	6.09
Toilet-in-dwelling (Yes)	1.77	2.57	2.24	2.08	1.50	2.33	2.24
Formal finance (Formal)	1.98	2.32	2.46	3.05	1.67	2.10	2.46
Formal finance (Informal)	1.36	1.37	1.28	1.16	1.15	1.24	1.28
Access to credit (Yes)	2.37	2.56	2.45	2.44	2.01	2.32	2.45
Household size (logs)	4.34	4.64	4.84	4.73	3.67	4.21	4.84
Mean VIF	**4.29**	**4.25**	**4.20**	**4.58**	**3.61**	**4.11**	**4.32**

Appendix F3: VIF test for Multicollinearity in the fuel availability model

Covariate	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Availability (Tier 2)	7.29	8.03	6.93	7.93	6.25	6.74	8.53
Availability (Tier 3)	8.17	8.99	7.76	8.88	7.00	7.55	9.55
Availability (Tier 4)	8.33	9.18	7.92	9.06	7.15	7.70	9.75
Availability (Tier 5)	6.75	7.43	6.42	7.34	5.79	6.24	7.90
Gender (Male)	29.03	25.63	21.90	28.14	21.61	22.64	22.06
Age (logs)	10.25	10.27	9.11	9.58	7.63	9.07	9.18
Education (Non-formal)	1.97	1.76	1.50	1.52	1.47	1.55	1.51
Education (Basic)	5.92	5.53	4.96	5.39	4.41	4.89	5.00
Education (Secondary)	1.40	1.53	1.43	1.47	1.05	1.35	1.44
Education (Tertiary)	1.11	1.14	1.01	1.75	0.83	1.01	1.02
Marita status (Never married)	2.71	2.94	2.89	4.69	2.02	2.60	2.91

Marita status (Div./Separated)	4.60	6.20	6.47	7.85	3.42	5.48	6.51
Main occupation (S&S.)	2.00	2.82	2.38	2.49	1.49	2.49	2.40
Main occupation (Unpaid-R&U)	2.24	2.54	2.62	3.65	1.67	2.25	2.63
Cooking Freq. (Sometimes)	1.55	1.50	1.36	1.39	1.15	1.32	1.37
Cooking Freq. (Never)	2.69	2.81	2.61	2.92	2.00	2.48	2.62
HH expenditure per capita (logs)	4.92	5.10	5.14	5.67	3.66	4.50	5.18
Drinking water (Borehole)	7.35	7.38	7.73	10.68	5.47	6.52	7.79
Drinking water (Unprotected)	1.54	1.56	1.37	1.47	1.14	1.37	1.38
Drinking water (Mineralized)	2.36	2.18	1.87	2.07	1.76	1.92	1.88
Dwelling (Multi-occupants)	1.50	1.64	1.54	1.63	1.12	1.45	1.55
Dwelling (Multi-houses)	1.38	1.34	1.20	1.23	1.03	1.19	1.20
Number of rooms	2.04	1.90	1.63	1.70	1.52	1.68	1.65
Roof type (BSCB, Others)	2.71	2.94	2.89	4.69	2.02	2.60	2.91
Roof type (Roofing sheet)	4.60	6.20	6.47	7.85	3.42	5.48	6.51
Toilet-in-dwelling (Yes)	2.00	2.82	2.38	2.49	1.49	2.49	2.40
Formal finance (Formal)	2.24	2.54	2.62	3.65	1.67	2.25	2.63
Formal finance (Informal)	1.55	1.50	1.36	1.39	1.15	1.32	1.37
Access to credit (Yes)	2.69	2.81	2.61	2.92	2.00	2.48	2.62
Household size (logs)	4.92	5.10	5.14	5.67	3.66	4.50	5.18
Mean VIF	4.59	4.78	4.37	5.24	3.54	4.17	4.62

Appendix F4: VIF test for Multicollinearity in the cookstove safety model

Covariate	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Safety (Tier 2)	6.33	6.97	6.01	6.88	5.43	5.85	7.40
Safety (Tier 3)	4.97	5.48	4.73	5.41	4.27	4.60	5.82
Safety (Tier 4)	5.92	6.52	5.63	6.44	5.08	5.47	6.92
Safety (Tier 5)	6.75	7.43	6.42	7.34	5.79	6.24	7.90

Gender (Male)	24.48	20.76	28.89	25.84	25.80	17.49	27.25
Age (logs)	8.64	8.32	12.02	8.80	9.11	7.01	11.34
Education (Non-formal)	1.66	1.42	1.98	1.40	1.75	1.20	1.86
Education (Basic)	5.00	4.48	6.54	4.95	5.26	3.78	6.17
Education (Secondary)	1.18	1.24	1.89	1.35	1.25	1.05	1.78
Education (Tertiary)	0.94	0.93	1.33	1.61	0.99	0.78	1.26
Marita status (Never married)	2.29	2.38	3.81	4.31	2.41	2.01	3.59
Marita status (Div./Separated)	3.88	5.02	8.53	7.21	4.08	4.23	8.05
Main occupation (S&S.)	1.69	2.29	3.14	2.29	1.78	1.93	2.96
Main occupation (Unpaid-R&U)	1.89	2.06	3.45	3.35	1.99	1.74	3.25
Cooking Freq. (Sometimes)	1.30	1.21	1.80	1.28	1.37	1.02	1.69
Cooking Freq. (Never)	2.27	2.28	3.44	2.68	2.39	1.92	3.24
HH expenditure per capita (logs)	4.15	4.13	6.79	5.21	4.37	3.48	6.40
Drinking water (Borehole)	6.20	5.98	10.20	9.81	6.53	5.03	9.62
Drinking water (Unprotected)	1.29	1.26	1.81	1.35	1.36	1.06	1.71
Drinking water (Mineralized)	1.99	1.76	2.46	1.90	2.10	1.49	2.32
Dwelling (Multi-occupants)	1.27	1.33	2.03	1.50	1.34	1.12	1.91
Dwelling (Multi-houses)	1.17	1.09	1.58	1.13	1.23	0.92	1.49
Number of rooms	1.72	1.54	2.16	1.56	1.81	1.30	2.03
Roof type (BSCB, Others)	2.29	2.38	3.81	4.31	2.41	2.01	3.59
Roof type (Roofing sheet)	3.88	5.02	8.53	7.21	4.08	4.23	8.05
Toilet-in-dwelling (Yes)	1.69	2.29	3.14	2.29	1.78	1.93	2.96
Formal finance (Formal)	1.89	2.06	3.45	3.35	1.99	1.74	3.25
Formal finance (Informal)	1.30	1.21	1.80	1.28	1.37	1.02	1.69
Access to credit (Yes)	2.27	2.28	3.44	2.68	2.39	1.92	3.24
Household size (logs)	4.15	4.13	6.79	5.21	4.37	3.48	6.40
Mean VIF	3.81	3.84	5.25	4.66	3.86	3.23	5.17

Appendix F5: VIF test for Multicollinearity in the cooking convenience model

Covariate	Total Cough Incidence	Women (≥15) years	Men (≥15) years	Girls (5-14) years	Boys (5-14) years	Children (<5) years	Total Health Spending per capita
Convenience (Tier 2)	7.83	8.92	7.29	7.66	7.95	8.74	8.82
Convenience (Tier 3)	7.28	8.29	6.78	7.12	7.39	8.12	8.19
Convenience (Tier 4)	8.54	9.72	7.95	8.35	8.66	9.53	9.61
Convenience (Tier 5)	7.93	9.03	7.39	7.76	8.05	8.85	8.93
Gender (Male)	25.88	21.20	24.77	25.58	27.55	27.46	22.75
Age (logs)	9.14	8.49	10.31	8.71	9.72	11.00	9.46
Education (Non-formal)	1.76	1.45	1.69	1.38	1.87	1.88	1.56
Education (Basic)	5.28	4.58	5.61	4.90	5.62	5.93	5.15
Education (Secondary)	1.25	1.27	1.62	1.34	1.33	1.64	1.48
Education (Tertiary)	0.99	0.95	1.14	1.59	1.05	1.23	1.05
Marita status (Never married)	2.42	2.44	3.27	4.26	2.57	3.15	3.00
Marita status (Div./Separated)	4.10	5.13	7.32	7.14	4.36	6.64	6.72
Main occupation (S&S.)	1.79	2.33	2.70	2.26	1.90	3.02	2.47
Main occupation (Unpaid-R&U)	2.00	2.10	2.96	3.32	2.13	2.73	2.72
Cooking Freq. (Sometimes)	1.38	1.24	1.54	1.26	1.47	1.61	1.41
Cooking Freq. (Never)	2.40	2.33	2.95	2.65	2.55	3.01	2.71
HH expenditure per capita (logs)	4.39	4.22	5.82	5.15	4.67	5.46	5.34
Drinking water (Borehole)	6.55	6.10	8.75	9.71	6.98	7.90	8.03
Drinking water (Unprotected)	1.37	1.29	1.55	1.34	1.46	1.67	1.42
Drinking water (Mineralized)	2.11	1.80	2.11	1.88	2.24	2.33	1.94
Dwelling (Multi-occupants)	1.34	1.36	1.74	1.48	1.43	1.76	1.60
Dwelling (Multi-houses)	1.23	1.11	1.35	1.12	1.31	1.44	1.24
Number of rooms	1.82	1.57	1.85	1.55	1.93	2.04	1.70
Roof type (BSCB, Others)	2.42	2.44	3.27	4.26	2.57	3.15	3.00
Roof type (Roofing sheet)	4.10	5.13	7.32	7.14	4.36	6.64	6.72
Toilet-in-dwelling (Yes)	1.79	2.33	2.70	2.26	1.90	3.02	2.47

Formal finance (Formal)	2.00	2.10	2.96	3.32	2.13	2.73	2.72
Formal finance (Informal)	1.38	1.24	1.54	1.26	1.47	1.61	1.41
Access to credit (Yes)	2.40	2.33	2.95	2.65	2.55	3.01	2.71
Household size (logs)	4.39	4.22	5.82	5.15	4.67	5.46	5.34
Mean VIF	4.24	4.22	4.83	4.79	4.46	5.09	4.72

Appendix F6: VIF test for Multicollinearity in the cooking exposure model

Covariate	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Exposure (Tier 2)	7.17	6.24	7.97	7.17	7.13	8.71	7.98
Exposure (Tier 3)	7.23	6.30	8.04	7.23	7.20	8.78	8.05
Exposure (Tier 4)	7.61	6.62	8.46	7.61	7.57	9.24	8.47
Exposure (Tier 5)	8.21	7.15	9.13	8.21	8.17	9.97	9.15
Gender (Male)	16.52	18.23	20.47	22.37	19.98	19.38	22.30
Age (logs)	5.83	7.30	8.52	7.61	7.05	7.76	9.28
Education (Non-formal)	1.12	1.25	1.40	1.21	1.36	1.33	1.52
Education (Basic)	3.37	3.93	4.64	4.28	4.08	4.18	5.05
Education (Secondary)	0.80	1.09	1.34	1.17	0.97	1.16	1.46
Education (Tertiary)	0.63	0.81	0.95	1.39	0.76	0.87	1.03
Marita status (Never married)	1.54	2.09	2.70	3.73	1.87	2.23	2.94
Marita status (Div./Separated)	2.62	4.41	6.05	6.24	3.16	4.69	6.58
Main occupation (S&S.)	1.14	2.01	2.23	1.98	1.38	2.13	2.43
Main occupation (Unpaid-R&U)	1.28	1.81	2.45	2.90	1.54	1.92	2.66
Cooking Freq. (Sometimes)	0.88	1.07	1.27	1.10	1.06	1.13	1.39
Cooking Freq. (Never)	1.53	2.00	2.44	2.32	1.85	2.13	2.65
HH expenditure per capita (logs)	2.80	3.63	4.81	4.51	3.39	3.86	5.24
Drinking water (Borehole)	4.18	5.25	7.23	8.49	5.06	5.58	7.87
Drinking water (Unprotected)	0.87	1.11	1.28	1.17	1.06	1.18	1.40

Drinking water (Mineralized)	1.34	1.55	1.75	1.65	1.63	1.65	1.90
Dwelling (Multi-occupants)	0.86	1.17	1.44	1.30	1.03	1.24	1.56
Dwelling (Multi-houses)	0.79	0.96	1.12	0.98	0.95	1.02	1.22
Number of rooms	1.16	1.35	1.53	1.35	1.40	1.44	1.66
Roof type (BSCB, Others)	1.54	2.09	2.70	3.73	1.87	2.23	2.94
Roof type (Roofing sheet)	2.62	4.41	6.05	6.24	3.16	4.69	6.58
Toilet-in-dwelling (Yes)	1.14	2.01	2.23	1.98	1.38	2.13	2.43
Formal finance (Formal)	1.28	1.81	2.45	2.90	1.54	1.92	2.66
Formal finance (Informal)	0.88	1.07	1.27	1.10	1.06	1.13	1.39
Access to credit (Yes)	1.53	2.00	2.44	2.32	1.85	2.13	2.65
Household size (logs)	2.80	3.63	4.81	4.51	3.39	3.86	5.24
Mean VIF	2.39	2.36	2.97	2.87	2.57	2.87	3.11

Appendix F7: VIF test for Multicollinearity in the overall access model

Covariate	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Overall access (Tier 2)	7.84	6.92	7.93	8.98	9.00	8.72	7.71
Overall access (Tier 3)	7.54	6.66	7.62	8.64	8.65	8.38	7.41
Overall access (Tier 4)	7.25	6.40	7.33	8.30	8.32	8.06	7.13
Gender (Male)	29.48	25.61	31.58	27.33	25.89	21.33	21.70
Age (logs)	10.41	10.26	13.14	9.30	9.14	8.54	9.03
Education (Non-formal)	2.00	1.75	2.16	1.48	1.76	1.46	1.48
Education (Basic)	6.02	5.53	7.15	5.23	5.28	4.60	4.91
Education (Secondary)	1.43	1.53	2.06	1.43	1.25	1.28	1.42
Education (Tertiary)	1.13	1.14	1.46	1.70	0.99	0.95	1.00
Marita status (Never married)	2.75	2.94	4.17	4.55	2.42	2.45	2.86
Marita status (Div./Separated)	4.67	6.19	9.33	7.62	4.10	5.16	6.41
Main occupation (S&S.)	2.03	2.82	3.44	2.42	1.79	2.35	2.36

Main occupation (Unpaid-R&U)	2.28	2.54	3.77	3.54	2.00	2.12	2.59
Cooking Freq. (Sometimes)	1.57	1.50	1.96	1.35	1.38	1.25	1.35
Cooking Freq. (Never)	2.73	2.81	3.76	2.84	2.40	2.34	2.58
HH expenditure per capita (logs)	5.00	5.10	7.42	5.51	4.39	4.24	5.10
Drinking water (Borehole)	7.47	7.37	11.15	10.37	6.55	6.14	7.66
Drinking water (Unprotected)	1.56	1.55	1.98	1.43	1.37	1.29	1.36
Drinking water (Mineralized)	2.40	2.18	2.69	2.01	2.11	1.81	1.85
Dwelling (Multi-occupants)	1.53	1.64	2.22	1.58	1.34	1.37	1.52
Dwelling (Multi-houses)	1.40	1.34	1.73	1.19	1.23	1.12	1.19
Number of rooms	2.07	1.90	2.36	1.65	1.82	1.58	1.62
Roof type (BSCB, Others)	2.75	2.94	4.17	4.55	2.42	2.45	2.86
Roof type (Roofing sheet)	4.67	6.19	9.33	7.62	4.10	5.16	6.41
Toilet-in-dwelling (Yes)	2.03	2.82	3.44	2.42	1.79	2.35	2.36
Formal finance (Formal)	2.28	2.54	3.77	3.54	2.00	2.12	2.59
Formal finance (Informal)	1.57	1.50	1.96	1.35	1.38	1.25	1.35
Access to credit (Yes)	2.73	2.81	3.76	2.84	2.40	2.34	2.58
Household size (logs)	5.00	5.10	7.42	5.51	4.39	4.24	5.10
Mean VIF	3.13	2.91	3.78	3.37	3.02	2.79	2.88

Appendix F8: VIF test for Multicollinearity in the binary model

Covariate	**Total Cough Incidence**	**Women (≥15) years**	**Men (≥15) years**	**Girls (5-14) years**	**Boys (5-14) years**	**Children (<5) years**	**Total Health Spending per capita**
Stove type (Clean)	2.57	2.85	3.27	2.44	2.99	3.29	3.29
Gender (Male)	24.15	27.92	20.47	20.13	19.05	21.36	21.29
Age (logs)	8.53	11.18	8.52	6.85	6.72	8.56	8.86
Education (Non-formal)	1.64	1.91	1.40	1.09	1.29	1.46	1.46
Education (Basic)	4.93	6.03	4.64	3.85	3.89	4.61	4.82
Education (Secondary)	1.17	1.67	1.34	1.05	0.92	1.28	1.39

Education (Tertiary)	0.92	1.25	0.95	1.25	0.73	0.95	0.98
Marita status (Never married)	2.26	3.21	2.70	3.35	1.78	2.45	2.81
Marita status (Div./Separated)	3.82	6.75	6.05	5.61	3.02	5.17	6.29
Main occupation (S&S.)	1.67	3.07	2.23	1.78	1.31	2.35	2.32
Main occupation (Unpaid-R&U)	1.87	2.77	2.45	2.61	1.47	2.12	2.54
Cooking Freq. (Sometimes)	1.29	1.63	1.27	0.99	1.01	1.25	1.32
Cooking Freq. (Never)	2.24	3.06	2.44	2.09	1.77	2.34	2.53
HH expenditure per capita (logs)	4.09	5.55	4.81	4.06	3.23	4.25	5.00
Drinking water (Borehole)	6.12	8.04	7.23	7.64	4.82	6.15	7.51
Drinking water (Unprotected)	1.28	1.69	1.28	1.05	1.01	1.30	1.33
Drinking water (Mineralized)	1.97	2.37	1.75	1.48	1.55	1.81	1.81
Dwelling (Multi-occupants)	1.25	1.79	1.44	1.17	0.99	1.37	1.49
Dwelling (Multi-houses)	1.15	1.46	1.12	0.88	0.91	1.12	1.16
Number of rooms	1.69	2.07	1.53	1.22	1.34	1.58	1.59
Roof type (BSCB, Others)	2.26	3.21	2.70	3.35	1.78	2.45	2.81
Roof type (Roofing sheet)	3.82	6.75	6.05	5.61	3.02	5.17	6.29
Toilet-in-dwelling (Yes)	1.67	3.07	2.23	1.78	1.31	2.35	2.32
Formal finance (Formal)	1.87	2.77	2.45	2.61	1.47	2.12	2.54
Formal finance (Informal)	1.29	1.63	1.27	0.99	1.01	1.25	1.32
Access to credit (Yes)	2.24	3.06	2.44	2.09	1.77	2.34	2.53
Household size (logs)	4.09	5.55	4.81	4.06	3.23	4.25	5.00
Mean VIF	**3.40**	**4.53**	**3.66**	**3.37**	**2.72**	**3.51**	**3.80**

Appendix G: Distribution of categorical households' covariates

Categorical covariates	Frequency	Percent
Marital status		
Married or Cohabitating	3,031	93.55
Never Married	67	2.07
Divorced, Separated or Widowed	142	4.38
Total	**3,240**	**100**
Primary occupation		
Salaried Employees	703	21.70
Self-Employed	2,380	73.46
Labourer, free labour, student & others	157	4.84
Total	**3,240**	**100**
Source of drinking water		
Piped and protected water	1,009	31.14
Bole Hole	1,203	37.13
Unprotected water	923	28.49
Sachet and Bottled water	105	3.24
Total	**3,240**	**100**
Cooking frequency		
Everyday	149	4.60
Occasionally	174	5.37
Never	2,917	90.03
Total	**3,240**	**100**

Appendix H: Checking overlap of households across tiers of attributes

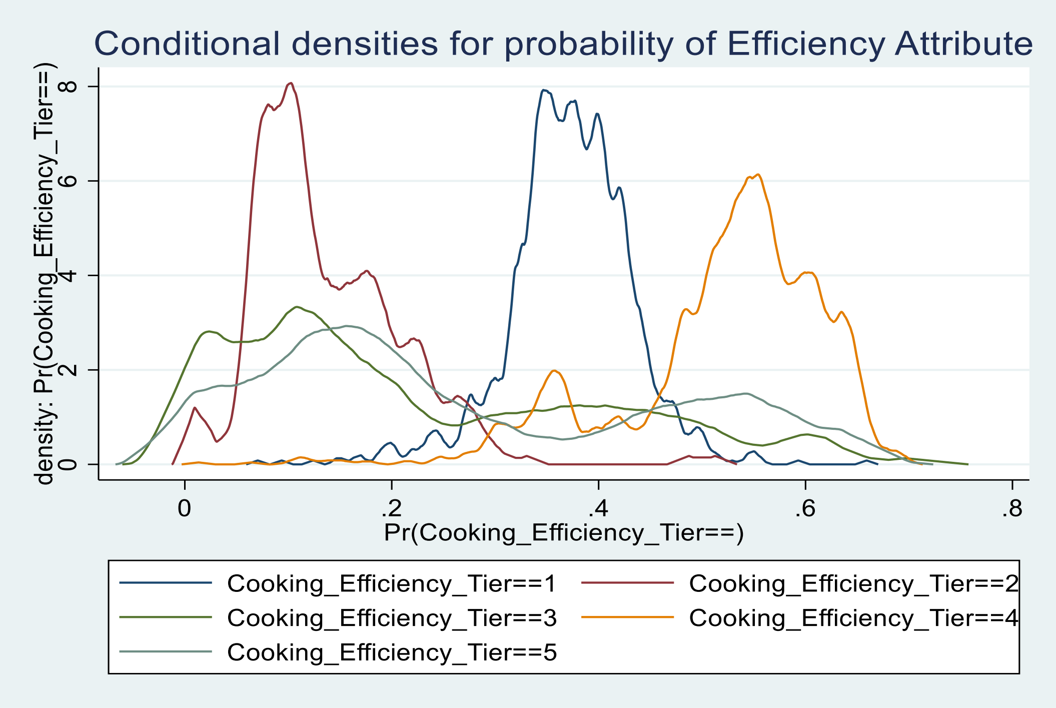

Figure H1: Overlap of households across tiers of the efficiency attribute

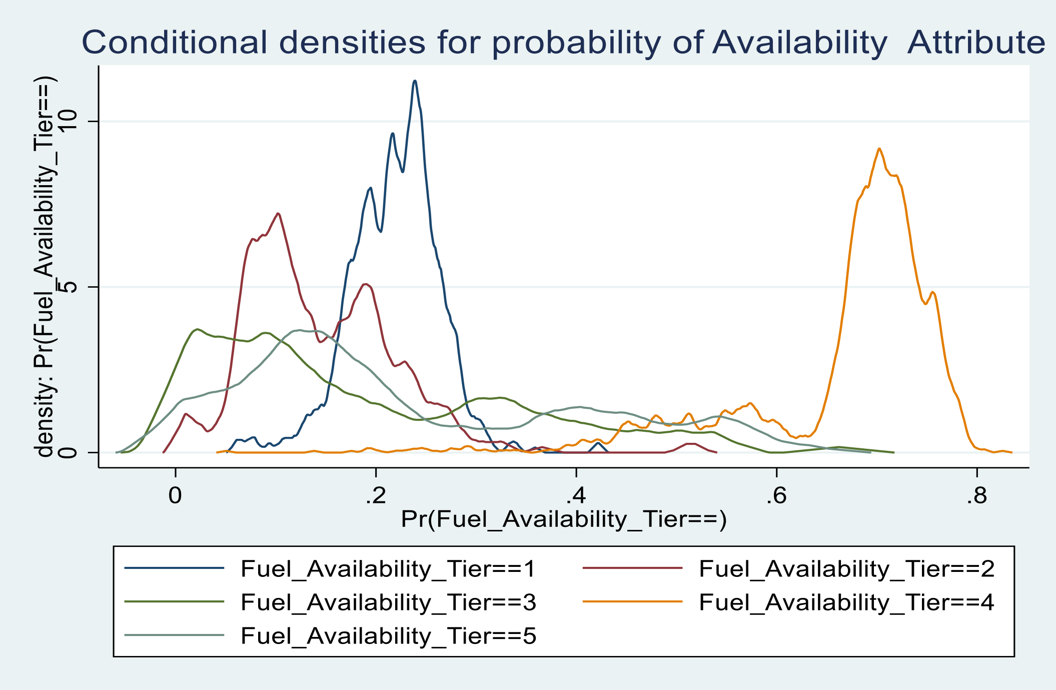

Figure H2: Overlap of households across tiers of the fuel availability attribute

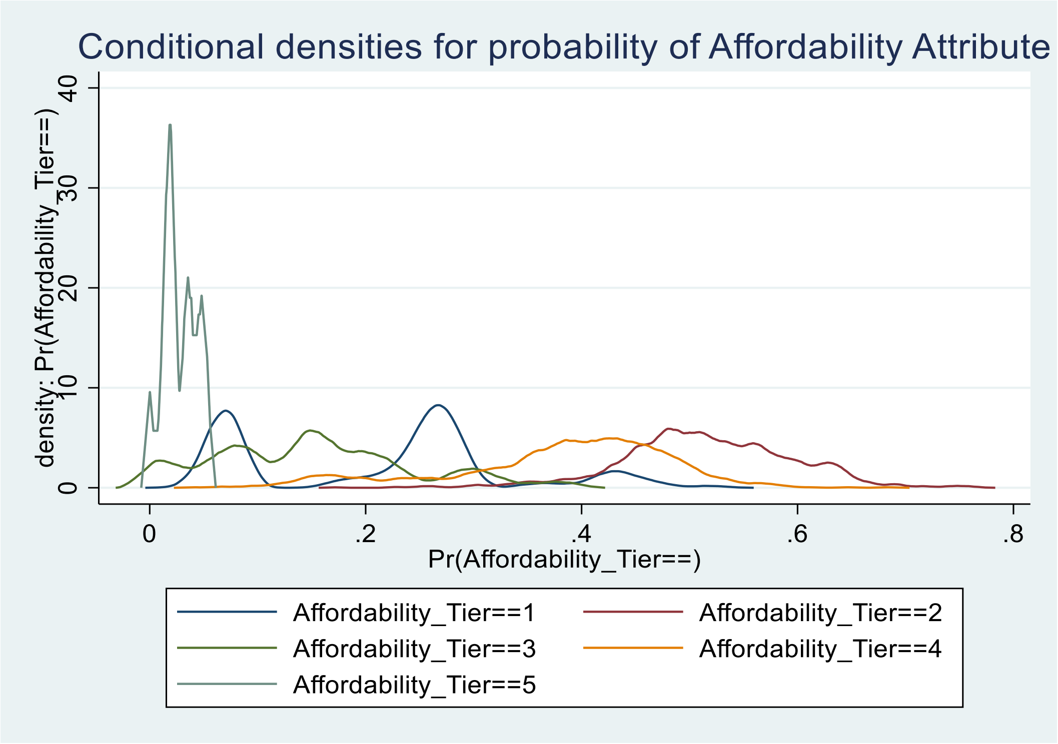

Figure H3: Overlap of households across tiers of the affordability attribute

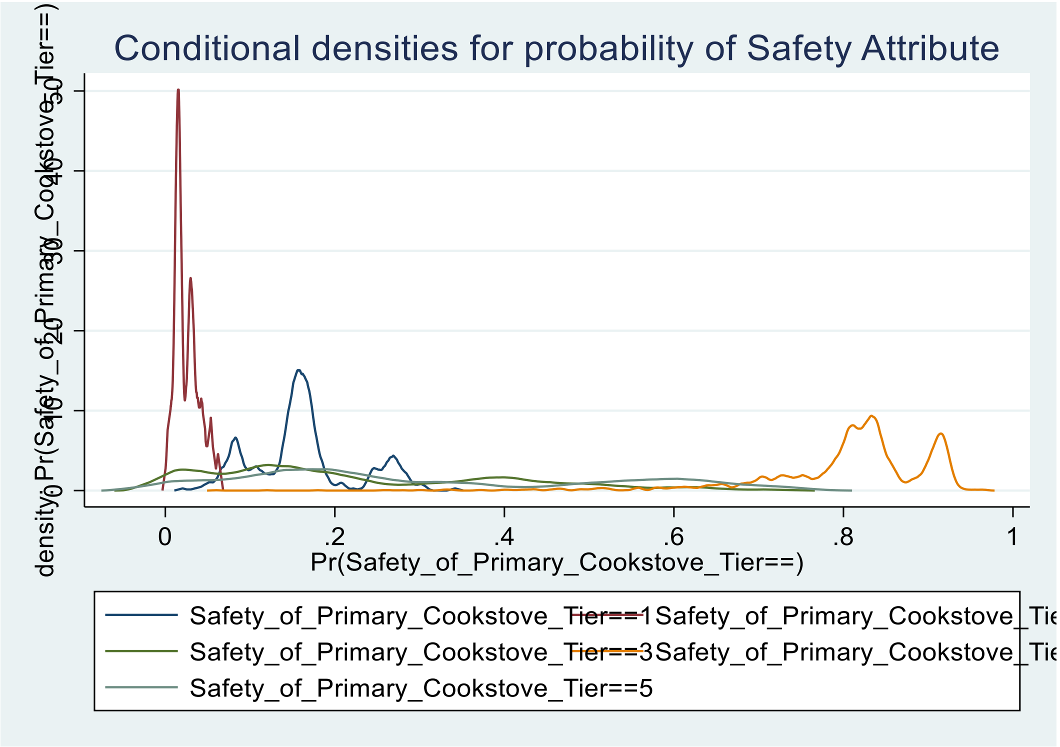

Figure H4: Overlap of households across tiers of the stove safety attribute

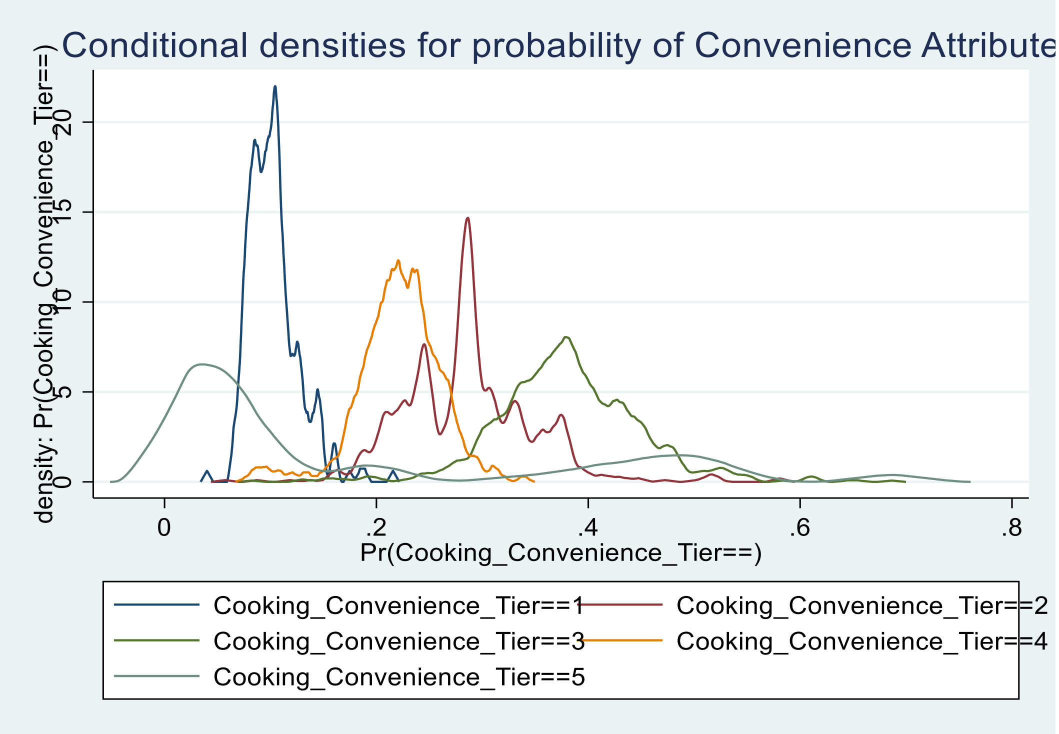

Figure H5: Overlap of households across tiers of the convenience attribute

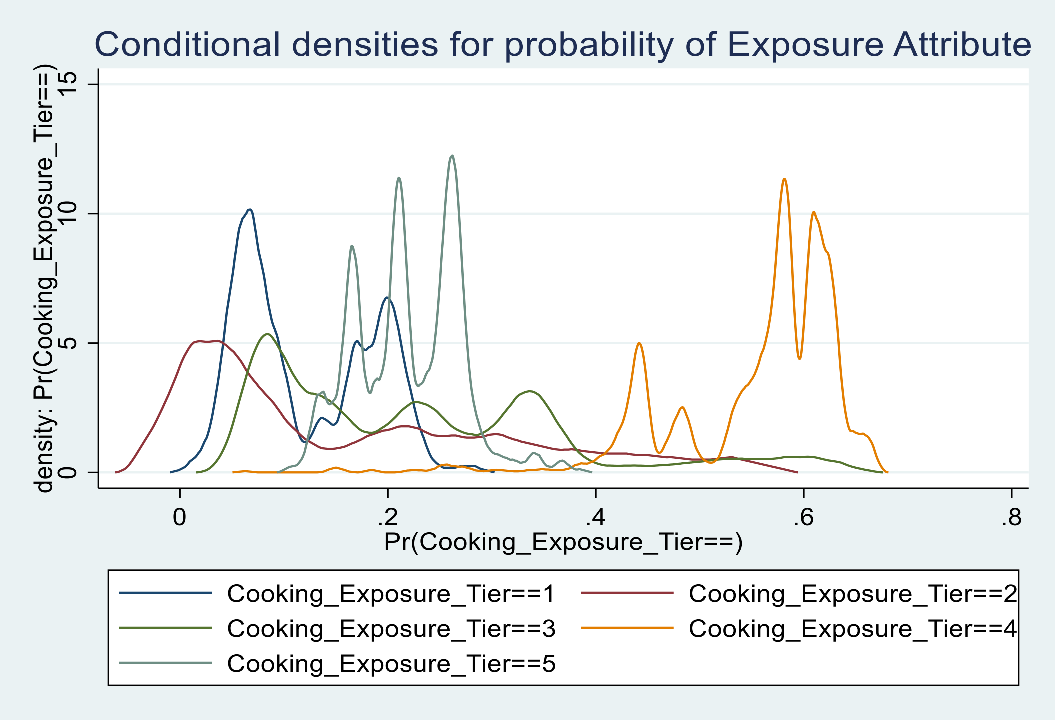

Figure H6: Overlap of households across tiers of the cooking exposure attribute

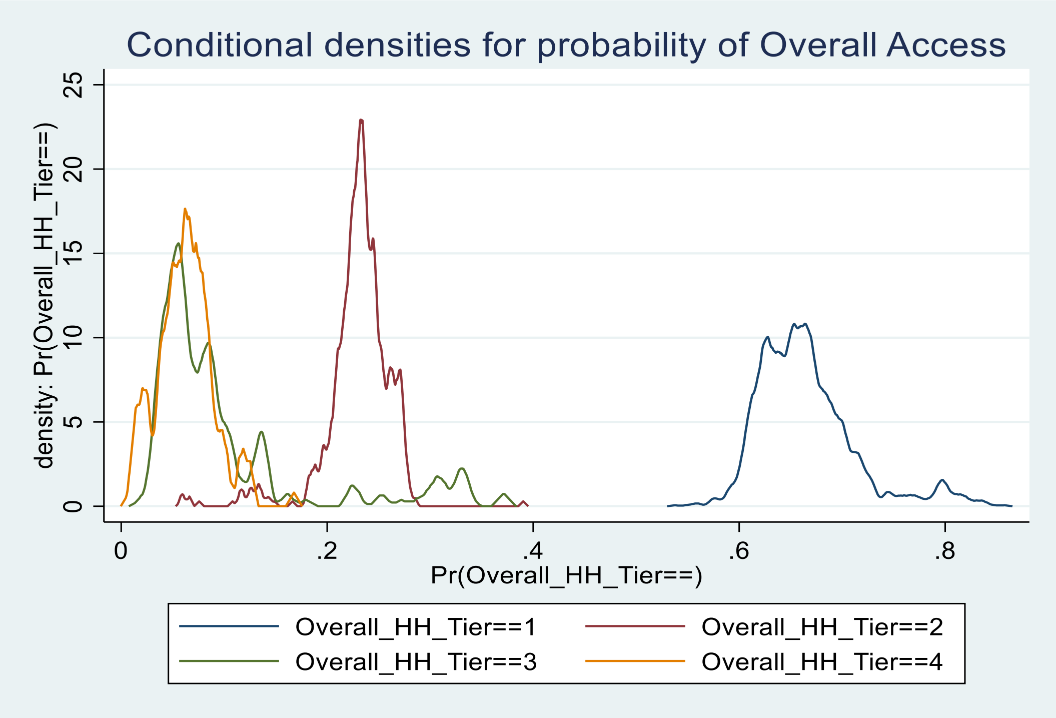

Figure H7: Overlap of households across tiers of Overall Access

Appendix I: Extract of World Bank MTF Global Survey Questionnaire on WTP for ICS

Energy Survey

Household Questionnaire

Medium Version

Version 58

English

K. WILLINGNESS TO PAY FOR AN IMPROVED COOKSTOVE

This module should be asked to only households WITHOUT an improved cookstove (CAPI/enumerator check). The respondent should be the household member who most frequently cooks food for the household, as identified in A.12 OR the household member who decides to purchase the cookstove in I.4.

For each household, determine whether the primary fuel is wood (or crop residues), charcoal or neither (based on responses in Section H). Then randomly assign one of the four following improved cookstoves:

Fuelwood users – (1) Aspirational wood ICS available in country (2) Popular affordable wood ICS available in local market.

Charcoal users – (1) Aspirational charcoal ICS available in country (2) Popular affordable charcoal ICS available in local market.

(After a type of improved cookstove is randomly chosen, price of this type of cookstove will be assigned based on one of the three percentages of the reference price: 33%, 66% or 100%.)

K1a Does the household have an improved cookstove?
Yes…1→ L1
No….2

K.1	***CAPI/ Enumerator:*** Recall responses to Section H (HOUSEHOLD FUEL CONSUMPTION) and record the most frequently used fuel. If not sure, ask respondent. ***Read options aloud***	HH uses more fuelwood or crop residues than charcoal………………………1 HH uses more charcoal than fuelwood or crop residues…………………………2 HH does not use any solid biomass (no charcoal, fuelwood or crop residues) …………………3→ **L.1**
K.2	***Enumerator:*** Record Respondent ID for this section	Individual ID from Household Roster

Interview: [INSERT DESCRIPTION OF THE IMPROVED COOKSTOVE] Please, describe and explain the benefit of having ICS and the features of the assigned cookstove. This cookstove can reduce the smoke and fuel consumption significantly. Possibly, your cooking time per meal will be shortened since firepower of this cookstove is stronger than the traditional cookstove. As you answer the next few questions, keep in mind the various benefits from this device as well as your household budget.

K.3	Would you be willing to purchase this cookstove at [CAPI: Price]?	Yes………………………1 No……………………….2
K.4	Would you be willing to pay ${CF} for this	Yes…………………………1 → **L.1** No………………………….2

	stove, if you were given 6 months to make the payment? This means that each month you will pay ${CF/6} per month for 6 months.	Don’t Know……………….888
K.5	Why would you not accept the offer?	Cannot afford the payment……1 Do not need an improved cookstove….2→ **L.1** Fuel for this stove is unreliable….3→ **L.1** Other, specify…………555
K.6	Would you be willing to pay ${CF} for this improved cookstove, if you were given 12 months to make the payment? This means that each month you will pay ${CF/12} per month for 12 months.	Yes……………………… → **L.1** No…………………………2 Don’t Know……………888
K.7	Why would you not accept the offer?	Cannot afford the payment……1 Do not need an improved cookstove….2→ **L.1** Fuel for this stove is unreliable….3→ **L.1** Other, specify…………555
K.8	Would you be willing to pay ${CF} for this improved cookstove, if you were given 24 months to make the payment?	Yes……………………………→ **L.1** No……………………………2 Don’t Know…………………888

	This means that each month you will pay ${CF/24} per month for 24 months.	
K.9	Why would you not accept the offer?	Cannot afford the payment……1 Do not need an improved cookstove….2→ **L.1** Fuel for this stove is unreliable….3→ **L.1** Other, specify…………555

Appendix J: Outcome variables and Socio-economic characteristics of households across ICS and credit regimes

Appendix J1: Mean estimation of model variables – Aspirational wood ICS (Full sample)

Model variables	Upfront	6-month	12-month	24-month
WTP Response (1=Yes) - outcome	.3330632	.4303079	.5494327	.606969
Bid ($) – Main covariate	16.64635	10.42146	10.32004	10.5491
Socio-economic covariates				
Gender (1=Yes)	.9428934	.9428934	.9428934	.9428934
Age (Years)	48.50127	48.50127	48.50127	48.50127
Primary Occupation	2.070431	2.070431	2.070431	2.070431
Marital Status	1.119924	1.119924	1.119924	1.119924
Household size	6.398477	6.398477	6.398477	6.398477
Monthly Income ($)	78.03303	78.03303	78.03303	78.03303
Access to Grid electricity (1=Yes)	.4041878	.4041878	.4041878	.4041878
Cooking-related covariates				
Cooking Frequency (1= Never)	2.85533	2.85533	2.85533	2.85533
Stove use duration (1=Long term)	.2227157	.2227157	.2227157	.2227157
Fuel Affordability (1=Affordable)	.4765228	.4765228	.4765228	.4765228
Fuel Availability (1=Always available)	.768401	.768401	.768401	.768401
Cookstove safety (1=Safe)	.8692893	.8692893	.8692893	.8692893
Cooking Convenience (1=Convenient)	.2982234	.2982234	.2982234	.2982234
Finance-related covariates				
Access to Credit (1=Yes)	.2392132	.2392132	.2392132	.2392132
Informal finance (1=Yes)	.1465736	.1465736	.1465736	.1465736
Formal finance (1=Yes)	.2138325	.2138325	.2138325	.2138325

Appendix J2: Mean estimation of model variables – Affordable wood ICS (Full sample)

Model variables	**Upfront**	**6-month**	**12-month**	**24-month**
WTP Response (1=Yes) - outcome	.3373015	.449206	.5626984	.6142857
Bid ($) – Main covariate	12.29391	7.56916	7.595514	7.686808
Socio-economic covariates				
Gender (1=Yes)	.9362776	.9362776	.9362776	.9362776
Age (Years)	50.44038	50.44038	50.44038	50.44038
Primary Occupation	2.054259	2.054259	2.054259	2.054259
Marital Status	1.129968	1.129968	1.129968	1.129968
Household size	6.377287	6.377287	6.377287	6.377287
Monthly Income ($)	80.8148	80.8148	80.8148	80.8148
Access to Grid electricity (1=Yes)	.3962145	.3962145	.3962145	.3962145
Cooking-related covariates				
Cooking Frequency (1= Never)	2.850473	2.850473	2.850473	2.850473
Stove use duration (1=Long term)	.2189274	.2189274	.2189274	.2189274
Fuel Affordability (1=Affordable)	.4681388	.4681388	.4681388	.4681388
Fuel Availability (1=Always available)	.7804416	.7804416	.7804416	.7804416
Cookstove safety (1=Safe)	.8662461	.8662461	.8662461	.8662461
Cooking Convenience (1=Convenient)	.2902208	.2902208	.2902208	.2902208
Finance-related covariates				
Access to Credit (1=Yes)	.2365931	.2365931	.2365931	.2365931
Informal finance (1=Yes)	.1634069	.1634069	.1634069	.1634069
Formal finance (1=Yes)	.222082	.222082	.222082	.222082

Appendix J3: Mean estimation of model variables – Aspirational wood ICS (Subsamples)

Model variables	Upfront	6-month	12-month	24-month
WTP Response (1=Yes) - outcome	.3483503	.2023609	.3356164	.2762646
Bid ($) – Main covariate	16.64635	2.871919	1.482731	.7559523
Socio-economic covariates				
Gender (1=Male)	.9428934	.9544688	.9657534	.9571984
Age (Years)	48.50127	47.35076	48.37215	47.31128
Primary Occupation	2.070431	1.868465	1.858447	1.844358
Marital Status	.9481361	.9409781	.9497717	.9416342
Household size	6.398477	6.311973	6.184932	5.898833
Monthly Income ($)	78.03303	78.30263	74.11402	73.28255
Access to Grid electricity (1=Yes)	.4041878	.3726813	.3584475	.3618677
Cooking-related covariates				
Cooking Frequency (1=Never)	.0769854	.0860034	.0753425	.077821
Stove use duration (1=Long term)	.2227157	.2107926	.2146119	.2062257
Fuel Affordability (1=Affordable)	.4765228	.5143339	.5182648	.5525292
Fuel Availability (1=Available)	.768401	.7925801	.7922374	.8054475
Cookstove safety (1=Safe)	.8692893	.8549747	.8607306	.8715953
Cooking Convenience (1=Convenient)	.2982234	.3102867	.2785388	.2217899
Finance-related covariates				
Access to Credit	.2392132	.2462057	.2305936	.233463
Informal financial service	.1465736	.1197302	.1050228	.1089494
Formal financial service	.2138325	.1686341	.1598174	.1712062

Appendix J4: Mean estimation of model variables – Affordable wood ICS (Subsamples)

Model variables	Upfront	6-month	12-month	24-month
WTP Response (1=Yes) - outcome	.3400631	.2266881	.3341121	.25
Bid ($) – Main covariate	12.29391	2.139908	1.119804	.5654087
Socio-economic covariates				
Gender (1=Male)	.9362776	.9533762	.9485981	.9346154
Age (Years)	50.44038	51.49839	52.21028	54.15769
Primary Occupation	2.054259	1.847267	1.859813	1.842308
Marital Status	.9515873	.9453376	.9392523	.9269231
Household size	6.377287	6.262058	6.086449	5.873077
Monthly Income ($)	80.8148	79.86796	77.0747	81.50412
Access to Grid electricity (1=Yes)	.3962145	.3424437	.3317757	.3
Cooking-related covariates				
Cooking Frequency (1= Never)	.0753968	.0900322	.0934579	.1
Stove use duration (1=Long term)	.2189274	.221865	.2172897	.2
Fuel Affordability (1=Affordable)	.4681388	.5482315	.5630841	.5884615
Fuel Availability (1=Available)	.7804416	.7797428	.7990654	.8076923
Cookstove safety (1=Safe)	.8662461	.8344051	.8621495	.9
Cooking Convenience (1=Convenient)	.2902208	.2700965	.2476636	.2576923
Finance-related covariates				
Access to Credit	.2365931	.2491961	.2593458	.2807692
Informal financial service	.1634069	.1237942	.1028037	.1038462
Formal financial service	.222082	.1688103	.1588785	.1346154

Appendix J5: Detailed inspection of some covariates – Main empirical strategy

Covariates	Aspirational (%)	Affordable (%)
Primary Occupation		
Labourer, Free labour, Student & Others	19.37	21.43
Retired and Unemployed	75.69	73.89
Self-Employed and Salaried	4.94	4.68
Monthly income ($)		
Up to Bid	12.24	12.86
>Bid – 31.81	7.86	8.33
>31.81 – 100	47.24	43.81
>100 – 200	25.04	26.03
>200 – 2,000	7.62	8.97
Age (Years)		
>60	8.76	11.98
51 – 60	15.87	14.37
41 – 50	25.29	25.08
31 – 40	29.09	30.95
18 – 30	20.99	17.62
Total (Observations)	**100 (1,234)**	**100 (1,260)**

Appendix J6: Detailed inspection of some covariates– Aspirational wood ICS

Covariates	**Upfront (%)**	**6-month (%)**	**12-month (%)**	**24-month (%)**
Primary Occupation				
Self-Employed and Salaried	4.94	5.23	5.02	5.81
Retired and Unemployed	75.69	76.39	75.80	73.26
Labourer, Free labour, Student & Others	19.37	18.38	19.18	20.93
Monthly income ($)				
Up to Bid	12.03	10.19	10.97	10.02
>Bid – 31.81	8.2	16.29	16.03	15.07
>31.81 – 100	50.04	48.33	49.31	49.48
>100 – 200	20.1	22.12	20.92	21.09
>200 – 2,000	9.63	3.07	2.77	4.34
Age (Years)				
>60	15.14	15.21	14.9	15.45
51 – 60	25.01	25.46	25.39	30.22
41 – 50	29.81	29.54	30.33	29.65
31 – 40	19.15	18.47	19.05	19.43
18 – 30	10.89	11.32	10.33	5.25
Total (Observations)	**100 (1,234)**	**100 (539)**	**100 (438)**	**100 (258)**

Appendix J7: Detailed inspection of some covariates – Affordable wood ICS

Covariates	Upfront (%)	6-month (%)	12-month (%)	24-month (%)
Primary Occupation				
Self-Employed and Salaried	4.68	5.47	6.31	5.00
Retired and Unemployed	73.89	73.79	73.36	74.23
Labourer, Free labour, Student & Others	21.43	20.74	20.33	20.77
Monthly income ($)				
Up to Bid	10.09	9.98	10.68	11.06
>Bid – 31.81	10.34	17.05	19.07	18.63
>31.81 – 100	43.54	45.04	44.56	43.21
>100 – 200	26.43	20.03	18.89	17.44
>200 – 2,000	9.6	7.9	6.8	9.66
Age (Years)				
>60	14.54	15.97	15.09	14.09
51 – 60	24.89	24.69	24.91	28.92
41 – 50	29.95	29.09	29.83	30.15
31 – 40	19.47	19.36	18.75	18.73
18 – 30	11.15	10.89	11.42	8.11
Total (Observations)	**100 (1,260)**	**100 (622)**	**100 (428)**	**100 (260)**

Appendix K: Full WTP regression results

Appendix K1: Determinants of WTP for Aspirational wood ICS (Main Empirical Strategy)

Covariate	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	-0.0126***	-0.0166***	-0.0022*	-0.0063***
(Main slope)	(0.00213)	(0.00140)	(0.00125)	(0.00146)
Gender	0.00789	-0.0762	0.105	0.0535
(1=Male)	(0.132)	(0.139)	(0.146)	(0.147)
Age	-0.211***	-0.243***	-0.185***	-0.205***
(logs)	(0.0481)	(0.0483)	(0.0478)	(0.0466)
Primary occupation	0.00684	0.0301	0.0543	0.0207
(2=Student, free labour etc)	(0.0339)	(0.0353)	(0.0384)	(0.0380)
Primary occupation	0.0305	0.0544	0.0811	0.122*
(3=Retired & Unemployed)	(0.0654)	(0.0671)	(0.0707)	(0.0660)
Marital Status	-0.129	-0.0575	-0.153	-0.0344
(2=Never married)	(0.0882)	(0.103)	(0.114)	(0.121)
Marital Status	0.0305	-0.0128	0.00507	-0.00776
(3=Divorced/Separated)	(0.118)	(0.116)	(0.128)	(0.125)
Households size	0.0163	0.0407	0.0591**	0.0608**
(log)	(0.0247)	(0.0248)	(0.0264)	(0.0258)
Monthly income	0.124***	0.0505***	0.0313**	0.0386***
(log)	(0.0145)	(0.0138)	(0.0140)	(0.0137)
Cooking frequency	0.0265	-0.0397	-0.0784	-0.0270
(1=Never)	(0.120)	(0.125)	(0.125)	(0.126)
Stove use duration	-0.00871	-0.0272	0.00639	0.00280
(1=Short term)	(0.0340)	(0.0347)	(0.0376)	(0.0371)
Fuel affordability	-0.0218	-0.0106	-0.0474	-0.0374
(1=Affordable)	(0.0273)	(0.0277)	(0.0295)	(0.0290)
Fuel availability	-0.0294	0.00463	-0.0226	-0.0246
(1=Always available)	(0.0300)	(0.0304)	(0.0325)	(0.0319)
Cookstove safety	-0.0489	-0.0854**	-0.113***	-0.109***

(1=Safe)	(0.0375)	(0.0380)	(0.0386)	(0.0372)
Cooking convenience	-0.0168	0.0451	-0.0903***	-0.0726**
(1=Convenient)	(0.0274)	(0.0282)	(0.0295)	(0.0290)
Grid electricity access	0.134***	0.156***	0.164***	0.143***
(1=Yes)	(0.0290)	(0.0295)	(0.0308)	(0.0300)
Access to credit	0.0196	0.0741**	0.0564*	0.0740**
(1=Yes)	(0.0312)	(0.0311)	(0.0325)	(0.0315)
Informal finance	0.0897**	0.0875**	0.0452	0.0567
(1=Yes)	(0.0378)	(0.0386)	(0.0405)	(0.0390)
Formal finance	0.0329	0.0503	0.0561	0.0476
(1=Yes)	(0.0359)	(0.0373)	(0.0398)	(0.0387)
Constant	0.323***	0.489**	0.0762**	0.0204**
(Intercept)	(0.0359)	(0.0357)	(0.0368)	(0.0156)
	PROBIT Statistics			
Observations	1,234	1,234	1,234	1,234
Pseudo R-squared	0.1173	0.1463	0.0606	0.0610
Prob > χ-squared	0.000	0.000	0.000	0.000
H-L (Prob)	0.5686	0.3871	0.0528	0.8480
	WTP Statistics			
Implied Mean WTP ($)	25.65**	29.50**	34.63*	32.32*
(Regime Level)	(17.45)	(13.35)	(17.91)	(21.74)
Mean WTP/Income	25.65/78.03	(29.50/6)/78.03	(34.63/12)/78.03	(32.32/24)/78.03
(Monthly Level)	=32.9%	=6.3%	=3.7%	=1.7%
Mean Bid/Income	16.67/78.03	10.42/78.03	10.32/78.03	10.59/78.03
(Monthly Level)	=21.2%	=13.4%	=13.2%	=13.6%

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix K2: Determinants of WTP for Affordable wood ICS (Main Empirical Strategy)

Covariate	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	-0.0219***	-0.0173***	-0.00166***	-0.0107***
(Main slope)	(0.00272)	(0.00201)	(0.0009)	(0.00194)
Gender	0.214**	0.171	0.150	0.0902
(1=Male)	(0.104)	(0.146)	(0.164)	(0.167)
Age	-0.0918**	-0.0331	-0.0405	-0.0614
(logs)	(0.0456)	(0.0423)	(0.0411)	(0.0392)
Primary occupation	0.0748**	0.0655*	0.0796**	0.0896**
(2=Student, free labour etc)	(0.0314)	(0.0347)	(0.0372)	(0.0373)
Primary occupation	0.107	0.106	0.194***	0.264***
(3=Retired & Unemployed)	(0.0668)	(0.0693)	(0.0674)	(0.0608)
Marital Status	-0.196**	-0.134	0.000102	0.0285
(2=Never married)	(0.0902)	(0.119)	(0.138)	(0.136)
Marital Status	0.251	0.0437	-0.140	-0.0962
(3=Divorced/Separated)	(0.168)	(0.154)	(0.151)	(0.154)
Households size	-0.0139	0.00831	0.0138	0.0208
(log)	(0.0240)	(0.0252)	(0.0260)	(0.0254)
Monthly income	0.110***	0.0473***	0.0170***	0.0466***
(log)	(0.0139)	(0.0135)	(0.00133)	(0.00132)
Cooking frequency	-0.107	-0.155	-0.211**	-0.122
(1=Never)	(0.126)	(0.119)	(0.0974)	(0.103)
Stove use duration	-0.0216	0.0365	0.0325	0.0152
(1=Short term)	(0.0311)	(0.0332)	(0.0341)	(0.0336)
Fuel affordability	-0.0196	-0.0273	-0.0205	-0.00618
(1=Affordable)	(0.0266)	(0.0279)	(0.0289)	(0.0283)
Fuel availability	0.0180	-0.0252	-0.0289	-0.0472
(1=Always available)	(0.0298)	(0.0315)	(0.0327)	(0.0319)
Cookstove safety	-0.0180	-0.121***	-0.170***	-0.155***
(1=Safe)	(0.0355)	(0.0373)	(0.0362)	(0.0348)

Cooking convenience	0.0218	0.0183	0.00130	-0.00615
(1=Convenient)	(0.0278)	(0.0291)	(0.0301)	(0.0296)
Grid electricity access	0.110***	0.122***	0.164***	0.158***
(1=Yes)	(0.0292)	(0.0306)	(0.0312)	(0.0302)
Access to credit	-0.0257	0.0172	0.0117	0.0253
(1=Yes)	(0.0305)	(0.0318)	(0.0324)	(0.0314)
Informal finance	0.136***	0.163***	0.151***	0.153***
(1=Yes)	(0.0354)	(0.0366)	(0.0362)	(0.0342)
Formal finance	0.0419	0.0293	0.0554	0.0421
(1=Yes)	(0.0360)	(0.0380)	(0.0398)	(0.0389)
Constant	0.325***	0.276***	0.0275	0.1829*
(Intercept)	(0.063)	(0.092)	(0.572)	(0.076)
	PROBIT Statistics			
Observations	1,260	1,260	1,260	1,260
Pseudo R-squared	0.1227	0.1146	0.0616	0.0651
Prob > χ-squared	0.000	0.000	0.000	0.000
H-L (Prob)	0.1146	0.0067	0.2467	0.0261
	WTP Statistics			
Implied Mean WTP ($)	14.87*	15.98**	17.21***	17.10*
(Regime Level)	(9.02)	(7.23)	(4.94)	(9.66)
Mean WTP/Income	14.87/80.81	(15.98/6)/80.81	(17.21/12)/80.	(17.10/24)/80
(Monthly Level)	=18.4%	=3.3%	81=1.8%	.81=0.9%
Mean Bid/Income	12.29/80.81	7.57/80.81	7.60/80.81	7.69/80.81
(Monthly Level)	=15.2%	=9.4%	=9.4%	=9.5%

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix K3: Determinants of WTP for Aspirational wood ICS (Robustness Check)

Covariate	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	-0.0126***	-0.0179***	-0.00386**	-0.00574***
(Main slope)	(0.00213)	(0.00149)	(0.00172)	(0.00162)
Gender	0.00789	-0.346	0.336***	-0.678***
(1=Male)	(0.132)	(0.247)	(0.0446)	(0.0448)
Age	-0.211***	-0.108*	-0.000244	-0.139
(logs)	(0.0481)	(0.0577)	(0.0666)	(0.0984)
Primary occupation	0.00684	0.0545	0.0842	-0.0818
(2=Student, free labour etc)	(0.0339)	(0.0410)	(0.0565)	(0.0791)
Primary occupation	0.0305	0.0247	0.129	0.242
(3=Retired & Unemployed)	(0.0654)	(0.0772)	(0.111)	(0.150)
Marital Status	-0.129	0.0545	-0.221*	0.720***
(2=Never married)	(0.0882)	(0.132)	(0.128)	(0.0302)
Marital Status	0.0305	-0.116	0.149	-0.146
(3=Divorced/Separated)	(0.118)	(0.0932)	(0.290)	(0.194)
Households size	0.0163	0.0579**	0.0782*	0.0737
(log)	(0.0247)	(0.0295)	(0.0439)	(0.0594)
Monthly income	0.124***	0.0169***	0.0798***	0.0200***
(log)	(0.0145)	(0.00137)	(0.0181)	(0.00238)
Cooking frequency	0.0265	-0.0677	-0.111	0.295***
(1=Never)	(0.120)	(0.162)	(0.205)	(0.0373)
Stove use duration	-0.00871	0.0501	0.0599	-0.0404
(1=Short term)	(0.0340)	(0.0486)	(0.0639)	(0.0737)
Fuel affordability	-0.0218	0.00823	-0.0872*	0.0339
(1=Affordable)	(0.0273)	(0.0341)	(0.0465)	(0.0571)
Fuel availability	-0.0294	0.00827	-0.0919	-0.0229
(1=Always available)	(0.0300)	(0.0392)	(0.0559)	(0.0706)
Cookstove safety	-0.0489***	-0.0589***	-0.0733***	-0.0413***
(1=Safe)	(0.00375)	(0.00497)	(0.00653)	(0.00846)

Cooking convenience	-0.0168	0.116***	0.158***	0.0292
(1=Convenient)	(0.0274)	(0.0371)	(0.0510)	(0.0677)
Grid electricity access	0.134***	0.0628*	0.0693	-0.0486***
(1=Yes)	(0.0290)	(0.0371)	(0.0508)	(0.00598)
Access to credit	0.0196	0.0945**	0.0111	0.109
(1=Yes)	(0.0312)	(0.0412)	(0.0540)	(0.0696)
Informal finance	0.0897**	0.0850	0.118*	0.0689
(1=Yes)	(0.0378)	(0.0560)	(0.0656)	(0.0963)
Formal finance	0.0329	0.0297	0.0147	-0.0270
(1=Yes)	(0.0359)	(0.0499)	(0.0679)	(0.0782)
Constant	0.323***	0.473***	0.1024**	0.1552**
(Intercept)	(0.0359)	(0.0685)	(0.0603)	(0.0637)
	PROBIT Statistics			
Observations	1,234	593	438	258
Pseudo R-squared	0.1173	0.0878	0.0784	0.0796
Prob > χ-squared	0.000	0.001	0.016	0.000
H-L (Prob)	0.5686	0.3303	0.1100	0.7771
	WTP Statistics			
Implied Mean WTP ($)	25.65**	26.43***	26.55*	27.04*
(Regime Level)	(17.45)	(5.22)	(13.14)	(16.22)
Mean WTP/Income	25.65/78.03	(26.43/6)/78.30	(26.55/12)/74.11=	(27.04/24)/73.28
(Monthly Level)	=32.9%	=5.6%	3.0%	=1.5%
Mean Bid/Income	16.67/78.03	2.87/78.30	1.48/74.11	0.76/73.28
(Monthly Level)	=21.2%	=3.6%	=2.0%	=1.0%

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix K4: Determinants of WTP for Affordable wood ICS (Robustness Check)

Covariate	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	-0.0219***	-0.0922***	-0.0560***	-0.227***
(Main slope)	(0.00272)	(0.0228)	(0.00652)	(0.0160)
Gender	0.214**	0.0582	0.00912	-0.711
(1=Male)	(0.104)	(0.184)	(0.227)	(2.395)
Age	-0.0918**	0.0341	-0.0135	-0.0795
(logs)	(0.0456)	(0.0429)	(0.0555)	(0.0595)
Primary occupation	0.0748**	0.0297	0.0626	0.102
(2=Student, free labour etc)	(0.0314)	(0.0411)	(0.0559)	(0.0641)
Primary occupation	0.107	0.00276	0.219**	0.474***
(3=Retired & Unemployed)	(0.0668)	(0.0801)	(0.106)	(0.150)
Marital Status	-0.196**	0.0193	0.382*	
(2=Never married)	(0.0902)	(0.152)	(0.216)	
Marital Status	0.251	-0.139	-0.315***	-0.279
(3=Divorced/Separated)	(0.168)	(0.111)	(0.0607)	(0.733)
Households size	-0.0139	0.0445	0.0260	0.0585
(log)	(0.0240)	(0.0334)	(0.0444)	(0.0532)
Monthly income	0.110***	0.0663*	0.0390**	0.0324*
(log)	(0.0139)	(0.0112)	(0.0156)	(0.0183)
Cooking frequency	-0.107	-0.171	-0.331*	0.189
(1=Never)	(0.126)	(0.218)	(0.190)	(0.123)
Stove use duration	-0.0216	0.0650	0.0420	-0.0345
(1=Short term)	(0.0311)	(0.0435)	(0.0572)	(0.0668)
Fuel affordability	-0.0196	-0.0395	-0.0316	0.0392
(1=Affordable)	(0.0266)	(0.0351)	(0.0471)	(0.0541)
Fuel availability	0.0180	-0.0905**	-0.0323	-0.107
(1=Always available)	(0.0298)	(0.0412)	(0.0573)	(0.0730)
Cookstove safety	-0.0180	-0.112**	-0.183***	-0.0620***
(1=Safe)	(0.0355)	(0.0482)	(0.0700)	(0.00900)

Cooking convenience	0.0218	0.0569	0.0174	0.00160
(1=Convenient)	(0.0278)	(0.0383)	(0.0525)	(0.0617)
Grid electricity access	0.110***	0.0974**	0.132**	0.0759***
(1=Yes)	(0.0292)	(0.0395)	(0.0541)	(0.00689)
Access to credit	-0.0257	0.0401	-0.00901	0.0855
(1=Yes)	(0.0305)	(0.0407)	(0.0539)	(0.0633)
Informal finance	0.136***	0.161***	-0.00142	0.0512
(1=Yes)	(0.0354)	(0.0554)	(0.0712)	(0.0887)
Formal finance	0.0419	0.000347	0.111	-0.0555
(1=Yes)	(0.0360)	(0.0485)	(0.0723)	(0.0877)
Constant	0.325***	0.1171	0.8602***	3.5434***
(Intercept)	(0.063)	(0.0786)	(0.0669)	(0.628)
	PROBIT Statistics			
Observations	1,260	640	432	261
Pseudo R-squared	0.1227	0.0881	0.0810	0.0947
Prob > χ-squared	0.000	0.000	0.0012	0.093
H-L (Prob)	0.1146	0.5771	0.1461	0.2646
	WTP Statistics			
Implied Mean WTP ($)	14.87*	15.98**	17.21***	17.10*
(Regime Level)	(9.02)	(7.23)	(4.94)	(9.66)
Mean WTP/Income	14.87/80.81	(15.98/6)/79.87	(17.21/12)/77.9	(17.10/24)/81.5
(Monthly Level)	=18.4%	=3%	7=2%	=1%
Mean Bid/Income	12.29/80.81	2.13/79.87	1.11/77.97	0.57/81.50
(Monthly Level)	=15.2%	=2.7%	=1.4%	=0.7%

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix L: VIF test for Multicollinearity in respect of WTP for ICS

Appendix L1: VIF test for Multicollinearity – Aspirational wood ICS (Main estimation)

Covariates	Upfront	6-month	12-month	24-month
Bid	9.32	2.65	2.42	2.42
Gender (Male)	23.28	19.18	19.09	19.09
Age *(logs)*	2.67	2.67	2.67	2.67
Primary occupation *(Student, free labour etc.)*	5.45	5.42	5.42	5.42
Primary occupation *(Retired & Unemployed)*	1.29	1.29	1.29	1.29
Marita status *(Never married)*	1.07	1.07	1.07	1.07
Marita status (*Divorced/Separated)*	2.07	2.01	2.01	2.01
Household size *(logs)*	3.99	3.99	3.98	3.98
Monthly income *(logs)*	1.82	1.85	1.86	1.86
Cooking Frequency *(Never)*	1.96	1.95	1.95	1.95
Stove use duration *(Short term)*	1.45	1.45	1.45	1.45
Fuel Affordability *(Affordable)*	2.55	2.55	2.55	2.55
Fuel Availability *(Always available)*	4.19	4.17	4.17	4.17
Safety of primary cookstove *(Safe)*	7.10	7.10	7.09	7.09
Cooking convenience *(Convenient)*	1.46	1.46	1.46	1.46
Grid electricity access *(Yes)*	2.00	1.99	1.99	1.99
Access to credit *(Yes)*	1.36	1.36	1.36	1.36
Informal finance *(Yes)*	1.27	1.27	1.27	1.27
Formal finance *(Yes)*	1.74	1.74	1.74	1.74
Mean VIF	**4.00**	**3.43**	**3.41**	**3.41**

Appendix L2: VIF test for Multicollinearity – Affordable wood ICS (Main estimation)

Covariate	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	9.41	2.65	2.46	2.44
Gender (Male)	26.66	21.36	21.34	21.33
Age *(logs)*	1.81	1.81	1.81	1.81
Primary occupation *(Student, free labour etc.)*	5.44	5.45	5.44	5.44
Primary occupation *(Retired & Unemployed)*	1.29	1.29	1.29	1.29
Marita status *(Never married)*	1.02	1.03	1.03	1.03
Marita status (*Divorced/Separated)*	2.49	2.37	2.37	2.36
Household size *(logs)*	4.22	4.22	4.22	4.22
Monthly income *(logs)*	1.84	1.87	1.87	1.87
Cooking Frequency *(Never)*	2.06	2.04	2.04	2.04
Stove use duration *(Short term)*	1.42	1.42	1.42	1.42
Fuel Affordability *(Affordable)*	2.47	2.46	2.46	2.46
Fuel Availability *(Always available)*	4.52	4.52	4.52	4.52
Safety of primary cookstove *(Safe)*	6.75	6.75	6.75	6.75
Cooking convenience *(Convenient)*	1.41	1.41	1.41	1.41
Grid electricity access *(Yes)*	2.17	2.17	2.17	2.17
Access to credit *(Yes)*	1.38	1.38	1.38	1.38
Informal finance *(Yes)*	1.27	1.27	1.27	1.27
Formal finance *(Yes)*	1.87	1.88	1.88	1.88
Mean VIF	**4.19**	**3.54**	**3.53**	**3.53**

Appendix L3: VIF test for Multicollinearity – Aspirational wood ICS (Robustness check)

Covariate	Upfront	6-month	12-month	24-month
Bid	8.32	9.59	9.76	9.18
Gender (Male)	23.28	24.30	27.55	28.97
Age *(logs)*	2.67	1.95	1.77	1.88
Primary occupation *(Student, free labour etc.)*	5.45	5.64	5.56	5.76
Primary occupation *(Retired & Unemployed)*	1.29	1.34	1.31	1.40
Marita status *(Never married)*	1.07	1.11	1.16	1.52
Marita status (*Divorced/Separated)*	2.07	2.31	2.24	2.40
Household size *(logs)*	4.99	5.25	7.09	9.20
Monthly income *(logs)*	1.82	2.25	2.78	3.36
Cooking Frequency *(Never)*	1.96	2.07	2.06	2.86
Stove use duration *(Short term)*	1.45	1.46	1.56	1.51
Fuel Affordability *(Affordable)*	2.55	2.42	2.51	2.68
Fuel Availability *(Always available)*	4.19	4.89	4.91	5.38
Safety of primary cookstove *(Safe)*	7.10	7.05	7.35	8.04
Cooking convenience *(Convenient)*	1.46	1.50	1.46	1.40
Grid electricity access *(Yes)*	2.00	1.90	1.92	1.84
Access to credit *(Yes)*	1.36	1.40	1.41	1.43
Informal finance *(Yes)*	1.27	1.26	1.27	1.29
Formal finance *(Yes)*	1.74	1.63	1.61	1.67
Mean VIF	**4.00**	**4.17**	**4.49**	**4.83**

Appendix L4: VIF test for Multicollinearity – Affordable wood ICS (Robustness check)

Covariate	**Upfront**	**6-month**	**12-month**	**24-month**
Bid	9.41	9.24	9.37	9.58
Gender (Male)	26.66	23.07	22.52	28.14
Age *(logs)*	1.81	1.58	1.54	1.52
Primary occupation *(Student, free labour etc.)*	5.44	4.98	5.10	5.39
Primary occupation *(Retired & Unemployed)*	1.29	1.38	1.47	1.47
Marita status *(Never married)*	1.02	1.03	1.04	1.75
Marita status (*Divorced/Separated)*	2.49	2.65	2.97	4.69
Household size *(logs)*	4.22	5.58	6.65	7.85
Monthly income *(logs)*	1.84	2.54	2.45	2.49
Cooking Frequency *(Never)*	2.06	2.29	2.69	3.65
Stove use duration *(Short term)*	1.42	1.35	1.40	1.39
Fuel Affordability *(Affordable)*	2.47	2.53	2.68	2.92
Fuel Availability *(Always available)*	4.52	4.59	5.29	5.67
Safety of primary cookstove *(Safe)*	6.75	6.64	7.95	10.68
Cooking convenience *(Convenient)*	1.41	1.40	1.41	1.47
Grid electricity access *(Yes)*	2.17	1.96	1.92	2.07
Access to credit *(Yes)*	1.38	1.48	1.58	1.63
Informal finance *(Yes)*	1.27	1.21	1.23	1.23
Formal finance *(Yes)*	1.87	1.71	1.68	1.70
Mean VIF	**4.19**	**3.94**	**4.12**	**5.01**