

VARIATION IN COOKSTOVE DEMAND:
AGE AND EDUCATION EFFECTS IN NORTHERN GHANA

by

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ABSTRACT

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Variation in Cookstove Demand: Age and Education Effects in Northern Ghana

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Nearly three billion people depend on solid fuels such as wood, dung, and crop residues for their daily energy needs. Burning these energy sources in open fires damages human and environmental health. Improved cookstove interventions, however, have the potential to reduce harmful emissions and better health and livelihoods (Bruce et al. 2000; Molnar 2015; Simon et al. 2014). Yet, owing to a combination of technological, social, cultural, and economic factors, not all interventions have been successful. Previous research demonstrates that successful interventions utilize stoves amenable to local cultural and socioeconomic conditions. By learning more about the factors that contribute to an individual's decision over what stove to use, aid organizations, governments, and private businesses can better match stove users with appropriate cooking technologies. In this work, I investigate the role that age and education play on the use of three different "tiers" of stove technologies; relatively speaking, these will be referred to as low, medium, and high. Within the context of the ongoing REACCTING (Research of Emissions, Air Quality, Climate, and Cooking Technologies in Northern Ghana) study, I find that older stove users prefer familiar (traditional) cooking technologies more than do their younger counterparts, while more educated users are partial to the highest technology stove available to them, which may provide more health and environmental benefits. Results for the medium tier stove are inconclusive with respect to age, but show that stove use is higher among less educated users. The findings presented combine regression analysis on available survey data

with an investigation of text-based survey responses. Results presented here substantiate those from previous work in both the improved cookstove sector as well as other technology disciplines.

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1. INTRODUCTION

Biomass such as wood, dung, and crop residues provides daily energy for roughly three billion people worldwide, with many studies suggesting this figure will rise in the coming decades (Barnes et al. 1994; IEA 2006; Legros et al. 2009; Taylor et al. 2011). Combusting biomass for energy accounts for roughly 9% of global energy use and more than half of the harvested wood on the planet (Masera et al. 2015). Developing economies rely heavily on bioenergy, with particularly high numbers seen among citizens of rural Africa (Bensch et al. 2012; IEA 2010). Burning biomass in open fires – as is done by the majority of solid fuel users – releases most of the smoke into the household in the case of indoor cooking, or the immediate vicinity for outdoor cooking (Bruce et al. 2006). This smoke contains many pollutants including carbon monoxide, particulate matter, sulfur and nitrogen oxides, aldehydes, benzene, and polyaromatic compounds (Bruce et al. 2006; Smith et al. 1987). Wood smoke pollutants such as these have been increasingly linked with both acute and chronic illnesses, with a growing body of literature linking these household air pollutants (HAP) with aggravated mucous membranes, cancers, and respiratory health maladies (Diaz et al. 2007; Naeher et al. 2007). Further, wood smoke from biomass fuels, such as those used for household cooking, has been shown – with varying levels of evidence – to play a causal role in tuberculosis, blindness, acute lower respiratory infections, chronic obstructive pulmonary disease, asthma, as well as lung, nasopharyngeal, and laryngeal cancers (Bruce et al. 2000; Ezzati et al. 2002). Exposure affecting pregnant women has also surfaced for its role in exacerbating perinatal conditions, including low birth weight (Ezzati et al. 2001; Florig 1997; Smith et al. 2000).

In addition to the associated human health burden, the burning of solid fuels is also responsible for contributing adversely to the environment on both local and global scales. Emissions such as carbon dioxide and black carbon are well-documented drivers of climate change. On a more regional level, it is known that a large portion of particulate matter in Africa and Asia is attributable to biomass burning (Dionisio et al. 2010). Meanwhile, overharvesting wood for residential energy needs continues to drive deforestation.

Although the negative impacts on human and environmental health associated with the combustion of solid fuels for household cooking are substantial, focusing solely on these ignores a litany of related issues. Deleteriously impacted populations typically belong to society's most marginalized groups. This includes women and children from the world's most economically disadvantaged regions, a natural result of which is a perpetuation of social injustice. This injustice can be seen, for example, in the substantial opportunity cost associated with fuelwood collection (an activity typically carried out by women in the developing world). Oftentimes this tradeoff displaces education or other remunerative tasks, exacerbating issues of female empowerment (Arnold et al. 2006). The scarcity of biomass in certain areas has also been the source of community conflicts (Matsa et al. 2009).

While complications with biomass cooking are substantial and widespread, methods to mitigate the problem exist. One such solution is the proliferation of improved cookstoves, technologies designed to reduce pollution and firewood consumption in the meal preparation process. In some cases, improved cookstoves have shown capable of reducing harmful emissions and bettering health and livelihoods (Bruce et al. 2000; Simon et al. 2014). A number of interventions have been touted as successful and have positively contributed to human and

environmental health; at the same time, a large number of interventions have failed (Hanbar et al. 2002). While much can be learned through examining failed interventions, unsuccessful interventions may taint user perceptions of these potentially life-saving technologies. Previous research demonstrates that successful interventions utilize stoves amenable to local cultural and socioeconomic conditions (Adrianzen et al. 2014). This suggests that approaches that consider these socioeconomic and cultural factors in conjunction with effective technologies and distribution practices may help contribute to successful cookstove interventions.

Prior work has examined a variety of determinants of demand for improved cookstoves, but few studies have extended this research to examine how demand for cookstoves varies across demographic groups (Jeuland et al. 2013; Kim et al. 2011; Lewis et al. 2012). Particularly, conclusive evidence on the relationship between age and adoption of new cooking practices is notably sparse (Troncoso et al. 2007). Where this relationship has been examined, chosen proxies for quantifying and measuring stove use have been insufficient (Muneer 2003). Theory from literature in related fields, such as farming technologies in Guinea, mobile phone use in Africa, and biogas technology in Uganda illustrates that younger household heads demonstrate higher degrees of openness, willingness, and ability to engage with and learn to operate more complicated technologies (Adesina et al. 1995; Aker et al. 2010; Walekhwa et al. 2009). In this work, I investigate whether this relationship between age and adoption is also present in the cookstove sector in the context of one cookstove intervention in Northern Ghana, and, further, I add to existing literature on the impact of education on cookstove use. Specifically, I explore and present results on whether older women, due to their established cooking practices, value and/or use improved stoves less than their younger counterparts and, additionally, whether more educated respondents demonstrate higher use for these improved stoves.

In answering these questions, I work within the context of the REACCTING (Research of Emissions, Air Quality, Climate, and Cooking Technologies in Northern Ghana) study – a partnership between the University of Colorado Boulder, the National Center for Atmospheric Research, and the Navrongo Health Research Center. REACCTING is a randomized intervention study, introducing two types of new stoves to 200 households. Regression analysis is performed on panel data collected from seven rounds of surveys, carried out between November 2013 and July 2015. These include one baseline (pre-intervention) survey and six follow-up surveys. Text responses from stove users are also coded and analyzed to add explanatory power to quantitative findings. This use of mixed methods comes in response to the growing number of requests for such methodology within the cookstove literature (Davis et al. 1998; Loo et al. 2016; Stanistreet et al. 2015; Stanistreet et al. 2016;).

2. LITERATURE REVIEW

The purpose of this research is to examine the effects of age and education on stove use patterns for three different types of cookstoves, each with varying levels of technological complexity, in the context of a cookstove intervention in Northern Ghana. To do this, I will begin with an overview of the current state of global bioenergy used for cooking as well as discuss the implications this has for both human and environmental health. Next, I will highlight the disproportionate strain placed on vulnerable populations and discuss the issue of time poverty. Moving toward potential solutions, I will introduce improved cookstoves and review available literature, illustrating examples of both successful and unsuccessful interventions. In the case of unsuccessful interventions, it is important to understand the reasons for failure.

By examining available studies, I will discuss factors that have been found to contribute to the success or failure of past cookstove interventions. This includes factors - such as education - which have seen significant attention from past studies, as well as factors - such as age - which have not been extensively studied in the cookstove literature. Since evidence on the relationship between age and stove adoption is sparse, findings on the effects of age and technology adoption in other sectors will be highlighted. I will conclude this section with anticipated results, which the proposed study hopes to contribute to the growing body of cookstove adoption literature.

2.1 Current State of Global Bioenergy

Approximately 40% of the world's population is reliant on biomass fuels (wood, crop residues, animal dung, etc.) for their primary source of energy (Saldiva et al. 2004; Pine et al. 2011). This percentage is particularly high in the developing world, particularly rural areas, with significant geographic variability. Despite these fuels being among the crudest energy sources, their use is expected to rise in the coming decades (IEA 2006; Legros et al. 2009). Residential energy needs such as heating and cooking are responsible for more than fifty percent of global wood harvest, and recent estimates suggest that as much as one-third of this fuel is collected in an unsustainable fashion (Bailis et al. 2015). In an effort to both mitigate the burden that unsustainable wood harvest places on landscapes as well as to address the human health maladies associated with combustion of open fires, the Ghanaian government has recently committed to lowering its country's reliance on biomass burning for household cooking (Jack et al. 2015; Smith et al. 2014). With this as a backdrop, my work - in combination with the REACCTING study as a whole - comes at a particularly opportune time.

2.2 Human Health

Combusting biomass in traditional fires, as is done in much of the developing world, releases harmful pollutants including carbon monoxide, sulfur oxides, nitrogen oxides, particulate matter, formaldehyde, and polycyclic aromatic hydrocarbons (Bruce et al. 2000; Lim et al. 2013; Smith et al. 1987). In the case of indoor cooking, all household members will experience some level of exposure to indoor air pollution, with those who spend more time in kitchens likely receiving higher exposure. In other societies, where the majority of residential cooking is performed outdoors, primary cooks and those in the immediate vicinity of the fire (often young children) are disproportionately exposed (Jack et al. 2015; Ezzati et al. 2001).

Repeated exposure to these emissions can negatively impact human health. Specifically, there is evidence that suggests associations with pneumonia, asthma, tuberculosis, low birth weight, and cataracts, as well as nasopharyngeal, laryngeal, and lung cancers (Bruce et al. 2000; Kim et al. 2011; Naehar et al. 2007). With nearly 3 billion people reliant on inefficient biomass for their cooking needs, associated indoor air pollution is a substantial public health challenge.

According to the World Health Organization, fuel stove emissions kill 4.3 million people annually (World Health Organization 2013). After high blood pressure (which also has been linked to smoke exposure), household air pollution (HAP) is the leading factor contributing to the global disease burden for women and the fourth largest disease burden overall (Simon et al. 2014). In fact, nearly five percent of “lost healthy life years” are attributable to HAP (Smith et al. 2014). This weight falls disproportionately on low-income nations, the majority of which are located in the global south.

In addition to household air pollution related maladies, the World Health Organization attributes nearly 300,000 deaths to burns resulting from cooking fires – almost exclusively in the developing world (World Health Organization 2013). While certainly a global problem, in context of the work in Ghana that follows here, it is relevant to note: “the recent Global Burden of Disease/Comparative Risk Assessment process concluded that household air pollution is the most impactful of the modifiable risk factors evaluated for Ghana” (Jack et al. 2015).

2.3 Disproportionate Burden

With exception, patriarchal societies continue to dominate in much of both the developing and developed world. In such hierarchical social structures, women are frequently charged with home tasks such as meal preparation (Muneer et al. 2003). With rural populations

in Africa relying nearly exclusively on open fires for their cooking energy needs, it is not unusual for women to be exposed to household air pollution for multiple hours each day (Bensch et al. 2012; IEA 2010). Women in these societies also bear a larger share of the childcare responsibility than their husbands (Köhlin et al. 2011). By association, children in these communities also spend significant time around woodsmoke – particularly infants carried on the backs of their mothers. In fact, “observational studies have indicated that smoke from household fuels ... affects more than half of the world’s children” (Smith et al. 2011). An implication of these established social structures is long exposure times that disproportionately jeopardize the health of women and children (Edwards et al. 2012). A study from the Gambia, for example, found that the incidence of acute lower respiratory infection among a group of 500 children carried on the backs of their mothers was more than five times higher than other children (Armstrong et al. 1991). In addition to respiratory infections, it is known that more children fall victim to pneumonia death – a disease, which increasing numbers of studies suggest to be associated with exposure to household air pollution - than any other disease (Smith et al. 2011).

2.4 Fuelwood Collection and Time Poverty

With the International Energy Agency anticipating the use of biofuels for residential energy use to remain high in the coming decades (particularly in regions such as Africa), it is important to consider the adverse effects related to fuelwood collection (IEA 2002). In many rural areas, gathering firewood is a lengthy and labor-intensive activity. This is further exacerbated in areas where improper land and forest management have made access to natural resources scarce. In patriarchal societies, where women and children bear the responsibility of collecting fuel wood, this contributes to an issue known as “time poverty” – pulling women and

children away from education and income generating activities and limiting female empowerment (Arnold et al. 2006; Blackden et al. 2006; Cecelski 1987). “[T]here is also significant evidence that health also affects the school attendance and productivity of children ... [and] if households tend to be in better health ... they can save much in medical expenditures, which tends to be a large portion of expenditures among the very poor” (Duflo et al. 2008). All of this evidence suggests that the collection and burning of solid fuels in open fires is not only problematic when viewed through the lens of human health, but also for related issues that continue to feed the cycle, which keeps the poor from breaking out of poverty, women from attaining empowerment, and children from pursuing education.

2.5 Environmental Health

With climate change now recognized by some to be a serious global risk, climate-driving pollutants and deforestation have become major concerns. Compared with cleaner alternatives (capable of efficiencies ranging from 30-70%), the inefficient combustion of traditional biomass stoves (typically realizing efficiencies of 10-20%) requires more fuel per unit of energy produced (Jetter et al. 2012; Masera et al. 2015; Singh et al. 2014; Smith et al. 2000). This increases the unsustainable harvest of firewood (shrinking the capacity of world forests to serve as carbon sinks) and increases the emissions of greenhouse gases such as methane, nitrous oxide, and black carbon. “Recent analyses estimate that traditional wood fuels, via unsustainable harvesting and incomplete combustion, contribute approximately 2% of global greenhouse gas (GHG) emissions including 20–30% of global black carbon (BC) aerosols” (Masera et al. 2015; Bailis et al. 2015; Bond et al. 2013; Ramanathan et al. 2008; Unger et al. 2014). Black carbon, while short-lived in the atmosphere, has incredible heat-trapping potential; it is thought to contribute to

reductions in crop yields and glacial melt and is shown to have localized impacts (Smith et al. 2010; Venkataraman et al. 2010). According to the recent IPCC Report, black carbon is the second most important climate-forcing anthropogenic pollutant (International Panel on Climate Change Fifth Assessment Report). Meanwhile, compared with carbon dioxide, methane and nitrous oxide are well documented to have higher, per ton, global warming potentials (Bruce et al. 2000; Venkataraman et al. 2010). The myriad negative externalities associated with traditional biomass-based cooking seem a clear invitation for changes in the way cooking is carried out in much of the developing world. Improved cookstoves offer one potential solution.

2.6 Improved Cookstoves

The technology sector has demonstrated the feasibility of designing and manufacturing improved stoves. A growing body of literature offers evidence, which largely (although not exclusively) supports the benefits of these improved stoves. A case study from Senegal, for example, shows a 25-30% reduction in firewood use after participants began using improved cooking technologies (Bensch et al. 2015). In a cookstove intervention in Mexico, kitchen levels of both particulate matter and carbon monoxide were each reduced by roughly 66% compared to pre-study concentrations (Masera et al. 2007). Conversely, a cookstove intervention in the Upper West region of Ghana did not find any statistically significant reductions in fuelwood use, time spent collecting fuelwood, or in households' exposure to carbon monoxide (Burwen et al. 2012). It would seem that the substantial variability in the success of stoves is due, at least in part, to the wide variety of different clean cooking technologies available. In fact, The Clean Cooking Catalog, compiled by the Global Alliance for Clean Cookstoves (GACC), lists more than 320 of these improved stoves. These cooking technologies range from simplistic, locally

made clay stoves, at prices of less than \$5 to more technically sophisticated and imported stoves in excess of \$100. Based on evaluations relating to general emissions, indoor emissions, safety, and efficiency, stoves are assigned a “tier” (on a scale of one to four, with four indicating the highest performance). Generally speaking, the cleaner - higher tier - stoves are also more expensive – an important consideration, when interpreting study results (Global Alliance for Clean Cookstoves 2016). Although this work focuses on improved biomass stoves, it is important to acknowledge that alternatives exist, notably stoves powered by LPG (liquid petroleum gas) and electricity.

The Global Alliance for Clean Cookstoves is a public-private partnership founded in 2010, in association with the United Nations Foundation. In an attempt to save lives, improve livelihoods, empower women and preserve the environment, they set a goal to distribute 100 million stoves by 2020. Current numbers reveal that they are ahead of this goal (Global Alliance for Clean Cookstoves 2016; The World Bank 2013). One estimate suggests that the successful distribution and adoption of 100 million improved cookstoves would cut carbon emissions from woodfuels by 11-17%. In a carbon market that included black carbon, these savings would be worth more than one billion USD (Bailis et al. 2015).

2.7 Cookstove Adoption

As discussed above, disseminating improved cookstoves does not always result in successful interventions. This may be attributable to the quality of stove technologies. Alternatively, recent empirical literature points to demographic, geographic, economic and cultural barriers as reasons for failed interventions (Adrianzen et al. 2014; Mobarak et al. 2012; Pandey et al. 1991). A wood stove in Kenya failed to be adopted due to time constraints faced

by women, who were required to cut wood into small pieces before feeding them into the combustion chamber (Openshaw et al. 1982). In Nepal, an improved stove that failed to take into account the extreme altitude also proved unsuccessful (Pandey et al. 1991). Meanwhile, in rural India, differences in cooking times between the laboratory and field measurements disincentivized stove use and resulted in yet another failure for an attempted intervention (Hanna et al. 2012). According to Ruiz-Mercado: “[n]o stove program can achieve its goals unless people initially accept the stoves and continue using them on a long-term basis” (Ruiz-Mercado et al. 2011). This suggests, therefore, that cookstove adoption plays an important role in the larger system governing successful cookstove interventions.

Measuring adoption, however, can be problematic. A lack of industry wide standards, no universally accepted definition for adoption, and funding limitations can all be blamed. Some of the confusion surrounding adoption can also be attributed to the existence of different stages in the adoption process; these include the acceptance phase, the initial use phase, and the sustained use phase (Ruiz-Mercado et al. 2015). As a result, it has been suggested to use a “new framework where the adoption of a new cooking device is seen as a dynamic ‘complex process and a stage in a larger process’” (Pareek et al. 1966; Ruiz-Mercado et al. 2011).

One method for increasing the accuracy of adoption measures is the collection of stove use data over a period of several months. By using panel data, researchers can avoid over-reporting stove use that may arise from initial excitement or social-desirability bias. Further, this allows time to witness decreased usage that may be arising from broken technologies. A study from Haryana, India, for example, showed a steady decline in stove use over time, with stove use levels first stabilizing after about 200 days (Pillarsetti et al. 2014). In addition to sustained use,

the frequency of stove use is also important. Pine et al. suggest that “[c]riteria for success should be expanded to include the intensity and rate of use of a new technology, rather than a simple count of the number of products that have been disseminated” (Pine et al. 2011). In some cases, households will also mix new and old stove technologies, a practice known as “stove stacking”. In the case of stove stacking, it is important to develop robust measures for quantifying the degree to which traditional stoves are being replaced, as the results have important implications for both human and environmental health (Hanna et al. 2012; Pareek et al. 1966; Shih et al. 2004).

Comprehending the factors that negatively impact adoption is important to the success of cookstove interventions; understanding the factors that *aid* in the adoption of improved stoves, however, is equally important. A review of 57 cookstove studies from Latin America, Asia, and Africa reveals many of these influencing characteristics. Higher socioeconomic status, a stove’s ability to recreate food taste on par with that of traditional stoves, substantive fuel savings, robust user training on stove maintenance and use, and increased education are all mentioned as having positive and significant effects on stove adoption (Rehfuess et al. 2014). For its relevance to this work, the relationship with education will be examined in further detail.

2.8 Education and Adoption

Increased education aids awareness of the existence of new technologies. In the case of health improving technologies, more educated individuals are also more likely to understand the benefits and importance of these innovations. For improved cookstoves, a comprehension of potential health benefits is shown to increase household willingness to use these technologies (Jan et al. 2012). From a study in urban India, Farsi et al. found that females with higher levels

of education were more likely to substitute modern fuels for their biomass counterpart (Farsi et al. 2007). Meanwhile, a 2014 review by Malla highlights several examples of studies demonstrating a positive relationship between education and a household's choice of fuel and stove (Heltberg 2004; Pandey et al. 2004; Pundo et al. 2006). Owing to its important effect on stove use patterns, education is included as a predictor variable in the model for this work.

2.9 Age and Technology Adoption

A review of the literature from related fields shows that, when it comes to the utilization and adoption of more complicated technologies, younger household heads demonstrate a higher degree of openness, willingness, and ability compared with their older counterparts. A case study in Uganda, for example, found the age of a household head to have a significant negative effect on the adoption of biogas technology (Walekhwa et al. 2009). Similar results were found in Burkina Faso, where the adoption of composting technologies was significantly higher among younger farmers (Somda et al. 2002). Despite such evidence, “[t]he association between age and adoption of new technologies is sensitive to variation in parameters and therefore the net effect of age on adoption cannot be determined a priori” (Walekhwa et al. 2009). With this in mind, it is important to consider each technology individually. In the case of improved cookstoves, few studies have investigated the relationship between age and cookstove adoption. Where this question has been asked, methodological robustness needs to be improved. In Sudan, for example, it was found that age had a significant negative effect on the adoption of a biomass stove (Muneer et al. 2013). In this study, adoption was defined to be whether or not a household “started using the stove”. From adoption literature, however, we know that household use of improved cookstoves may diminish substantially up to 200 days after beginning use (Pillarisetti

et al. 2014). Thus, results stemming from measurements that ignore this time component must be dealt with cautiously.

In a case study in rural Mexico, age was also examined for its potential to influence the adoption of Patsari biomass cookstoves. “With respect to age, even though a few old women adopted a Patsari, all women who rejected the new technology were old women. More studies need to be conducted focusing on this age group separately” (Troncoso et al. 2007). In response to this call for more studies to focus on the relationship between age and cookstove adoption outcomes, I will investigate the effect of age and education on cookstove adoption using panel data from the REACCTING intervention in Northern Ghana.

2.10 Research Question and Motivation

This paper investigates the relationship between both age and education on the use of cookstove technologies. Specifically, it examines the relationship between age and the use of three different stove technologies in the Kassena-Nankana District of Northern Ghana as well as the relationship between education and the use of three different stove technologies in this area. To allow for comparisons between age and education effects related to low, medium, and high technology stoves, the stoves chosen represent three separate tiers on the technology ladder. It is the hope that by better understanding how cooking behaviors vary with age and education, cookstove manufacturers and distributors will be better positioned to target new stoves to users more likely to adopt. By extension, this work has implications for bettering both human and environmental health.

2.11 Hypotheses

Leveraging aforementioned literature from related fields, it is my expectation that age will have a positive relationship with the continued use of the low technology traditional cookstove, the three stone fire (H1).

Further, I expect age to have a negative relationship with the use of higher technology cookstoves (H2).

With much evidence supporting the positive effect of education on the adoption of advanced cookstove technologies, it is my suspicion that increased education amongst the Ghanaian study population will prove to foster and contribute to the use of the high technology Philips cookstove (H3).

In the case of the lower technology three stone stoves, I anticipate continued use to be highest among members of the study population with the least amount of education (H4).

3. METHODOLOGY

3.1 Context and Study Area

The investigation has been carried out in northern Ghana's Kassena-Nankana Districts (Figures 1 and 2).

Figure 1

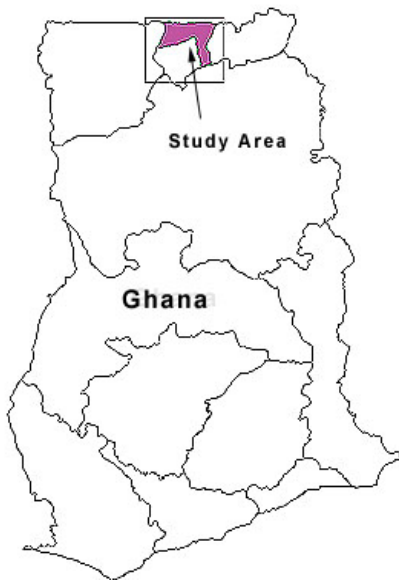
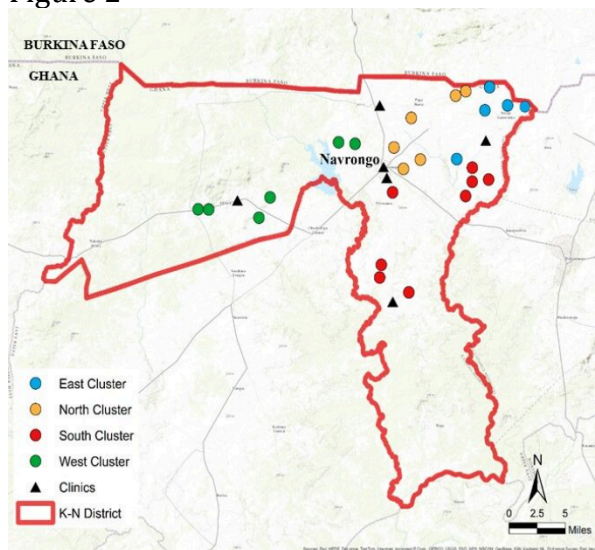


Figure 2



The study area is characteristic of Savanna vegetation zones; it has a warm and dry climate with the exception of the rainy season, which lasts from roughly May to October. Regional demographic and socioeconomic information stems from a Health and Demographic Surveillance Survey, partial results of which are shown below in the district snapshot. The area, bordered by Burkina Faso to the north, contains a population of 156,000 across a land area of roughly 1700 square kilometers. More than 95% of the households lack sanitation facilities and only 13% have access to electricity. The District is fairly evenly divided into two major ethnicities with 52% reporting to be of Kasem ethnicity and 45% of Nankam ethnicity. The majority (84%) of households use traditional biomass (typically wood and agricultural waste) as their primary fuel source and cook over traditional three stone fires (Oduro et al. 2012).

Using a random sampling technique, 200 households were chosen to participate in the REACCTING study. Rural households distant from the city of Navrongo were chosen from four regions: North, East, South, and West – relative to the city center (Figure 2). A distribution proportional to population was used such that 48 households from the North, 40 from the East, 64 from the South, and 48 from the West were chosen. In order to be eligible to participate in the intervention, households needed to contain at least one woman between the ages of 18-55 and one child under five. Additionally, the intervention required that participating households used biomass as their primary fuel source.

3.2 Background

The primary objectives of this paper are to examine the roles of age and education on cookstove adoption, where stove use (once stoves are already in participants' homes) in the

presence of decreased use of traditional stoves, will be used as a proxy for cookstove adoption. The REACCTING study in northern Ghana provides an ideal context for answering these questions, given the study's design, multidisciplinary and abundant data, and its research partnerships.

As previously mentioned, the analysis here looks at three stoves: one "low-tech" stove, one "medium-tech" stove, and one "high-tech" stove. The lowest technology stove, already in use prior to the REACCTING intervention, is the traditional three stone stove. The three stone stove is a simple open fire, in which wood is fed underneath three large stones, used to support a pot. The medium-tier technology is the Gyapa stove - a locally manufactured and durable wood stove. Its simple design consists of a ceramic liner surrounded by an aluminum casing. It has no electrical wirings or other advanced technological features. It offers the closest cooking experience to that of the three stone, while potentially offering reductions in fuel use. The Philips stove is the highest technology stove. It uses a fan to drive gasification and can burn any kind of biomass. It is considerably more advanced than the Gyapa in that it uses a fan, battery, and solar panel. The solar panel is used to charge the battery, which powers an internal fan. By using a control knob to adjust fan speed, the Philips stove can quickly control its combustion rate, a feature designed to improve combustion efficiency. In turn, this improved efficiency may result in both smoke and fuel use reductions.

The sample population of 200 households was randomized into four different intervention groups (A, B, C, and D), each containing 50 households. Group A received two Gyapa stoves; group B received two Phillips stoves; group C received one Gyapa and one Philips

stove; group D is held as a control, receiving the stoves of their choosing at the conclusion of the study. Participating households are monitored over the duration of the investigation. Specifically, cooking practices, ambient air quality, indoor air pollution, individual exposure levels, and health indicators are measured (Dickinson et al. 2015).

3.3 Measuring Stove Use

In order to examine the effects of age and education on cookstove use, I analyze data from the project's household surveys, which have been conducted on seven occasions (referred to here as rounds) since the study began in November 2013. Survey respondents are households' primary cooks. The baseline data (round 1) is omitted, since this was before households had received improved cookstoves. The surveys gather information pertaining to cooking habits, anthropometric measurements, household data, etc. For the purposes of this analysis, however, responses related to stove use and respondents' ages and educational attainment are most relevant.

Since stoves are already in participants' homes, I assume that users who will adopt a particular stove will demonstrate this by using that stove. To quantify this, stove use is examined in several ways. During each survey round, respondents are asked to respond to questions about their cooking habits on each of the stoves present in the household. Respondents answer questions about whether they used the stove yesterday and how many times they have used the stove in the past week. Possible responses for the number of days in the past week that the stove was in use are: 0 days, 1-3 days, 4-6 days, and 7 days. If a survey respondent reported cooking

on a stove either 4-6 days or 7 days during the previous week, they were considered to be “high frequency users” for that stove. If they reported cooking 0 days or 1-3 days during the previous week, they were considered to be “low frequency users” for that stove. These results are then paired with overall trends of three stone use, to see if, in fact, traditional stove use has decreased.

3.4 Age Analysis

At the beginning of the cookstove intervention, study participants were asked for their age. This was simply reported as the numerical value corresponding to the age, in years, of the respondent at the time of the baseline survey (November 2013). To enable analysis between younger and older cookstove users, the binary variable, *respageunder30*, was created; this independent variable divides respondents into two categories: “younger than 30” and “30 and older”. Based on consultation with members of the local survey team, thirty was determined to be a culturally appropriate threshold for looking at the stove demand of younger vs. older respondents.

3.5 Education Analysis

The second independent variable measures the education of the respondent. Listed from lowest to highest educational attainment, the six possible responses include: never attended school, less than primary, primary, junior high, secondary, and tertiary/higher. Since educational attainment is a categorical variable, dummy variables were created for different educational levels. Respondents with no education or with less than a primary education were grouped into a

“low education” category. Individuals who have finished primary school, but have not received education beyond junior high were placed into a “medium education” category. Those who have completed high school or beyond were grouped into the “high education” group.

3.6 Stove Use Analysis

Since intervention participants were provided different stove combinations based on group, only those groups that possessed a given stove were included in that category’s analysis. For example, only members of groups A & C were included in the analyses relating to the Gyapa stove. If the respondent (regardless of having received one or two Gyapa stoves) answered that they had cooked on at least one Gyapa stove on the previous day, they were assigned a “1”. [For naming purposes this variable was termed *yest_G*. The “G” denotes Gyapa and would similarly be labeled “P” for Philips and “T” for three stone.] Those in groups A and C, who had not used their Gyapa stove the previous day, were assigned a “0”.

Similarly, if Gyapa users reported using their stove between 0-3 days in the previous week, they were assigned a “0” (indicating placement in the low frequency user category) and those users reporting 4-7 days of Gyapa use were assigned a “1” (indicating placement in the high frequency user category). For naming purposes this variable was termed *high_cook_freq_G*. Again, the “G” denotes Gyapa and would similarly be labeled “P” for Philips and “T” for three stone. The same methodology was also used for the Philips and three stone users, with the exception that Philips users were drawn exclusively from groups B and C and three stone users were represented in every group (that is, groups A, B, C, and D).

3.7 Robustness Measures

Several robustness measures were performed during the data cleaning process. While the survey respondent is the household's primary cook, it is possible that other in-household survey participants also perform cooking tasks. In survey rounds where non-respondent cooks are the stove users, age is updated accordingly to avoid confounding results. To accomplish this, observations reflecting non-respondent cooks were first identified in the data during specific rounds. The age values for these non-respondent cooks were then manually entered for the corresponding round(s) to override the previous age value (i.e. respondent age). Data for the educational attainment of non-respondent cooks is unknown and thus could not be updated. During each survey round, respondents are asked to report on the condition of each of their stoves. Where maintenance issues exist, data on each damaged part is available. With minor problems (i.e. small cracks in the liners of the Gyapa stoves), stove use can continue uninterrupted, and so these observations were kept. Major problems (i.e. broken batteries, stove bases, and fans for Philips stoves), more directly prohibit use, and thus these observations have been dropped.

It is also important to note that this study measures stove use (a proxy for adoption) in a fashion consistent with what has been called for in recent cookstove adoption literature (Pillarisetti et al. 2014; Ruiz-Mercado et al. 2011). To further buttress these results, other members of the study team have installed stove use monitors on the distributed stoves, capable of reporting temperature spikes. Rapid temperature spikes are assumed to be indicative of a

cooking event. These results are triangulated with self-reported and observed cooking data to present a more robust picture of stove use. While the specific incorporation of stove use monitor data is beyond the scope of this investigation, evidence from other REACCTING members shows that SUMs and surveys were fairly consistent in their measurements of stove use patterns across groups (Piedrahita et al. 2016). By monitoring stove use with multiple measures, over six rounds (baseline excluded), dispersed over nearly two years, this methodology seeks to avoid pitfalls of over-reporting that have been suggested to have occurred in similar studies (Muneer et al. 2003; Pine et al. 2011; Ruiz-Mercado et al. 2012).

3.8 Regressions

Models employed considered both logistic (logit) regression and the Ordinary Least Squares method. Due to the binary nature of the dependent variable, however, only models using logistic regression are reported. Initially, simple models looking exclusively at the age variable as a predictor of stove use were utilized. For each stove, *respageunder30* was first regressed on variables for “high frequency use” and later regressed on variables for “any use yesterday”. The model was then expanded to include both age and education as explanatory variables. For each stove, *respageunder30*, *education_medium*, and *education_high* were first regressed on variables for “high frequency use” and later regressed on variables for “any use yesterday”. In both model permutations, concerns about pooled non-independent data were addressed by clustering standard errors by household and separating analyses based on individual survey rounds (rounds 2-7).

3.9 Text-based Survey Analysis

Recent literature on cookstove adoption calls for both qualitative studies as well as studies that combine both quantitative and qualitative methodologies (Adkins et al. 2010; Loo et al. 2016; Puzzolo et al. 2013; Stanistreet et al. 2015). In this work, I leverage text responses to add limited explanatory power to results found through regression analysis. During the sixth survey round (24 months after the start of the cookstove intervention), respondents were given an opportunity to respond to a hypothetical question of whether or not they would be interested in trading stoves with another household. As an example, a household with two Gyapa stoves could choose to respond that they wished to trade one or both of their stoves for Philips stoves. After indicating their stove trading preferences (only five percent of households in groups A, B, and C wished to trade), survey respondents were then asked to explain these choices and, specifically, answer why they were or were not willing to trade. Since the group D members serve as a control group, and do not have firsthand experience using the improved cookstoves, their responses are not included. Using Rubin's methodology for coding as a baseline, participant responses were analyzed for text patterns (Rubin et al. 2011). Due to the small number of text responses (N=138), this analysis was carried out by hand and observed patterns were then quantified. In this way, the hope was to gain nuance that might have been overlooked through traditional coding. The coding process revealed six responses, which were frequently mentioned by members of the various stove groups (Group A – Gyapa/Gyapa; Group B – Philips/Philips; Group C – Gyapa/Philips; Group D – Three Stone):

1. [Combination]: With this group, respondents voice a preference for a combination of stoves, which is to say, one Gyapa and one Philips. Typically (in 80% of cases) these

individuals already belong to group C, meaning they have experience owning one of each stove type. Respondents preferring a combination of stoves cite the specific advantages of owning different cooking technologies. The Gyapa stove, for example, is superior for preparing TZ (a type of millet porridge) and the Philips stove is often preferred for cooking vegetables. This idea is similar to the suite of cooking technologies used in the developed world, where a cook may choose, for example, to use a microwave, electric stove, and gas grill to prepare one meal.

2. [Familiarity]: Responses that receive this label all contain some permutation of the idea that stove users are comfortable with (used to cooking on) their current fleet of stoves. These respondents have directly stated or strongly implied that they do not want to have to change to a different technology. Households citing familiarity as an influencing factor for their trade decisions belong almost exclusively (with only one exception) to the Gyapa-Gyapa group.
3. [Fuel Savings]: With this group, respondents cite fuel savings as a motivating factor for trade decisions. Specifically, these survey participants mention the Philips stove as the technology best suited to offer substantive fuel savings. Respondents who cite fuel savings as an important factor come from all relevant stove groups (A-C).
4. [Performance]: In the performance category, respondents prefer to trade for stoves, which they believe to have better cooking performance. Cooking performance includes indicators such as speed of boiling water, improved taste, and a general increase in the ease of food preparation. Once again, respondents in this group stem from all relevant stove groups.

5. [Portability]: The ease of stove transport proved to be a motivating factor for a number of households' trade decisions. Respondents in this category reveal that stove portability is useful, insomuch as it offers the option of cooking both indoors and outdoors; this flexibility is particularly useful during the rainy season. Portability is also a factor that receives roughly equal mention in each of the groups A-C.
6. [Technology]: Responses placed into this category all cite difficulties in understanding how the Philips stove is operated as motivators for their trade decisions. In some cases, answers clearly indicate that the respondent did not understand how to operate a Philips stove. This includes misperceptions about electricity, solar charging panels, batteries, and fans. Yet again, respondents motivated by technological issues, stem from stove groups A, B, and C.

Once coding was completed, dummy variables were created for each of the six categories. This allowed descriptive statistics (discussed in more detail below) - specifically the arithmetic mean - to be compiled and sorted according to education and age. Education was then broken into two categories, high and low. Respondents indicating less than a primary school education were, as with the regression analysis, placed into a "low education" category; conversely, respondents indicating a primary school education or higher were placed into a "high education" category. The reader should note that this is slightly different than how education is categorized for the regression analysis; in this iteration, the medium and high education groups from the regression portion are combined into one group, termed high education. This is done to account for the relatively few text-based survey respondents belonging to the medium and high education groups. For age, the binary measures "30 and above" and "under 30" were once again

employed. Responses were also sorted according to willingness to trade (labeled “trader” and “non-trader”) and, finally, by stove group. This was done to account for respondent variability attributable to stove trading preference as well as being exposed to a different combination of stove technologies. Arithmetic means, specifically, allow for simplistic comparisons between stove groups, attributable to the independent variables of interest. While this text-based analysis does offer the ability to bolster or contradict findings from the regression analysis, it is critically important to note the limitations do exist in its explanatory power, due to the small number of available observations.

3.10 Descriptive Statistics

The age distribution of the population of reported cooks is fairly young, with less than five percent over the age of 50. The majority of these fall between the ages of 20-39. As a whole, the population has attained fairly low levels of education, with less than five percent having completed past primary school, and roughly half with no education at all. Interestingly, large discrepancies exist between groups. Group A has the largest percentage of individuals with no education (67%), while group B has the lowest (37%).

Stove use for both the Gyapa and Philips stoves (as measured by “use yesterday”) follows a steady pattern of decline over the duration of the six follow-up rounds. Between round two and round seven, the use of the Gyapa stove decreases from 85% to 60% for group A and from 64% to 43% for group C. For the same time interval, use of the Philips stove decreases from 56% to 15% for group B and from 33% to 6% for group C. Conversely, three stone use for groups A-C

shows a steady increase: 37% to 60% (group A), 65% to 89% (group B), and 42% to 70% (group C). While the improved cookstoves follow a pattern of decreasing use demonstrated in other studies, it is encouraging to note that use of traditional three stone stoves (one important proxy for adoption), is lower at the end of the study in each of the groups receiving alternative cooking technologies (Pillariseti et. al 2014). With an improved understanding of relevant descriptive statistics (tables 1-5) the next section transitions to discuss results.

Table 1: Descriptive Statistics, Age

<u>AGE:</u>	<u>Under19</u>	<u>20-29</u>	<u>30-39</u>	<u>40-49</u>	<u>50-59</u>	<u>60-69</u>	<u>70-79</u>	<u>80-89</u>
<u>GROUP A</u>								
Observations	55	92	71	61	25	11	0	6
Cumulative	17.13	45.79	67.91	86.92	94.7	98.13	98.13	100
<u>GROUP B</u>								
Observations	47	113	61	74	24	6	0	0
Cumulative	14.46	49.23	68	90.77	98.15	100	100	100
<u>GROUP C</u>								
Observations	18	80	112	53	48	15	3	0
Cumulative	5.47	29.79	63.83	79.94	94.53	99.09	100	100
<u>GROUP D</u>								
Observations	24	91	125	44	24	10	13	0
Cumulative	7.19	34.43	72.75	85.93	93.11	96.11	100	100

Table 2: Descriptive Statistics, Education

EDUCATION:	<u>None</u>	<u>Less than Primary</u>	<u>Primary</u>	<u>Junior High</u>	<u>High School</u>	<u>Post Secondary</u>
<u>GROUP A</u>						
Observations	214	7	58	42	0	0
Cumulative	66.67	68.85	86.92	100	100	100
<u>GROUP B</u>						
Observations	120	26	92	66	14	7
Cumulative	36.92	44.92	73.23	93.54	97.85	100
<u>GROUP C</u>						
Observations	175	34	78	28	14	0
Cumulative	53.19	63.53	87.23	95.74	100	100
<u>GROUP D</u>						
Observations	167	35	65	60	7	0
Cumulative	50	60.48	79.94	97.9	100	100

Table 3: Descriptive Statistics, Gyapa Use Yesterday

	<u>Round 2</u>	<u>Round 3</u>	<u>Round 4</u>	<u>Round 5</u>	<u>Round 6</u>	<u>Round 7</u>
<u>GROUP A</u>						
Observ.	46	46	47	42	45	47
Percent	84.7	84.7	74.4	73.8	66.6	59.6
<u>GROUP B</u>						
Observ.	N/A	N/A	N/A	N/A	N/A	N/A
Percent	N/A	N/A	N/A	N/A	N/A	N/A
<u>GROUP C</u>						
Observ.	45	48	47	47	46	47
Percent	64.4	58.3	48.9	59.6	52.1	42.5
<u>GROUP D</u>						
Observ.	N/A	N/A	N/A	N/A	N/A	N/A
Percent	N/A	N/A	N/A	N/A	N/A	N/A

Table 4: Descriptive Statistics, Philips Use Yesterday

	<u>Round 2</u>	<u>Round 3</u>	<u>Round 4</u>	<u>Round 5</u>	<u>Round 6</u>	<u>Round 7</u>
<u>GROUP A</u>						
Observ.	N/A	N/A	N/A	N/A	N/A	N/A
Percent	N/A	N/A	N/A	N/A	N/A	N/A
<u>GROUP B</u>						
Observ.	46	46	47	43	47	47
Percent	56.2	50	48.9	41.8	36.2	14.9
<u>GROUP C</u>						
Observ.	45	48	47	47	46	47
Percent	33.3	18.7	27.6	19.1	13	6.3
<u>GROUP D</u>						
Observ.	N/A	N/A	N/A	N/A	N/A	N/A
Percent	N/A	N/A	N/A	N/A	N/A	N/A

Table 5: Descriptive Statistics, Three Stone Use Yesterday

	<u>Round 1</u>	<u>Round 2</u>	<u>Round 3</u>	<u>Round 4</u>	<u>Round 5</u>	<u>Round 6</u>	<u>Round 7</u>
<u>GROUP A</u>							
Observ.	48	46	46	47	42	45	47
Percent	91.6	36.9	45.6	46.8	54.7	51.1	59.6
<u>GROUP B</u>							
Observ.	49	46	46	47	43	47	47
Percent	97.9	65.2	63	74.4	74.4	80.8	89.3
<u>GROUP C</u>							
Observ.	49	45	48	47	47	46	47
Percent	87.7	42.2	64.5	48.9	53.2	60.8	70.2
<u>GROUP D</u>							
Observ.	50	46	48	49	45	48	48
Percent	94	89.1	93.7	87.7	100	93.7	93.7

4. RESULTS

4.1 Three Stone Stoves

Reducing traditional stove use in favor of improved stoves (as mentioned above) is one key indicator of a successful intervention. With this information in mind, it is important to understand factors that influence cookstove use. From a randomized control study carried out between November, 2013-December, 2015, I find that both education and age are significant predictors of cookstove use in the Kassena-Nankana Districts of Northern Ghana. The most conclusive finding is that the use of three stone stoves is significantly higher among older users, both in models including and omitting education as an explanatory variable. Models that omitted education will be discussed first. When we directly compare our younger and older age categories, we see that in round three those under 30 are 92% less likely to have cooked on their three stone stove on the previous day compared to those 30 and older ($P < .01$) (table 6).

Table 6: Use Yesterday by Respondent Age < 30

	<u>Gyapa</u>	<u>Philips</u>	<u>Three Stone</u>
Resp. Age < 30	- .89, .237, .583, -.11, .082, .389 (.50), (.48), (.45), (.46), (.45), (.43)	-.14, .403, .229, .111, -.04, 1.33 (.44), (.44), (.44), (.47), (.49), (.73)	.305, -.919** , .113, -.51, -.488, -.601 (.35), (.35), (.35), (.36), (.36), (.38)
Constant	1.45, .823, .277, .722, .348, -.10 (.34), (.28), (.27), (.30), (.27), (.26)	-.14, -.83, -.56, -.89, -1.1, -2.85 (.27), (.29), (.27), (.30), (.31), (.60)	-.196, .711, .223, .654, .806, 1.27 (.22), (.23), (.22), (.24), (.24), (.27)
R-Squared	.0319, .0022, .0138 .0005, .0003, .0063	.0009, .0069, .0022 .0005, .0001, .0583	.0040, .0362, .0006 .0114, .0102, .0150
N	91, 94, 95, 89, 91, 94	91, 94, 95, 89, 91, 94	137, 140, 141, 132, 138, 141

Standard errors appear in parentheses. 95%, and 99% significance levels are represented by *, ** respectively. Values are reported for each survey round in chronological order: round 2, round 3, round 4, round 5, round 6

When we look at age effects on the likelihood that users cooked frequently (four or more days) during the previous week on the three stone stove, we see a similar story. In round three, those under 30 are 99% less likely to have used their three stone with high frequency, than their older counterparts ($P < .01$) (table 7).

Table 7: High Frequency Use by Respondent Age < 30

	<u>Gyapa</u>	<u>Philips</u>	<u>Three Stone</u>
Resp. Age < 30	-.927, .042, .711, .232, .259, -.16 (.80), (.67), (.57), (.49), (.52), (.48)	-.414, .219, .267, .273, .170, .072 (.46), (.44), (.43), (.44), (.44), (.50)	.190, -.996** , -.217, -.519, -.496, -.375 (.36), (.39), (.36), (.36), (.35), (.39)
Constant	2.91, 2.01, 1.14, .902, 1.05, 1.07 (.60), (.41), (.31), (.31), (.30), (.30)	.941, .435, .069, -.330, -.666, -1.27 (.30), (.28), (.26), (.27), (.28), (.33)	-.446, -.245, .693, .158, .530, 1.19 (.22), (.22), (.24), (.23), (.23), (.26)
R-Squared	.0277, .0001, .0175 .0022, .0025, .0010	.0071, .0020, .0030 .0032, .0012, .0002	.0016, .0392, .0020 .0117, .0107, .0058
N	91, 94, 95, 89, 91, 94	91, 94, 95, 89, 91, 94	137, 140, 141, 132, 138, 141

Standard errors appear in parentheses. 95%, and 99% significance levels are represented by *, ** respectively. Values are reported for each survey round in chronological order: round 2, round 3, round 4, round 5, round 6

To ensure the observed effect is, in fact, attributed to age, education is included in the subsequent model; it is found that this inclusion does not change the impact of age. In fact, the magnitude of the observed difference for stove use between younger and older age categories in

round three increases, and these regression permutations remain significant at the 1% level (tables 8-9).

Table 8: Use Yesterday by Respondent Age < 30 and Education

	<u>Gyapa</u>	<u>Philips</u>	<u>Three Stone</u>
Medium Education	.038, -.098, -.406, -.322, .052, .366 (.55), (.52), (.48), (.52), (.49), (.48)	-.675, -.101, .815, -.169, .952, .235 (.48), (.46), (.47), (.52), (.51), (.63)	.570, .172, .240, .476, -.356, .007 (.38), (.38), (.38), (.42), (.41), (.46)
High Education	.000, .000, .000, .000, .000, .000 (om), (om), (om), (om), (om), (om)	.355, .141, .000, 2.80** , 1.31, .000 (.96), (.92), (om), (1.14), (.99), (om)	-.119, .359, .225, .132, -.279, .527 (.97), (.87), (.95), (.82), (.91), (1.1)
Resp. Age < 30	-.912, .318, .616, .016, .103, .310 (.53), (.51), (.47), (.49), (.48), (.46)	.065, .426, -.167, -.169, -.478, 1.29* (.47), (.45), (.48), (.52), (.49), (.65)	.133, -.979** , .035, -.678, -.348, -.616 (.37), (.37), (.36), (.40), (.40), (.44)
Constant	1.54, .904, .449, .842, .379, -.145 (.37), (.32), (.30), (.32), (.29), (.28)	.025, -.807, -.933, -1.34, -1.43, -2.87 (.31), (.34), (.34), (.38), (.39), (.69)	-.339, .660, .159, .555, .897, 1.26 (.25), (.26), (.24), (.26), (.26), (.28)
R-Squared	.0322, .0037, .0160 .0038, .0007, .0122	.0213, .0076, .0258 .0804, .0339, .0659	.0168, .0377, .0028 .0190, .0147, .0164
N	89, 92, 93, 87, 89, 92	91, 94, 89, 90, 93, 89	137, 140, 141, 132, 138, 141

Standard errors appear in parentheses. 95%, and 99% significance levels are represented by *, ** respectively. Values are reported for each survey round in chronological order: round 2, round 3, round 4, round 5, round 6

Table 9: High Frequency Use by Respondent Age < 30 and Education

	<u>Gyapa</u>	<u>Philips</u>	<u>Three Stone</u>
Medium Education	-.489, .063, .001, -.492, -.607, -.549 (.69), (.77), (.63), (.56), (.53), (.49)	-.348, .045, .009, .730, 1.07* , .751 (.48), (.48), (.46), (.47), (.49), (.58)	.619, .494, .188, .396, -.236, .006 (.39), (.42), (.39), (.41), (.40), (.46)
		.494, .889, .000, .973, .760, .247	.214, .657, -.079, -.238, .073, .442

High Education	-2.79* , -2.09, .00, 1.06, .000, -1.24 (1.3), (1.5), (om), (.34), (om), (1.46)	(1.2), (1.2), (om), (.97), (.98), (1.22)	(.95), (1.0), (.97), (.88), (.90), (1.1)
Resp. Age < 30	- .764, .077, .557, .449, .553, .029 (.67), (.70), (.63), (.55), (.54), (.48)	-.307, .173, .179, .056, -.294, -.245 (.47), (.48), (.47), (.46), (.48), (.58)	.000, -1.17** , -.272, -.662, .410, -.388 (.38), (.44), (.38), (.39), (.39), (.44)
Constant	3.17, 2.06, 1.29, 1.06, 1.26, 1.22 (.82), (.45), (.34), (.34), (.35), (.35)	1.02, .395, -.002, -.595, -.990, -1.49 (.35), (.31), (.30), (.32), (.34), (.38)	-.619, -.390, .649, .086, .583, 1.19 (.25), (.25), (.26), (.25), (.25), (.28)
R-Squared	.0842, .0273, .0109 .0108, .0163, .0155	.0147, .0074, .0014 .0270, .0389, .0179	.0158, .0485, .0035 .0180, .0128, .0068
N	91, 94, 93, 87, 89, 94	92, 94, 89, 90, 93, 94	137, 140, 141, 132, 138, 141

*Standard errors appear in parentheses. 95%, and 99% significance levels are represented by *, ** respectively. Values are reported for each survey round in chronological order: round 2, round 3, round 4, round 5, round 6*

While the third round is the only round with statistically significant values, coefficient directions from other rounds largely suggest a similar trend (with aberrations attributable to normal variability in the data). Significant effects of education on three stone use are not observed.

4.2 Gyapa Stoves

Age is not a significant predictor for the use of the Gyapa stove; education, however, is. In the majority of regression permutations, we see a negative relationship between education and Gyapa use. When using “high-frequency use” as the proxy for stove use, these educational effects are significant at the 5% level. Specifically, individuals in round two with a high school education or above were more than twice as likely to have reported using the Gyapa stove four or

more days in the previous week compared with individuals who did not complete primary school. We see largely similar effects looking at different rounds as well as when “stove use yesterday” is substituted for “high-frequency use” as the proxy for stove use, although these were not statistically significant. Interestingly, a subgroup analysis (combining all survey rounds) that investigated high frequency stove use amongst Gyapa owners revealed a significant difference between members of group A and group C. While more educated individuals in the Gyapa/Philips group (C) did use their Gyapa stoves less than their less educated counterparts, this same relationship did not surface amongst members of the Gyapa/Gyapa group (A).

4.3 Philips Stoves

Based on the analysis performed, we do not find convincing evidence to suggest that age impacts the likelihood that users cooked with their Philips stove; the effect of education, however, remains significant. Education is shown to have a positive relationship (across the vast majority of rounds) with the use of the Philips stove. Specifically, in round five, individuals receiving at minimum a high school education were 280% more likely than those with less than a primary school education to have reported having used the Philips stove on the previous day ($P < .01$). Similarly, in round six, those in the middle education categories were 107% more likely to have used the Philips stove four or more days in the previous week compared with those in the lowest education category ($P < .05$).

4.4 Text-based Survey Results

For the purpose of this work, two categories that surfaced during the coding process are particularly interesting: technology and familiarity. If my hypotheses are correct, we would

expect younger and more educated users to less frequently cite technological issues as reasons for wanting to trade stoves (although, again, it is important to reiterate that only five percent of households in groups A, B, and C wanted to trade). Similarly, we would expect familiarity with current technologies (i.e. a desire to hold on to technologies, with which one is already comfortable) to more frequently play a role in hypothetical trading patterns among older and less educated stove users. Actual results largely corroborate these hypotheses. Results for the non-trader category will be discussed first. Combining results from stove groups A, B, and C, I find that 6% of low educated stove users cite familiarity as a reason for wanting to stick with their current technology, versus only 4% from the high-education category. Similarly, 7% of non-trader respondents 30 and over compared with just 2% of non-trader respondents under 30, mention familiarity as a reason for keeping with their current combination of stoves. 8% of less educated users attribute technology concerns, associated with the use of the Philips stove, to their stove trading preferences; this is compared with just 2% of more educated users. Respondents aged 30 and above cite technology concerns as rationale for their stove choices in 7% of cases, compared with just 2% in the under thirty group (table 10).

Table 10: Arithmetic Means, Stove Trading Factors, Combined Groups, Non-Trader

	Low Educ.	High Educ.	Resp. Age < 30	Resp. Age ≥ 30
GROUP	Groups A,B,C	Groups A,B,C	Groups A,B,C	Groups A,B,C
Combination	0.205	0.189	0.142	0.225
Familiarity	0.064	0.037	0.024	0.067
Fuel Savings	0.397	0.491	0.476	0.416
Performance	0.372	0.358	0.476	0.315
Portability	0.141	0.170	0.167	0.146
Technology	0.077	0.018	0.024	0.067
Observations	78	53	42	89

This may be attributable to younger users possessing a superior technical understanding of the stoves. A younger user, for example, states: “I will not trade with the Philips because during the rainy season when the sunshine is limited, it is difficult to charge the Philips because we don’t have electricity” – demonstrating a knowledge for the limitations of solar technology.

The aforementioned associations for non-traders were also examined by individual stove group (table 11).

Table 11: Arithmetic Means, Stove Trading Factors, Separated by Group, Non-Trader

	Low Educ.	High Educ.	Resp. Age < 30	Resp. Age ≥ 30	Low Educ.	High Educ.	Resp. Age < 30	Resp. Age ≥ 30	Low Educ.	High Educ.	Resp. Age < 30	Resp. Age ≥ 30
GROUP	Grp. A	Grp. A	Grp. A	Grp. A	Grp. B	Grp. B	Grp. B	Grp. B	Grp. C	Grp. C	Grp. C	Grp. C
Combination	0	0.167	0.077	0.033	0.052	0.000	0.000	0.038	0.536	0.471	0.417	0.545
Familiarity	0.161	0.083	0.077	0.166	0	0.042	0	0.038	0	0	0	0
Fuel Savings	0.226	0.417	0.307	0.266	0.684	0.542	0.529	0.654	0.392	0.471	0.583	0.363
Performance	0.452	0.083	0.308	0.366	0.368	0.375	0.471	0.308	0.286	0.529	0.666	0.273
Portability	0.129	0.250	0.153	0.166	0.105	0.167	0.118	0.154	0.179	0.117	0.25	0.121
Technology	0.1	0.083	0	0.133	0.053	0	0	0.038	0.071	0	0.083	0.030
Observations	31	12	13	30	19	24	17	26	28	17	12	33

Numbers represent the percent (where .161 = 16.1%) of observations in each education/age category whose text response placed them into the respective trade rationale groups (i.e. combination, familiarity, etc.)

Since group C users have experience with both the Philips and Gyapa stoves, it is not surprising that no users from this group cite familiarity as a reason impacting their trading preferences. Interestingly, however, low educated users with two Gyapa stoves (group A) mention familiarity twice as often (16% vs. 8%) as their more educated counterparts, while younger users in both groups A and B less frequently cite familiarity as a factor influencing their trade decisions. A 63 year old user in group A, for example, states: “I am used to cooking with the Gyapa, but not the Philips, so I would not trade.”

In the group receiving two Gyapa stoves (A), 13% of older users cited technology issues as a deterrent for swapping for a Philips stove, compared with 0% from the younger group. Additionally, not a single group B user (two Philips stoves) belonging to either the high education or younger category mentioned that technology issues influenced their trading decisions; this is in comparison to 5% and 4% from the low education and older categories, respectively (group B).

With the trader group we are dealing with extremely small sample sizes and thus only combined results (groups A, B, and C) will be discussed (table 12).

Table 12: Arithmetic Means, Stove Trading Factors, Combined Groups, Trader

	Low Educ.	High Educ.	Resp. Age < 30	Resp. Age ≥ 30
GROUP	Groups A,B,C	Groups A,B,C	Groups A,B,C	Groups A,B,C
Combination	0.330	0.500	0.333	0.5
Familiarity	0.000	0.000	0.000	0.000
Fuel Savings	0.667	0.25	0.333	0.5
Performance	0.333	0.000	0.000	0.25
Portability	0.333	0.000	0.000	0.25
Technology	0.333	0.000	0.000	0.25
Observations	3	4	3	4

In this combined group no users mention familiarity as a factor motivating trade decisions. Meanwhile only one user (belonging to the lower education and older population) cites technology as an influencing factor.

Although familiarity and technology are most germane for this work, other categories also provide interesting insight into participants' stove trading decisions. The following statistics refer to all respondents (traders and non-traders) grouped together. 21% of users (nearly exclusively from group C) cite a desirable combination of stoves as a motivating trading factor: "The Gyapa is for TZ, the Phillips if for small meals like soup. Therefore I don't plan to trade or

sell.” These sentiments are recorded in participants of all ages and education levels. Fuel savings and portability are also important issues, with more than 40% and 15% of users of varying age and education citing these respectively. Permutations of “They use less fuel” and “...you can easily move them around” are common responses.

The last category, performance, also receives frequent mention (more than 35% of all users). There are not large differences seen by users with high and low education, but we do see 44% of younger respondents versus 31% of older respondents citing this as a factor influencing their trade decisions. While all of this text-based survey data is useful for helping to explain phenomena seen in the quantitative analysis, it is important to remember that all descriptive statistics discussed here are sensitive to the small number of observations at hand.

5. DISCUSSION

This paper investigated two potentially important demographic determinants of cookstove demand in rural Ghana. By leveraging data collected as part of the randomized control study REACCTING, effects of age and education on the use of three stone, Gyapa, and Philips stoves – three different tiers on the energy ladder - are presented.

To more accurately assess cookstove use, respondents report on both the amount of use in the past week as well as use on the previous day. Measuring whether or not stoves were used on the previous day mitigates recall bias, while measuring stove use over the previous week captures a larger number of potential cooking days and thus provides a more continuous measure of stove use frequency. The nature of the panel data analyzed in this study minimizes over-reporting thought to occur in studies of shorter duration (Pillarsetti et al. 2014).

5.1 Hypothesis 1 (H1)

Results validate my first hypothesis (H1), that age has a positive relationship with the continued use of the low technology (traditional), three stone stove. This finding corroborates findings from literature in related fields, where older respondents have shown a lower willingness to stray from familiar technologies; it also adds information to the cookstove sector, which, to the author's knowledge, had not been previously investigated with equivalent rigor (Aker et al. 2010; Gupta et al. 2006). Conversely, younger respondents seem to actually embrace the opportunity to experiment with multiple technologies and then decide for

themselves, which is best aligned to serve their cooking needs, with one stating: “I would want to trade one [Philips stove] with the Gyapa because I would want to use both and see.”

5.2 Hypothesis 2 (H2)

My second hypothesis (H2) put forward that age would have a negative relationship with the use of higher technology stoves. Results from the regression analysis put forward little evidence in support of this claim. Text-based evidence, however, continues to suggest that age plays a role in the use of the Philips stove (although it is important to remember that text-based responses are limited by the size of observations).

As previously mentioned, Philips stoves make use of a small fan to help drive gasification. Since study participants do not have household access to electricity, those receiving the Philips stove are provided a solar panel, capable of charging this fan. Many respondents, particularly those in the older category, seem to struggle to grasp the concept of solar energy. Specifically, a number cite a lack of household electricity as a reason for not being able to use the Philips stove - a clear demonstration that technological misunderstandings serve as a barrier to adoption for some in this group. An 82 year-old respondent, for example, stated: “I do not have electricity, hence trading with the Philips stove is not possible. That is why I won’t trade.”

The Gyapa stove represents a step up on the energy ladder from the three stone stove, but its simple design requires little technical knowledge. Thus, since it is not truly a “high technology stove”, it is, perhaps, not surprising that age does not appear to be a significant factor

influencing its use. An alternative explanation is that because it is still a different and potentially improved solution compared with the three stone, older users might be willing to change behavior, just not to the same degree as is required of a more involved technology such as the Philips stove.

5.3 Hypothesis 3 (H3)

As anticipated in my third hypothesis, increased education contributed to more frequent use of the Philips stove. In certain rounds, respondents in the highest education group show a 280% higher likelihood than respondents in the lowest education category of having cooked with their Philips stove on the previous day. While quantitative data directly measured stove use, an understanding of stove preferences (made possible through text-based survey data) allows us to understand *why* stove use patterns develop. These text results suggest that an established comfort with current stove technologies as well as technological issues with more advanced technologies both contribute to the decreased use among less educated respondents. A 45 year-old respondent with no education, for example, stated: “I have not used the Philips before and am comfortable with the Gyapa, hence I will not want to trade or sell my Gyapa”.

5.4 Hypothesis 4 (H4)

Previous cookstove literature has shown a negative relationship between education and continued use of traditional stoves - as they are replaced with cleaner stoves. This phenomenon may be due to more educated respondents having a better understanding of the health dangers

associated with burning solid fuels in an open fire; it may also be attributable to a superior ability to problem solve and grasp new technologies. My fourth hypothesis (H4) posited that, in the case of the lower technology three stone stoves, continued use would be highest among members of the study population with the least amount of education. Regression analysis conducted in this study, however, provided no statistically significant evidence to support this relationship. While education was not a significant predictor of three stone use, we do see a statistically significant negative relationship between education and use of the Gyapa stove. In the second round, for example, having at least a high school education makes respondents 279% less likely than those who have not finished primary school to frequently use the Gyapa stove. I provide two separate theories to help explain this surprising discrepancy.

In the Kassena-Nankana district of northern Ghana, where TZ (millet porridge) and banku (fermented cassava and corn dough) are frequently cooked, households require sturdy stoves to perform the vigorous stirring required to make these dishes; traditionally, the three stone stove has served this purpose. With the advent of improved cookstoves, many of the group C respondents (those given one Philips and one Gyapa stove), report that only the Gyapa stove is suitable for preparing banku and TZ: “[t]he Gyapa is good for stirring TZ and banku, while the Philips is good for soup and rice...” In this way, the Gyapa can be seen to be a near replacement for the three stone stove (both are sturdy, wood-burning stoves, capable of preparing local dishes in a manner consistent with local cooking practices). Thus, with its technical simplicity, the Gyapa is perhaps better described as a low technology stove. Viewed in this light, it is possible that the educational effect typically associated with traditional stoves, has been captured by the

educational effect associated with the Gyapa stove. In this case, this study's findings align with previous literature on education and cookstove use (Lewis et al. 2012; Rehfuess et al. 2014).

Alternatively, the negative relationship between education and Gyapa use may be attributable to differences in stove group placement. In the case of the Gyapa/Gyapa group (A), individuals wishing to cook with a different technology, only have the traditional three stone stove as an option. Conversely, individuals belonging to group C can opt for the Philips stove over the Gyapa. In this case, the idea of low and high technology stoves is relative. For group A members, the Gyapa stove represents their higher technology choice, while for group C, the Gyapa is actually the lower technology option. With this in mind, it is perhaps not surprising that we see significant education effects solely with group C. In this group, the highest education members are 52% less likely than the lowest education group to report having cooked on the Gyapa stove. This could be attributed to the fact that these well-educated individuals might be opting for the most technologically advanced technology available to them, the Philips. With the group A members, we don't see a statistically significant education effect on Gyapa use. Following similar reasoning, it could be the case that some of the more well-educated users are preferring the Gyapa, for its relative advantage over the three-stone stove. At the same time, however, the lower educated group C members have an easier time using the Gyapa (compared with the Philips) and thus also are frequent users. The combination of these effects could explain the above-mentioned discrepancy in education effect seen between group C and group A respondents.

5.5 Limitations

The study has a number of limitations. As previously discussed, the explanatory power of the text-based survey data presented in this investigation is severely bounded by the sample size. More information on number of observations can be seen in tables 5 and 6. The low magnitude of R-squared values also deserves mention. Literature demonstrates myriad factors that influence stove use, including cultural values, socioeconomic status, occupation, gender, geography, demographics, religious preferences, time spent at home, and size of household (Lewis et al. 2012, Malla et al. 2014). As such, it would be shortsighted to assume that age and education could explain the majority of variation in cookstove use. Nevertheless, the work done here is meant to illustrate additional factors, which may contribute to households' decisions to use cookstoves. Where possible, future work should incorporate these additional explanatory variables into models. Another limitation is the susceptibility to social desirability bias where stove use is reported. To account for this, interviewers report whether or not there are fresh ashes in the stove or if it is in use at the time of questioning. Where discrepancy between interviewer perception of stove use and survey respondent answer exist, interviewers always reminded respondents of the importance of truthful responses. As previously mentioned, other members of the study team have installed stove use monitors, capable of reporting temperature spikes. This evidence shows that SUMs and surveys were fairly consistent in their measurements of stove use patterns across groups (Piedrahita et al. 2016). While the specific incorporation of SUMs data is beyond the scope of my investigation, this direction is recommended for future research. Additionally encouraged, are future in depth interviews with respondents to better understand stove use patterns and behaviors. By continuing to improve our

understanding of the barriers to cookstove use, current pitfalls limiting their impact can be mitigated.

5.6 Implications

Improved cookstoves have been suggested as a solution for mitigating the health and environmental burdens associated with the combustion of solid fuels in open fires. In many cases, adoption of these stoves, which “requires changing technologies and individual behaviors in and around the kitchen: a complex social space...”, has encountered substantial hurdles (Bailis et al. 2009). By better comprehending the complexities of cooking behaviors, however, we can also better understand factors that contribute to successful adoption. Complexities in cooking behavior relate to differences in cultures, geography, economics, demographics, etc. In rural Ghana, where the effects on cookstove use of two demographic factors - age and education - are examined, it is found that both age and education play a role in determining cookstove use. While more educated users demonstrate a higher preference for the high technology Philips stove, less educated users show higher preference for the low technology Gyapa stove, and older users show highest continued use of their three stone stove.

These results suggest that cookstove manufacturers should continue to produce both low-tech and high-tech stoves (if we assume both have benefits over traditional stoves), while policy makers should incentivize the distribution of both varieties. If these stoves varieties prove capable of catalyzing substantive willingness to pay, these should, where possible, also be made available in the local marketplace. The advanced stoves will likely continue to appeal most to

more educated populations, while more traditional models will better be able to reach older, less educated, populations. Targeting users of all ages and educational attainment will increase the total number of improved cookstoves, with implications for bettering both human and environmental health.

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