Empirical and Behavioural Economic Applications to the Energy Sector

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Declaration

I, Rebecca Afua Klege, hereby declare that the work on which this dissertation/thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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Declaration for the inclusion of publications

I confirm that I have been granted permission by the University of Cape Town's Doctoral Degrees Board to include the following publications in my thesis, and where co-authorships are involved, my co-authors have agreed that I may include the publications:

Klege R.A and Visser, M., 2019. Competition and Gender in the Lab vs Field: Experiments with Off-Grid Renewable Energy Entrepreneurs in Rural Rwanda, EfD Discussion Paper Series 19-24 URL: https://efdinitiative.org/publications/competition-and-gender-lab-vs-field-experiments-grid-renewable-energy-entrepreneurs

Klege, R., Visser, M., Datta, S. and Darling, M., 2018. The Power of Nudging: Using Feedback, Competition and Responsibility Assignment to Save Electricity in a Non-Residential Setting. URL: https://efdinitiative.org/publications/power-nudging-using-feedback-competition-and-responsibility-assignment-save-electricity.

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Abstract

This thesis contributes to the energy literature by leveraging insights from empirical and experimental economics. The thesis presents four papers with a common goal of understanding specific themes in the energy sector namely: households energy use patterns, behavioural preferences among entrepreneurs operating energy businesses and applications of behavioural nudges to reduce energy use.

The first paper set the tone for the two subsequent chapters. The paper: **'Energy Choices and Tenancy in Rwanda'** examines the energy choice patterns of households based on their rental status and dwelling types. The fifth Integrated Household Living Conditions Survey (EICV5) conducted over one year, October 2016 to October 2017, together with a bivariate probit model is used. A heterogeneous analysis focused on gender and income differentiated impacts, as well as geographical differences based on the tenancy status of households, is further examined. The results signal that households energy choices in Rwanda differ by rental and dwelling types.

The second and third papers ascertain the role of competition and risk preferences among entrepreneurs working in off-grid renewable energy microenterprises and its effects on business success in the context of including more women as entrepreneurs in the energy sector. Specifically, the second paper: '**Competition and Gender in the Lab vs Field: Experiments with Off-Grid Renewable Energy Entrepreneurs in Rural Rwanda'** examines the gender differences in competitiveness and how this affects the business success of entrepreneurs operating renewable energy enterprises. Results from the economic experiments are compared to the day to day activities of the business. Findings show that female entrepreneurs are not less likely to compete and are not outperformed by male entrepreneurs. This stands in contrast to several studies, mostly conducted on university students of developed countries.

The third paper: **'Risk attitudes, Gender and Business Performance Among off-grid Renewable Energy Entrepreneurs in Rural Rwanda'** in a similar context examines the risk attitudes among entrepreneurs and its effect on the performance from a gender perspective. The study adopts a choice list experimental approach to elicit risk attitudes. The results indicate a strong risk aversion among entrepreneurs. The risk aversion found is higher for women compared to men. Entrepreneurs with high risk-taking abilities also tend to record better performance levels. The

paper concludes that policies geared towards hedging against risk aversion in entrepreneurial programs may be vital in reducing gender gaps in business performance.

The fourth paper: '**The power of nudging: Using feedback, competition and responsibility assignment to save electricity in a non-residential setting'** answers the question 'can behavioural interventions achieve energy savings in non-residential settings where users do not face the financial consequences of their behaviour?' The paper relies on a randomized control trial and two behavioural interventions. Results show that behavioural nudges can be useful in reducing energy consumption in a non-residential environment.

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To my amazing husband, Joseph Ollennu, words cannot describe my gratitude to you. Your patience and understanding gave me the peace to keep pushing. Thank you for coping with the many days I was away and the consistent encouragement you gave me. You are one of a kind!

Dedication

To the lady that endured the test of time, the unforeseen challenges, the roller coaster emotions but kept going, I dedicate this work to no other but myself! To the many PhD students out there I say it is not about the title but the resilience you learn along the way. Keep pushing!

Contents

List of Acronyms

SSA:	Sub-Sahara Africa
LPG:	Liquefied Petroleum Gas
VLEs:	Village level Entrepreneurs
EICV:	Integrated Household Living Conditions Survey
NISR:	National Institute of Statistics of Rwanda
IEA:	International Energy Agency
WIRE:	Women’s Integration into Renewable Energy
LED:	Light Emitting Diodes
RCT:	Randomized Control Trials
USD:	United States Dollars
RWF:	Rwandan Francs
OLS:	Ordinary Least Squares
CDF:	Cumulative distribution function
MPL:	Multiple Price List
CE:	Certainty equivalent
CRRA:	Constant Relative Risk Aversion
OECD:	Organisation for Economic Co-operation and Development
Kw:	Kilowatts

Chapter 1: Introduction

The commitment and investment efforts by developmental agencies and governments to achieve energy access for all is remarkable yet; energy poverty remains a challenge. Globally, 860 million people are without electricity, and over 2.6 billion people do not have access to clean cooking energy (IEA,2019a). Sub-Saharan Africa (SSA) alone has close to 600 million people living without electricity, and over 900 million people are without clean cooking energy (IEA, 2019a). Most households in the region are heavily reliant on fuelwood, crop residue, kerosene and charcoal. The utilization of such biomass fuels has adverse effects on health, forest, ecosystem, climate and the overall wellbeing of households (Chomert-Nkolo, Motel & Le Roux, 2019; Bos, Chaplin & Mamun 2018; Bonan, Pareglio & Tavoni, 2017; Köhlin et al., 2015; Heltberg, Arndt & Sekhar, 2000).

Amidst the global energy deficit, demand for energy continues to rise. It is projected that by 2050, the global energy demand will double due to rapid population growth and harsh climatic conditions (Whitesides & Crabtree, 2007; Lewis & Nocera, 2006). This presents significant challenges for climate change mitigation as fossil fuels continue to dominate the energy mix, providing over 80% of the total energy consumed (Yoon, Sun & Rogers, 2010).

The population growth of Africa is among the fastest in the world, making it more difficult for the continent to catch up with energy demands despite efforts by policymakers to provide energy access for all. According to Africa's outlook report by IEA (2019b), the continent in the case of electricity will need to triple the yearly number of people gaining access to meet the 100% electricity target for its citizenry.

One of the many solutions has been to promote the expansion and development of the continent's renewable energy resources. Africa's renewable energy sector is currently booming as several governments are working towards increasing the share of renewables in the energy mix. This climate-friendly alternative serves as a cleaner energy option in the quest to provide energy access to the poorest of the poor who are usually women and children.

The central role women play in the energy system cannot also be underestimated. Access to cleaner lighting and cooking energy can increase their participation in development. However, in recent times, studies have shown that providing modern energy sources alone is not enough to achieve the desired empowerment levels and economic freedom for women. Women's journey towards better welfare opportunities and livelihoods could be fast-tracked if they are well represented at all levels of the energy supply chain (Baruah, 2017; 2015). Entrepreneurship has since been used as a breakthrough point for women in the sector (Clancy et al., 2012; Clancy, Oparaocha & Roehr, 2004). This has resulted in projects targeted at female entrepreneurship. Typical examples are the Solar Sisters initiative, Women Integration into Renewable Energy (WIRE) and Women's Entrepreneurship in Renewables (wPOWER) under the Energy4Impact initiative. This goes to suggest that the challenges faced in the energy sector are complex, intertwined and multifaceted.

Against this background, this thesis uses survey and experimental approaches to address some of the complexities in the energy sector. The thesis examines the energy use patterns of households and the application of behavioural techniques to promote energy conservation and empowerment of women which provides insights on critical challenges facing the energy sector. Specifically, the four papers in the thesis will consider (i) households energy choices based on tenancy status ; (ii) the role of competitiveness and risk-taking and its effects on the successfulness of energy businesses from the perspective of including more women in the energy sector and (iii) the effectiveness of behavioural nudges in promoting energy conservation in a non-residential sector. While the first paper relies on an empirical approach, the other three papers in the thesis use experimental methods. In the subsequent subsections, a more detailed discussion of the four papers is provided.

1. Energy Choices and Tenancy in Rwanda

Rwanda over the last decade has embarked on several developmental initiatives in the energy sector with the primary objective of increasing electricity access to all by the year 2024 while reducing the usage of biomass fuels. Efforts to increase electricity supply to households and firms through multi projects such as the Nyabarongo hydropower and methane gas are on the rise. The latest update from the Rwanda Energy Group shows that as of December 2019, 52.2% of households had electricity access with a national grid connection share of 38.2% and an off-grid connection share of 14%. Despite the progress and continuous commitment of the government of

Rwanda, households are heavily dependent on bio-energy products. The country energy-use statistics show that of the 91% of total energy consumed by households, 85% depend on biomass energy with fuelwood dominating the cooking energy mix. Another primary energy policy in Rwanda is the objective to expand the usage of Liquefied Petroleum Gas (LPG) although the current adoption rate of LPG is still low.

The country also has one of the unique house ownership patterns in Sub-Saharan Africa, with over 60% of households currently living in centralized settlements. This paper ascertains the effect of Rwanda's house ownership patterns and rental status on energy choices by examining the role of tenancy status (rented or owner occupant) and dwelling types (private or compound dwelling) on households lighting and cooking energy choices. Using a bivariate probit model and the fifth Integrated Household Living Conditions Survey data of Rwanda conducted over one year, October 2016 to October 2017, results show that rental status and dwelling types have varying effects on cooking and lighting fuel choices.

Renters and compound house residents compared to homeowners and private unit residents are more likely to adopt electricity and "other" sources of lighting energy but are less likely to use oil lamps and torches. They are also more likely to choose charcoal but tend to use less fuelwood for cooking. A heterogeneous analysis further shows that renters in higher-income quartiles, who are female household heads and living in urban communities are more likely to adopt relatively better cooking and lighting fuels compared to homeowners. Rwanda's unique geographical distribution of homeowners which emanates from the country's rural resettlement policy is an explanatory factor for these results.

2. Competition and Gender in the Lab vs Field: Experiments with Off-Grid Renewable Energy Entrepreneurs in Rural Rwanda

The renewable sector of Rwanda is booming as the government of Rwanda is determined to promote private sector involvement, in its quest to accelerate rural electrification to off-grid communities in order to provide 100% energy access to its citizenry. However, women's participation in the private energy sector of Rwanda is low, as no gender policies are governing the private energy sector (Parshotam & van der Westhuizen, 2018). Though entrepreneurship is a vital tool for promoting women's empowerment, it is essential to note that a predominant characteristic associated with successful entrepreneurship is the ability to compete (Shane, Locke & Collins, 2003). A deliberate attempt to empower women in the renewable energy industry through entrepreneurship initiatives may have limited potential if due consideration is not given to women's competitiveness and performance abilities.

To date, very little is known about the competitive and performance capabilities of women working as sales point entrepreneurs in the renewable energy sector. This paper contributes to the global discussion on women's competitive decisions and performance levels by using lab-in-the-field experiments to examine how gender attitudes towards competition differ amongst village-level entrepreneurs (VLEs) in Rwanda. The study also demonstrates how performance under competitive situations in the lab reflects microenterprise operations in the field by using a unique dataset from off-grid microenterprises managed by entrepreneurs already working in mixed and single-sex teams since 2016. The study measures willingness to compete and performance under competition using the standard experimental design of Niederle and Vesterlund (2007) for a sample of 374 entrepreneurs from off-grid microenterprises. Subsequently, field outcomes – sales and self-reported incomes from microenterprise operations – are used to measure the field performances of gender teams.

The study finds that female entrepreneurs are not less likely to compete and are not outperformed by male entrepreneurs. This stands in contrast to several studies, mostly conducted on university students of developed countries. Furthermore, the study leverages administrative and self-reported business data to show that the female entrepreneurs who chose to compete in the lab perform as well as their male counterparts, providing some external validity to the lab results.

3. Risk attitudes, Gender and Business Performance Among off-grid Renewable Energy Entrepreneurs in Rural Rwanda

Theory predicts that entrepreneurs' ability to take risks positively affect business success. Yet, empirical findings are mixed, with no available experimental evidence. This paper fills the gap by conducting a lab-in-the-field experiment among 374 entrepreneurs operating off-grid renewable energy recharge stations in assigned gender teams, to examine risk attitudes among entrepreneurs and the effect of risk aversion on business performance in rural Rwanda from the perspective of including more women as entrepreneurs in the energy sector.

The study relies on both subjective and experimental measures of risk. Experimentally, the multiple price list design, following notable studies such as Booth et al. (2018), Tanaka, Camerer and Nguyen (2016), Brick and Visser (2015), Brick, Visser and Burns (2012) and Holt and Laury (2002) is used to elicit entrepreneurs risk attitudes. Survey risk measures were based on entrepreneurs self-reported ability to take risks on a scale of 1 (never take risks) to 5 (always take risks). Following the Willebrands et al. (2012) and Daniel and Mead (1998), the study employs sales levels as a measure for business performance.

Findings show a strong risk aversion among entrepreneurs. Results also reveal a negative relationship between risk aversion and business performance. Thus, entrepreneurs with high risk-taking abilities tend to record better sales. Contrary to experimental results, we find no significant relationship between risk attitudes and business performance for subjective risk measures. Women reveal higher risk aversion levels than men for both experimental and survey risk measures. Despite the gender differences in risk aversion, findings seems to suggest that women are not outperform by men. The findings raise important insights female participation in the private energy sector of Rwanda. Given the many benefits associated with the inclusion of more women in the energy sector, policies geared towards hedging against risk aversion in entrepreneurial programs can be vital in reducing gender gaps in business success.

4. The power of nudging: Using feedback, competition and responsibility assignment to save electricity in a non-residential setting

This paper addresses the question 'Can behavioural interventions achieve energy savings in non-residential settings where users do not face the financial consequences of their behaviour?'

Using a high-frequency data based on 30 minutes interval, the paper addresses this question by leveraging social comparison and responsibility assignment aimed at reducing electricity consumption in a large provincial government office building with 24 floors, a total of 1008 occupants. The study relies on a randomized control trial with two treatments arms and a control group. Both treatment groups received regular emails encouraging recipients to turn off appliances and lights before leaving the office, as well as weekly ranked energy consumption results by floors. Additionally, weekly "energy advocates" were assigned to each floor in treatment group two.

Findings show that floors that participated only in the inter-floor competitions reduced energy consumption by 9%, while those additionally assigned floor-wise "energy advocates" reduced energy consumption by 14%. A further investigation of the sustainability of the results shows that, although the intervention effect observed in the first month of the post-intervention period attenuates monthly, by the fifth month, these initial declines in the intervention effect completely dies out. The five months intervention period reductions reveal that financial consequences are not necessarily a pre-requisite for reducing energy consumption when using behavioural nudges.

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Chapter 2: Energy Choices and Tenancy in Rwanda

Rebecca A. Klege

Abstract

Rwanda has one of the unique house ownership patterns in Sub-Saharan Africa. This paper ascertains the effect of Rwanda's house ownership patterns and rental status on energy choices by examining the role of tenancy status (rented or owner occupant) and dwelling types (private or compound dwelling) on households lighting and cooking energy choices. Using a bivariate probit model and the fifth Integrated Household Living Conditions Survey data of Rwanda, we find that rental status and dwelling types have varying effects on cooking and lighting fuel choices. An analysis of impact of heterogeneity using income quartiles, gender and rural-urban differences reveals that renters in higher-income quartiles, who are female household heads and living in urban communities are more likely to adopt relatively better cooking and lighting fuels compared to homeowners. Rwanda's unique geographical distribution of homeowners which emanates from the country's rural resettlement policy is an explanatory factor for our results. The study only partly supports the energy ladder hypothesis which suggests how evidence does not always provide conclusive support of the energy ladder. Other factors such as rental agreements and the ability for renters to choose better housing conditions are discussed in the paper.

Keywords: Cooking fuel, Lighting fuel, Dwelling type, Rental status, Bivariate Model

1. Introduction

The commitment and investment efforts by developmental agencies and governments to achieve energy access for all is remarkable yet; energy poverty remains a challenge. Globally, 860 million people are without electricity, and over 2.6 billion people do not have access to clean cooking energy (IEA,2019). Sub-Saharan Africa (SSA) alone has close to 600 million people living without electricity, and over 900 million people are without clean cooking energy (IEA, 2019). Most households in the region are heavily reliant on fuelwood, crop residue, kerosene and charcoal. The utilization of such biomass fuels has adverse effects on health, forest, ecosystem, climate and the overall wellbeing of households (Chomert-Nkolo, Motel & Le Roux, 2019; Bos, Chaplin & Mamun 2018; Bonan, Pareglio & Tavoni, 2017; Köhlin et al., 2015; Heltberg, Arndt & Sekhar, 2000).

The energy landscape of Rwanda is not any different from the SSA region. Rwanda over the last decade has embarked on several developmental initiatives in the energy sector with the primary objective of increasing electricity access to all by the year 2024 while reducing the usage of biomass fuels. Efforts to increase electricity supply to households and firms through multi projects such as the Nyabarongo hydropower and methane gas are on the rise. The latest update from the Rwanda Energy Group shows that as of December 2019, 52.2% of households had electricity access with a national grid connection share of 38.2% and an off-grid connection share of 14%. Despite the progress and continuous commitment of the government of Rwanda, households are heavily dependent on bio-energy products. The country energy-use statistics show that of the 91% of total energy consumed by households, 85% depend on biomass energy with fuelwood dominating the cooking energy mix. Another major energy policy in Rwanda is the objective to expand the usage of Liquefied Petroleum Gas (LPG) although the current adoption rate of LPG is still low.

Existing literature identifies income, education, gender, age, household size, location, prices, preferences, culture and dwelling characteristics as important factors influencing household cooking and lighting choices in developing countries (see review by Muller & Yan, 2016). Tenancy status and dwelling types arguably also affect household energy investments (Baiyegunhi & Hassan 2014; Lay, Ondraczek & Stoever, 2013; Arthur et al., 2010). Martey (2019) show that households' ability to own a house or rent, live in a private or compound residential unit have varied effects on energy-use decisions. The tendency to free ride is also likely when housing units are shared with landlords (Kholodilin, Mense & Michelsen, 2017; Gillingham, Harding & Rapson, 2012; Myers, 2015; Maruejols & Young, 2011). Although prior studies such as Baiyegunhi and Hassan (2014), Lay et al., (2013) and Arthur et al., (2010) suggest that homeowners compared to tenants, tend to shift towards cleaner energy, until the recent study conducted in Ghana by Martey (2019), research focused on exploring the differential impacts of housing ownership and dwelling status on energy choices in a developing country context was non-existent.

This paper contributes to this grey research area by examining the role of tenancy (owned or rented) and dwelling status (private or compound habitat) on households' cooking and lighting energy choices in Rwanda. Our study compared to Martey (2019) is distinct in three ways. First, the study is conducted in Rwanda. Rwanda, unlike other SSA countries, has a unique housing and ownership distribution pattern. After the blurred history of the country, the government of Rwanda launched a resettlement campaign to relocate dispersed habitat to a more centralized location with the primary objective of providing better basic amenities to rural communities. This campaign which later became known as the rural settlement policy, increased the number of homeowners in the country with over 60% of households currently living in such centralized settlements. The policy ensures that relocated households receive free building materials, and the cost of construction is mitigated through the country's compulsory community participation law - Umuganda. Consequently, homeownership in Rwanda is not necessarily associated with high socioeconomic status, which is mostly the case for other African countries. The unique housing characteristics and ownership pattern of Rwanda enable the study to distinctively contribute to the household energy use literature by examining the relationship between housing characteristics and energy choices.

Secondly, cooking energy is grouped into three categories: fuelwood, charcoal and other sources, unlike the four categories: LPG, charcoal, fuelwood and other sources used in Martey (2019). The categorization is informed by the number of households using a specific fuel type. For instance, only 1% of households utilizes LPG in Rwanda compared to the 23.6% LPG adoption rates in Ghana reported in 2015 (Mensah & Adu,2015). We argue that the effects of tenancy and dwelling types on fuel choices may yield varied results in Rwanda. Finally, the study, unlike Martey (2019) additionally examines the disaggregated effect of tenancy and dwelling types based on household heads gender and geographical location to explore the heterogeneity potential of our results.

The study relies on the most recent household national survey conducted by the Rwandan National Institute of Statistics to achieve its objective. We disaggregate lighting energy into five categories: electricity, oil lamp or lanterns, solar, battery-powered torches and other energy sources. Cooking energy, on the other hand, is categorized into three groups, namely: fuelwood, charcoal and “other” fuel types. The empirical strategy first relies on the probit estimation technique. However, arguable factors such as unobserved preferences and welfare characteristics may correlate with both tenure status and energy choices. We, therefore, employ the bivariate probit model to attenuate potential endogeneity biases associated with univariate discrete choice models (Heckman, 1978). The study further analyses the heterogeneity in household energy choices using income, the gender of household heads and the geographical location of households by tenure status and dwelling type. Following Martey (2019), we disaggregated households into welfare quartiles, and the effect of tenancy status on energy choices (cooking and lighting) are distinctly examined for each quartile. Additionally, we estimate the effect of tenure status for female and male-headed households and rural and urban households separately.

Findings after accounting for endogeneity reveal that households who were renting compared to homeowners are 9% and 5% more likely to use electricity and “other” lighting sources, but 3% and 10% tend to use less of oil lamps and torches respectively. Households living in compound houses compared to private unit residents tend to adopt electricity for lighting (4%) yet, they are less likely to choose torches and “other” lighting sources (7% and 3% respectively). For cooking energy, renters compared to homeowners are 11% less likely to adopt fuelwood. Renters also tend to adopt charcoal and “other” cooking sources with a probability of 8% and 3% respectively. Similarly, compound dwellers are less likely than private unit residents to adopt fuelwood but tend to use charcoal.

Further, when households are sub-divided into income quartiles results show that as income increases, renters and homeowners are likely to increase their consumption of electricity and solar technologies but tend to use less oil lamps, torches and “other” lighting sources. Compound and private unit residents are also likely to use more electricity but use less oil lamps, torches and other forms of lighting energy as household’s income increases. We observe an inverted U-shape relationship between income and fuelwood. A U-shape relationship is also found between charcoal use and income.

Female household heads living in rented houses are more likely to use electricity than households headed by males. The magnitude of cooking energy choices also differs among female and male-headed households. For female-headed households, renters are 10% more likely to adopt charcoal and 12% less likely to choose fuelwood compared to owners, unlike male-headed households who show a 7% likelihood of utilizing charcoal and a 9% less likelihood of using fuelwood. Renters in rural and urban households compared to owners tend to use less fuelwood but more likely to adopt charcoal as their source of cooking energy. The magnitude of the low usage of fuelwood is higher for rural households than for urban households. Although findings from Martey (2019) strongly supports the energy ladder hypothesis, our study only partly support this hypothesis. This highlight how evidence does not always provide conclusive support of the energy ladder and how different contexts could yield varied results.

The rest of the paper progress as follows. Section 2 discusses the theoretical and empirical literature underpinning household energy choices. Section 3 outlines the descriptive statistics and data for the study. The empirical model is presented in section 4. In section 5, we present the results and discussion of the study. Section 6 concludes.

2. Theoretical and empirical literature

Conceptually, the study relies on the theory of consumer choice to develop a framework showing the possible relationship between homeownership status or dwelling type and household energy choices. Households are usually faced with expenditure decisions subject to a budget constraint (income). As depicted in Figure 1, a typical household will allocate their resources between food expenditure and non-food expenditure which includes energy use expenditures. Focusing on energy use, key demographic factors such as age, household size, education, household's location may determine the choice of fuel and amount spent on energy. Such a relationship is well documented in the energy literature (see Rahut et al., 2017; Alem et al., 2016; Rahut et al., 2014; Mensah & Adu, 2015; Baiyegunhi & Hassan, 2014).

An important characteristic that is usually not mentioned is the role of rental status or the type of dwelling. Owning or renting a house is likely to affect energy use in the following ways. First, home ownership requires fixed investment which implies higher level expenditure when building. As a result, homeowners who are in the process of completing their building especially in sub-Saharan Africa tend to devote less capital towards cleaner energy. Further, homeowners are likely to lean towards space intensive fuels at the initial stages before considering better energy sources when the capital investment of owning a home lessens. Renters on the other hand are likely to be limited by space and tend to opt for less space-intensive fuels when considering expenditure allocation. Further, the location of homeowners and renters could impact the energy choices of household. For instance, in the case of Rwanda, renters are more abundant in urban areas like Kigali where existing infrastructure can support access to cleaner fuels. The structure of houses can equally impact the choice of fuel. As such, in compound houses where two or more households share the same electricity metering system, which is usually inconvenient, households are likely to choose alternative sources of energy.

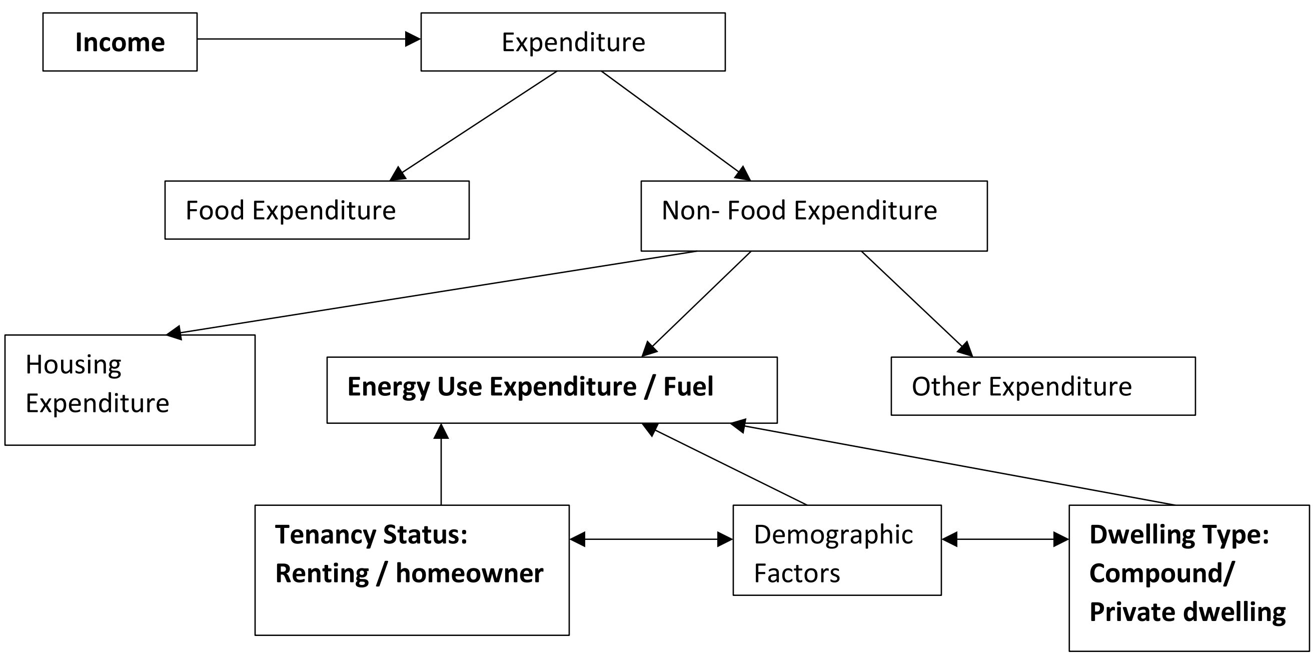

Figure 1: Conceptual Framework

The energy ladder hypothesis is also one of the early theories underlying household energy choices. The model assumes that with increasing income, households completely switch from inefficient fuels to more sophisticated and cleaner energy options (Hosier & Dowd, 1987). Climbing up the ladder is assumed to occur from one stage to the other depending on the physical characteristics of fuels, efficiency, cleanliness, and cooking time required. As a result, a move up the ladder implies a complete halt in the usage of previous energy sources (Hiemstra-vanderHorst & Hovorka,2008; Heltberg 2005). Households at the first stage steadily shift from traditional fuels (fuelwood) to transition energy sources (charcoal and kerosene) and finally to modern fuels (LPG, and electricity) as their socio-economic status rises.

A growing body of literature in recent decades have challenged the accuracy of the energy ladder hypothesis resulting in the conceptualization of the fuel-stacking hypotheses (Ruiz-Mercado & Masera, 2015; Heltberg, 2004; Masera, Saatkamp, & Kammen, 2000). According to the proponent of this concept, energy transition does not occur in an orderly manner as households from low- and middle-income countries often use multiple sources of fuels and do not linearly move to better fuels. Thus, with increases in income, cleaner energy sources do not necessarily replace traditional fuels as perfect substitutes.

Over the years, empirical evidence from low- and middle-income countries have been focused on factors influencing fuel choices and thereby contributing to the debate on the income-fuel choice relationship. Choumert Nkolo et al. (2019) identified factors influencing energy choices in Tanzania. The results of their study show that income is a significant determinant of household choices with results supporting the fuel-stacking concept. Their analysis of intrahousehold bargaining power shows that spouse education significantly informs decisions to shift to modern fuels. Other studies conducted in Ethiopia, Malawi, Bhutan, Nigeria and Ghana also show that age, education, gender of household heads, electricity access, location, prices and type of dwelling unit influences households choice of cleaner fuels (Rahut et al., 2017; Alem et al., 2016; Rahut et al., 2014; Mensah & Adu, 2015; Baiyegunhi & Hassan, 2014).

To date, existing studies on the relationship between tenancy and dwelling types on household fuel choices are limited. Martey (2019) recently stepped in by examining this topic for the Ghanaian economy. The study shows that renters compared to homeowners tend to use fuelwood, crop residue and candles as their lighting sources but depend on LPG, charcoal and “other” fuels for cooking. We extend the literature on tenancy and energy choices in the context of Rwanda – a country undergoing a structural transformation in the energy sector with different energy use and housing patterns.

3. Data and descriptive statistics

3.1 Rwandan National Survey

The study relies on the fifth Integrated Household Living Conditions Survey (EICV 5) from Rwanda. The EICV 5 is a nationally representative dataset conducted over one year from October 2016 to October 2017 by the Rwandan National Institute of Statistics. A multi-stage stratified sampling technique is used to sample 14,580 households across the five provinces of Rwanda based on the 2012 census frame. The initial stage sampled 1,260 villages. These villages were subdivided into urban and rural sampling areas. This provides the study with a sample of 2, 526 urban households. Rural households were 12,054 of the total sample.

The data offers a range of indicators such as poverty, inequality, employment, migration, living conditions, education, health, agriculture, energy use, water and sanitation at the individual, household and community levels (NISR,2018). The study makes use of the personal, housing, income and expenditure sections of the EICV 5 data which provides information on household demographics, economic and geographical variables as well as household cooking and lighting fuels, type of dwelling and tenancy status (owned or rented). However, EICV 5 does not allow for multiple fuel use (fuel stacking) analysis as information on energy use is limited to only households' primary cooking and lighting fuels types.

3.2 Construction and household patterns of energy use

Cooking energy is categorized into three main groups: fuelwood, charcoal and other fuel types. The reported number of households per each fuel type informed our choice of categories. The use of modern energy cooking fuels example, LPG and electricity in Rwanda compared to other SSA countries is on the low side. Most households heavily rely on biomass energy to meet their cooking energy needs. EICV 5 shows that only 386 households use "other" forms of cooking in Rwanda, including LPG and electricity. We show the distribution of the "other fuel" category in *Table A1* of *Appendix A*. Lighting fuels, on the other hand, are categorized into five main groups: electricity, oil lamp or lanterns, solar, battery-powered torches and "others".

Table 1 presents cooking energy choice patterns based on households' tenancy status (owned or rented) and dwelling type (private or compound). For clarity purposes, a private dwelling type in this study refer to a single house or group of dwellings occupied by one household. A compound house on the other hand refers to a single house or group of dwelling occupied by multiple households with shared amenities.

From Table 1, fuelwood remains the most used cooking energy type with 82.59% share of total cooking energy despite the effort by the government to promote other cleaner cooking fuels such as LPG use in Rwanda. Comparing homeowners to renters, 91.29% of homeowners prefer fuelwood, 7.35% prefers charcoal, whereas only 1.36% prefer to use “other” cooking energy types. On the other hand, 50.34% of renters use fuelwood, while 42.32% and 7.44% uses charcoal and “other” fuel types respectively.

For dwelling type, 87.7% of private unit residents use fuelwood, 10.26% use charcoal and the remaining 2% use “other” fuel sources. On the other hand, compound house dwellers prefer cooking with charcoal (63,28%) with only 9.93% using “other” forms of fuel types. Also, 10.26% and 1.97% of households living in private residential units use charcoal and “other” fuels, respectively.

Table 1: Distribution of Cooking Energy Choices by tenancy and residency type (in %)

	Cooking Energy types		
Tenancy Status	Fuelwood	Charcoal	Other fuel
Owned	91.29	7.35	1.36
Rented	50.24	42.32	7.44
Dwelling Type	Fuelwood	Charcoal	Other fuel
Private housing	87.77	10.26	1.97
Compound housing	26.80	63.28	9.93
All	82.59	14.77	2.65
Sample	12,041	2,153	386

Source: Authors’ calculations using Rwandan EICV 5 (2016–2017) data. Values are in percentages

Table 2 reports the lighting energy use pattern by tenancy status and dwelling type. Most homeowners (56.90%) use torches which are powered by batteries. This is not surprising in the context of Rwanda, as most homeowners live in rural areas where electricity access is either limited or unavailable. About 18% of house owners rely on electricity with 10% using “other” types of lighting fuels, and a fraction (9% and 5%) depend on solar and oil lamps respectively. Compared to house owners, renters primary lighting energy source is electricity (49%), followed by torch users (34%). Only 2% and 3% of renters depend on solar and oil lamps respectively, with the remaining 12% relying on other sources of lighting energy.

Table 2: Distribution of Lighting Energy Choices by tenancy and residency type (in %)

	Lighting Energy Sources				
Tenancy Status	Electricity	Oil lamp/lantern	Solar	Torches	Other
Owned	18.37	5.59	9.02	56.90	10.12
Rented	48.82	3.17	1.94	34.16	11.91
Dwelling Type	Electricity	Oil lamp/lantern	Solar	Torches	Other
Private housing	20.30	5.34	8.11	55.60	10.66
Compound housing	73.61	2.26	1.13	14.21	8.80

Source: Authors' calculations using Rwandan EICV 5 (2016–2017) data. Values are in percentages

A high proportion of private home dwellers (56%) are torch lights users. About 20% use electricity as their primary source of lighting. Solar and lamp users are 8% and 5% respectively, with about 10% using other lighting sources. However, most compound house dwellers (73%) rely mainly on electricity. Torch users living in compound units are 14% with about 8% using "other" lighting sources. Only 2% and 1% of compound unit dwellers use oil lamps and solar respectively.

Table 3 presents differences in means for cooking and lighting fuels by the ownership and renting status of households as well as the type of dwelling units. We find significant differences for households dwelling types and tenancy status. Thus, households fuel choices differ based on the dwelling type or tenancy status of households. The result first reveals that renters frequently use electricity as their lighting source compared to owners. Similarly, compound house dwellers compared to private unit residents are more likely to use electricity. Renters also rely on "other" lighting sources compared to house owners. Private house residents and owners, on the other hand, tend to adopt oil lamps, solar and torch lights for lighting purposes. Results for cooking energy show that renters use charcoal and "other" cooking fuel types compared to owners. Compared to private unit residents, compound house occupants also tend to use charcoal and other sources of cooking energy.

Table 3: Mean comparisons for lighting and cooking energy

Energy Variables	Diff. in mean Owned-Rented	P-value	Diff. in Mean (Private-Compound)	P-value
Lighting energy				
Electricity	-0.3044	0.000	-0.533	0.000
oil lamp/lantern	0.0242	0.000	0.031	0.000
Solar	0.071	0.000	0.069	0.000
Torches	0.227	0.000	0.414	0.000
Other lighting types	-0.018	0.006	0.019	0.028
Cooking energy				
Fuelwood	0.410	0.000	0.609	0.000
Charcoal	-0.349	0.000	-0.530	0.000
Other cooking types	-0.061	0.000	-0.079	0.000

Source: Authors' own calculations using Rwandan EICV 5 (2016–2017) data. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

3.3 Housing habitat and tenancy status

The housing landscape of Rwanda reflects the country's unique rural settlement policy known as "Imidugudu" (villagization). The policy ensures that dispersed settlements are relocated to a more centralized settlement. Over 60% of households live in these settlements – *Umudugudu*[1] (NSIR,2018). These houses are mainly constructed through the compulsory community participation law (*Umuganda)*. As a result, there are more homeowners in the rural part of the country than in urban areas. Table 4 shows the dwelling types and tenancy status of households based on their location (urban-rural distribution). Majority of rural households are homeowners (85.7%) and mainly staying in private units (97%). On the other hand, urban dwellers have a higher proportion of renters (54%) and a lower percentage of compound unit dwellers (33%). House ownership in Rwanda, therefore, does not necessarily depend on the wealth status of households especially in rural areas where exogenous factors like assistance from government and non- profit agencies can accelerate the ownership of houses.

[1] Umudugudu is the singular form of Imidugudu in Kinyarwanda the official local language of Rwanda

Table 4: Distribution of household tenancy status and dwelling types by location (in %)

	Tenancy Status		Dwelling Type	
Rural/ Urban	Owned	Rented	Private	Compound
Rural	85.71	14.29	96.73	3.97
Urban	45.84	54.16	66.5	33.45

Source: Authors' calculations using Rwandan EICV 5 (2016–2017) data. Values are in percentages

3.4 Explanatory Variables

We identify several variables that can influence household energy choices. Among these are demographic, socio-economic, geographical, and housing characteristics summarized in *Table A2* in *Appendix A.*, Demographic variables capture household heads information as well as the household's membership distributions. Socio-economic variables are measured using adult equivalent expenditure indicators. Housing characteristics capture the type of building materials and dwelling space. Finally, location characteristics of the household are included as dummies. We compare the mean differences of these variables by tenancy and dwelling status Table 5, 6 and 7.

Table 5: Mean Comparisons for socio-demographic variables

Socio-demographic Variables	Diff. in mean Owned -Rented	P-value	Diff. in Mean (Private– Compound)	P-value
Sex household head	0.01	0.24	0.03	0.04
Age of household head	11.51	0.00	9.47	0.00
Household size	1.36	0.00	1.27	0.00
Household head education	-0.14	0.00	-0.16	0.00
Poverty Status (1= poor)	0.12	0.00	0.25	0.00
Dependency Ratio	0.22	0.00	0.32	0.00
Ratio of women to men	0.27	0.00	0.33	0.00
Wage Salary (1=Yes)	-0.04	0.00	0.12	0.00
log per-adult-eq. non- energy expenditure	-0.48	0.00	-0.79	0.00
log per-adult-eq. energy expenditure	-2.07	0.00	-3.28	0.00

Source: Authors' own calculations using Rwandan EICV 5 (2016/2017) data. *** p<0.01, ** p<0.05, * p<0.1

Table 5 presents the mean comparison of demographic and socioeconomic variables. The computed P-values shows that our groups of interest are unbalanced. Homeowners tend to be older, have larger household size, higher dependency ratio with more women and tend to be poor. Renters, on the other hand, have higher non-energy and energy expenditure and are more educated. We find similar patterns when private house dwellers are compared to compound house dwellers.

Table 6: Comparison of means for geographical variables

Geographic Variables	**Difference in mean Owned -Rented**	**P-value**	**Difference in Mean (Private – Compound)**	**P-value**
Urban (Yes=1)	-0.342	0.000	-0.556	0.000
Kigali City (Yes=1)	-0.274	0.000	-0.548	0.000
Southern Province (Yes=1)	0.044	0.000	0.129	0.000
Western Province (Yes=1)	0.097	0.000	0.135	0.000
Northern Province (Yes=1)	0.111	0.000	0.142	0.000
Eastern Province (Yes=1)	0.022	0.008	0.141	0.000

Source: Authors' own calculations using Rwandan EICV 5 (2016/2017) data. *** p<0.01, ** p<0.05, * p<0.1

Table 6 reports differences in means for geographical variables. Results show that renters compared to homeowners tend to live in urban areas, usually in the capital city of Rwanda, Kigali. Similarly, compound residential dwellers tend to stay in Kigali city. Homeowners and private residential dwellers are more likely to live in the southern, western, northern and eastern provinces of Rwanda.

We present the mean comparisons of housing characteristics in Table 7. The result indicates that renting households are likely to live in buildings with cement, mud walls, metallic roofs and cement floors. They are also more likely to share their rooms and dwellings with others compared to homeowners. A similar pattern is observed for compound house dwellers.

Table 7: Mean comparisons of housing characteristics

Housing Variables	Difference in mean Owned -Rented	P-value	Difference in Mean (Private – Compound)	P-value
Number of Rooms	0.97	0.00	1.247	0.00
Number of Sleeping Rooms	0.57	0.00	0.564	0.00
Share dwelling (1-yes)	-0.42	0.00	-1.266	0.00
Number years in dwelling	8.70	0.00	5.994	0.00
Mud walls (1= yes)	-0.08	0.00	-0.070	0.00
Cement walls 1=yes)	-0.05	0.00	-0.053	0.00
Other walls (1= yes)	0.12	0.00	0.122	0.00
Metalic roof (1= yes)	-0.19	0.00	-0.29	0.00
Clay tiled roof (1= yes)	0.19	0.00	0.290	0.00
Other roofs (1= yes)	0.00	0.09	0.000	0.97
Earth floor (1= yes)	0.31	0.00	0.480	0.00
Cement floor (1= yes)	-0.32	0.00	-0.484	0.00
Dung/clay floors (1= yes)	0.00	0.39	-0.002	0.76
Other floor types (1= yes)	0.00	0.04	0.006	0.06
Access to electric. connection	-0.23	0.00	-0.46	0.00

Source: Authors' own calculations using Rwandan EICV 5 (2016/2017) data. *** p<0.01, ** p<0.05, * p<0.1

A predominant characteristic of developing countries is the low access to electricity as the connection to the grid is limited in supply. Thus, electricity may not necessarily be present in the household's decision set, which may flaw their utility maximization process. EICV5 provides information on households' access to the national grid or other mini-grids. This information enables the study to account for electricity access in our model. Table 7 additionally shows that renters and compound unit dwellers tend to have access to electricity connection than owner-occupants and private unit residents.

4. Empirical Model

Using a random utility probit framework, differences between renters and homeowners as well as private and compound dwellers choice of cooking and lighting energy is modelled as a dichotomous dependent variable:

$$\pi_{ij}^* = \begin{cases} 1\ if\ y_{ij}^* > 0 \\ 0\ if\ \ otherwise \end{cases}$$

Where π_{ij}^* is an unobserved latent variable expressing whether household i chooses a specific lighting or cooking energy type $j = 1,2, \dots k$ defined as a function of household dwelling type (D_i), tenancy status – (rented or not – R_i), socio-demographic, geographical and housing variables (X_i) as expressed in equation (1)

$$\pi_{ij}^* = \alpha_0 + \beta_{1j}R_i + \beta_{2j}D_i + \sum_{i=1}^{n} \gamma_{ij}X_i + \varepsilon_{ij} \tag{1}$$

ε_{ij} represents the idiosyncratic error term and $\alpha_0, \beta_{1j}, \beta_{2j,} and\ \gamma_{ij}$ denote parameters to be estimated. Given that the latent variable π_{ij}^* is conditioned on explanatory variables Ψ_i ($\Psi_i = R_i, D_i, and\ X_i$), the probability that for each household i we observe π_{ij} = 1 (chooses a specific lighting or cooking energy type $j = 1,2, \dots k$) can be estimated as:

$$Pr(\pi_i = 1|\Psi_i) = Pr\left(\beta'\Psi_i + \varepsilon_{ij} \geq 0\middle|\Psi_i\right) = \Phi\ \frac{\beta'\Psi_i}{\sigma_1} \tag{2}$$

where Φ is the cumulative standard normal distribution function with error terms $\varepsilon_{ij} \sim N\ (0,1)$. Consequently, following Greene (2003) and Wooldridge (2002), the likelihood function is expressed as:

$$L = \Pi_{\pi_{ij}^* < 0}\left[1 - \Phi\ \frac{\beta'\Psi_i}{\sigma_1}\right]\Pi_{\pi_{ij}^* > 0}\left[\Phi\ \frac{\beta'\Psi_i}{\sigma_1}\right] \tag{3}$$

Given that π_{ij}^* is unobservable, we employ the maximum likelihood estimation technique in equation 4. This provides the study with the resulting parameter of interest β_{1j} which compares households tenancy status (rented or owned) based on their choice of lighting and cooking energy types and β_{2j} which compares the dwelling units of households (private or compound house) given their energy choices.

$$\pi_{ij} = \alpha_0 + \beta_{1j}R_i + \beta_{2j}D_i + \sum_{i=1}^{n} \gamma_{ij}X_i + \varepsilon_{ij} \tag{4}$$

It is plausible that factors such as preferences and income levels may correlate with both household's energy choices and tenancy status. Martey (2019) argues that differences in wealth and income levels may affect the type of cooking and the lighting fuels adopted by households as well as their tenancy status. Consequently, the probit model may lead to biased estimates as unobserved factors and other sources of endogeneity may cause a correlation between error terms ε_{ij} and energy choice as well as tenancy status R_i in equation 4.

Heckman (1978) developed the bivariate probit (biprobit) model to address such biases. This model is widely used by applied economists such as Han and Vytlacil (2017), Acosta (2011), Fleming and Ker (2008), Bhattacharya, Goldman and McCaffrey (2006) and Brown, Pagan and Bastida (2005). In the energy context, selected studies such as Martey (2019), Gebreegziabher et al. (2012) and Yoo, Lee and Kwak (2009) have also used the biprobit model to examine energy choices. The model enables easy identification of parameters irrespective of the inclusion of an endogenous explanatory variable. Han and Vytlacil (2017) and Altonji, Eder and Taber (2005) confirm this characteristic by showing that omitting restrictions is of less importance for identification if the same controls are included in the estimation of biprobit simultaneous equations.

Based on Cameron and Trivedi (2005) and Greene (2003), two variables are defined (energy choice and household rental status where 1=rented, 0=owned) based on the unobserved latent variables as follows:

$$\pi_{ij}^{*} = \alpha_0 + \beta_{1j}R_i + \beta_{2j}D_i + \sum_{i=1}^{n}\gamma_1 X_{1i} + \varepsilon_{1i} \tag{5}$$

$$R_i^{*} = \beta_{2j}D_i + \sum_{i=1}^{n}\gamma_2 X_{2i} + \varepsilon_{2i} \tag{6}$$

π_{ij}^{*} is previously defined in equation 1. R_i represent the rental status of households, D_i is the dwelling type. X_{1i} and X_{2i} are exogenous explanatory variables summarized in Appendix A. ε_{1i} and ε_{2i} are jointly determined such that:

$$E[\varepsilon_{1i}|X_{1i}, X_{2i}] = E[\varepsilon_{2i}|X_{1i}, X_{2i}] = 0,$$

$$Var[\varepsilon_{1i}|X_{1i}, X_{2i}] = Var[\varepsilon_{2i}|X_{1i}, X_{2i}] = 1, \tag{7}$$

$$Cov[\varepsilon_{1i}\varepsilon_{1i}|X_{1i}, X_{2i}] = \rho.$$

A seemingly unrelated bivariate probit model based on a maximum likelihood estimation is adopted to estimate the indicator variables π_{ij}, R_i of equation 5 and 6 following Woodbridge (2010).

5. Results and Discussion

This section reports the marginal effects of the bivariate probit estimates to examine the differences in households lighting and cooking energy choices by rental status and dwelling types having accounted for potential correlations. For comparison purposes we report the probit estimation results in *Appendix B.* Additionally, we conduct a heterogeneous analysis to understand how differences in income, gender and geographical location of households affect energy choices based on tenancy status and dwelling types.

5.1 Bivariate probit estimates of lighting and cooking energy choices

Table 8 and 9 present the marginal effect of the bivariate model. We report the results in two parts. The first part "panel A" control for demographic and geographical variables. The second part (panel B) additionally includes housing characteristics. Arguably, housing characteristics can simultaneously influence both energy choice decisions and tenancy status (Martey, 2019). For instance, the size of renter's apartment is likely to influence their choice of energy investments. Reporting results with and without housing characteristics enables the study to observe and attenuate any potential biases. These estimates show the effect of households' tenancy status and dwelling type on cooking and lighting energy choices. Comparing the bivariate probit model to the probit model (*Appendix B*), we find that the expected signs remain unchanged. Marginal effects are steadily higher for the bivariate probit model compared to the probit model when we control for housing characteristics. This suggests an improvement in estimates after correcting for endogeneity. Given the assumption that the distributional properties underlying the biprobit model hold for our data, we can conclude that the probit model estimates were downwardly biased.

Results from Table 8 reveal that renting households compared to owners are 11% less likely to use fuelwood. They are, however, more likely to use charcoal and "other" cooking energy sources with a probability of 8% and 3% respectively. Similarly, compound dwellers are less likely than private unit residents to adopt fuelwood but more likely to adopt charcoal; however, these effects disappear when we include housing characteristics in the model.

Table 8**:** Biprobit estimates of cooking energy choices

	Cooking Energy Sources					
Tenancy/Residency Status	Fuelwood 1(a)	Fuelwood 1(b)	Charcoal 2(a)	Charcoal 2(b)	Other 3(a)	Other 3(b)
Renting	-0.040	-0.106***	0.066***	0.077***	-0.0200	0.028*
	(0.035)	(0.015)	(0.022)	(0.015)	(0.021)	(0.017)
Dwelling type	-0.042***	-0.003	0.017*	-0.011	0.009	0.002
(Compound housing)	(0.015)	(0.009)	(0.009)	(0.007)	(0.007)	(0.005)
Housing variables	NO	YES	NO	YES	NO	YES
Demographic var.	YES	YES	YES	YES	YES	YES
Geographic var.	YES	YES	YES	YES	YES	YES
Wald (df)	6515(33)	7434(57)	6665(33)	7000(57)	3894(33))	4227(57)
P-value	0.00	0.00	0.00	0.00	0.00	0.00
Observations	14,580	14580	14,580	14,580	14,580	14,580

Notes: Biprobit marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Table 9 shows that renters are 9% and 5% more likely to adopt electricity and "other" lighting sources but 3%, and 10% not likely to adopt oil lamps and torches compared to homeowners when household characteristics are included in the estimation. Rental status, however, does not affect the choice of solar lighting. Households living in compound houses tend to adopt electricity for lighting yet, are less likely to adopt torches and "other" lighting sources compared to private unit residents.

Our results suggest that rental status and household dwelling types have varying effects on fuels choices in Rwanda. Contrary to the finding of Martey (2019), Baiyegunhi and Hassan (2014), Lay et al., (2013) and Arthur et al., (2010) our findings show that renters and compound house residents compared to homeowners and private unit residents tend to use relatively cleaner lighting sources. The finding that renters and compound house occupants adopt less fuelwood but use transition fuel such as charcoal for cooking is, however, in line with the results from Martey (2019).

Table 9: Biprobit Estimates of lighting energy choices

	Lighting Energy Sources				
			Panel A		
Tenancy/Residency Status	Electricity 1(a)	Oil Lamp/lantern 2(a)	Solar 3(a)	Torches 4(a)	Other 5(a)
Renting	0.034	-0.015	-0.046	-0.059	0.040
	(0.026)	(0.021)	(0.029)	(0.059)	(0.027)
Dwelling type	0.085***	-0.013	-0.013	-0.102***	-0.024*
(Compound housing)	(0.014)	(0.012)	(0.019)	(0.030)	(0.015)
Housing variables	NO	NO	NO	NO	NO
Demographic var.	YES	YES	YES	YES	YES
Geographic var.	YES	YES	YES	YES	YES
Wald chi 2 (df)	7009(33)	3625(33)	4266(33)	5798(33)	3897(33)
P value	0.000	0.000	0.000	0.000	0.000
Observations	14,580	14,580	14,580	14,580	14,580
			Panel B		
Tenancy/Residency Status	Electricity 1(b)	Oil Lamp/lantern 2(b)	Solar 3(b)	Torches 4(b)	Other 5(b)
Renting	0.088***	-0.029*	-0.0233	-0.104***	0.049**
	(0.025)	(0.0167)	(0.0238)	(0.0325)	(0.0198)
Dwelling type	0.040***	-0.006	-0.008	-0.069**	-0.026*
(Compound housing)	(0.013)	(0.013)	(0.022)	(0.028)	(0.015)
Housing variables	YES	YES	YES	YES	YES
Demographic var.	YES	YES	YES	YES	YES
Geographic variables	YES	YES	YES	YES	YES
Wald chi 2 (df)	4483(57)	3931(57)	4605(57)	5163(57)	4132(57)
P value	0.000	0.000	0.000	0.000	0.000
Observations	14,580	14,580	14,580	14,580	14,580

Notes: Biprobit marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Geographical distribution of homeowners in Rwanda could be an explanatory factor for our results. Rationally, owning a home is associated with higher socioeconomic status and wellbeing, but this is not necessarily the case for Rwandan residents. Most Rwandan homeowners are poor, live in rural communities and are unable to access modern energy. Their homeownership comes as a result of the social housing intervention by the Rwandan government (*imudugudu*) which see to the relocation of scattered residents in rural communities to a more centralized settlement to provide better amenities to enhance development in such areas. The resettlement policy enables the ownership of simple homes which are built through community participation. In effect, most homeowners in Rwanda are still reliant on traditional fuels. Kigali, the capital city of Rwanda, has the highest number of renters compared to other provinces and has better access to electricity and other transitional energy. Given that urban areas have relatively better access to cleaner energy than in rural areas, renters in Rwanda who are mostly based in Kigali city are more likely to access better cooking and lighting fuels explaining their fuel choices.

Further, factors such as sanitation, efficient energy appliances, access to the grid, basic amenities and proximity to work are among the many factors considered before an individual settle for a rental unit. Consequently, informed decisions about preferred energy investments are considered before signing a rental agreement resulting in their ability to adopt relatively cleaner fuels. Homeowners on the other hand, especially in a developing country context where people build their own houses may move into an uncompleted house or less developed areas with the hope of gradually completing and accessing better amenities in future due to the additional financial burden associated with relocating to new a house. Such decisions slow their ability to adopt cleaner household fuels quickly, therefore explaining why renters are more likely to use better energy types compared to homeowners. Martey (2019) additionally identifies preferences, ownership rights and building structure as potential mechanisms for these varying effects.

Further, the use of fuelwood requires ample cooking space. Compound house dwellers, unlike private house residents, do not have the luxury of residential space as they tend to share their compound with other residents. This may be an explanatory factor to why compound unit residents are less likely to adopt fuelwood for cooking.

5.2 An Analysis of Impact of Heterogeneity

Differences in income levels, gender of household heads and geographical location of households (rural-urban) can account for differences in household's energy choices (Choumert-Nkolo et al., 2019; Das, De Groote & Behera, 2014; Baiyegunhi & Hassan, 2014; van der Kroom, Brouwer & van Beukering, 2013; Pachauri and Jiang, 2008 Hosier & Dowd,1987). In this section, an analysis of impact of heterogeneity as a form of robustness test to examine the varying effect of households rental or ownership status and dwelling types on energy choices based on differences in income quartiles, female and male-headed households and location (rural-urban).

5.2.1 Income Differences

We categorize income into quartiles (lowest to the highest income group) to demonstrate the degree to which the energy ladder hypothesis holds for the Rwandan economy. The potential to explore multiple fuel use (fuel-stacking) is, however, limited given that households provided answers on only their primary source of lighting and cooking fuels. The binscatter plot in figures 2 and 3 show the relationship between households choice of lighting energy and income by tenancy status and dwelling type, respectively.

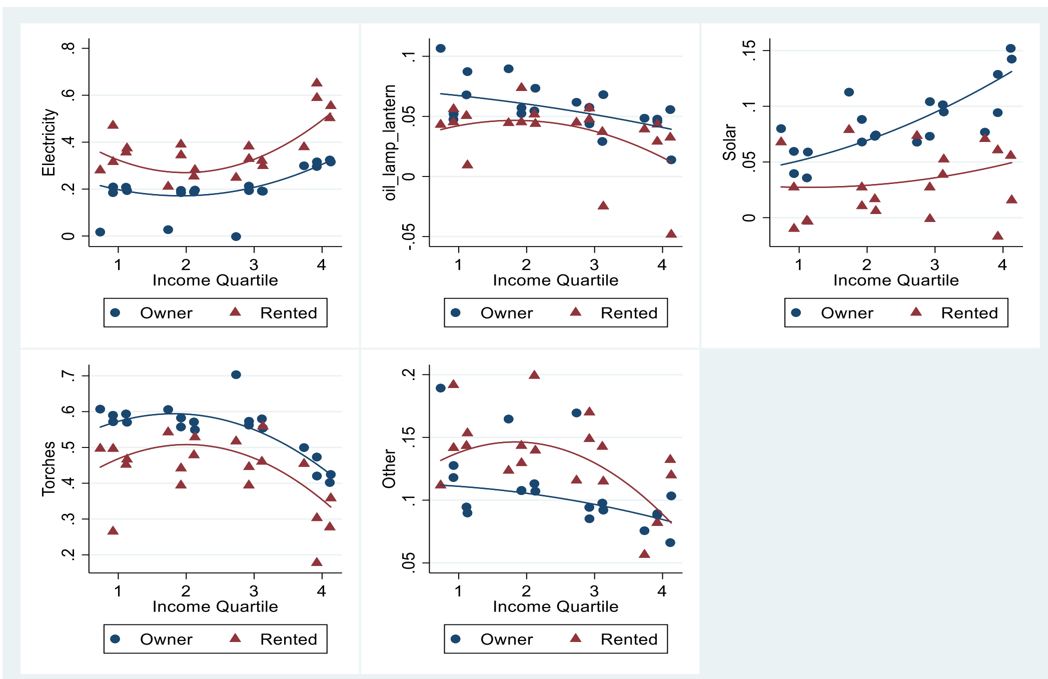

Figure 2: Lighting energy choices and income by rental status

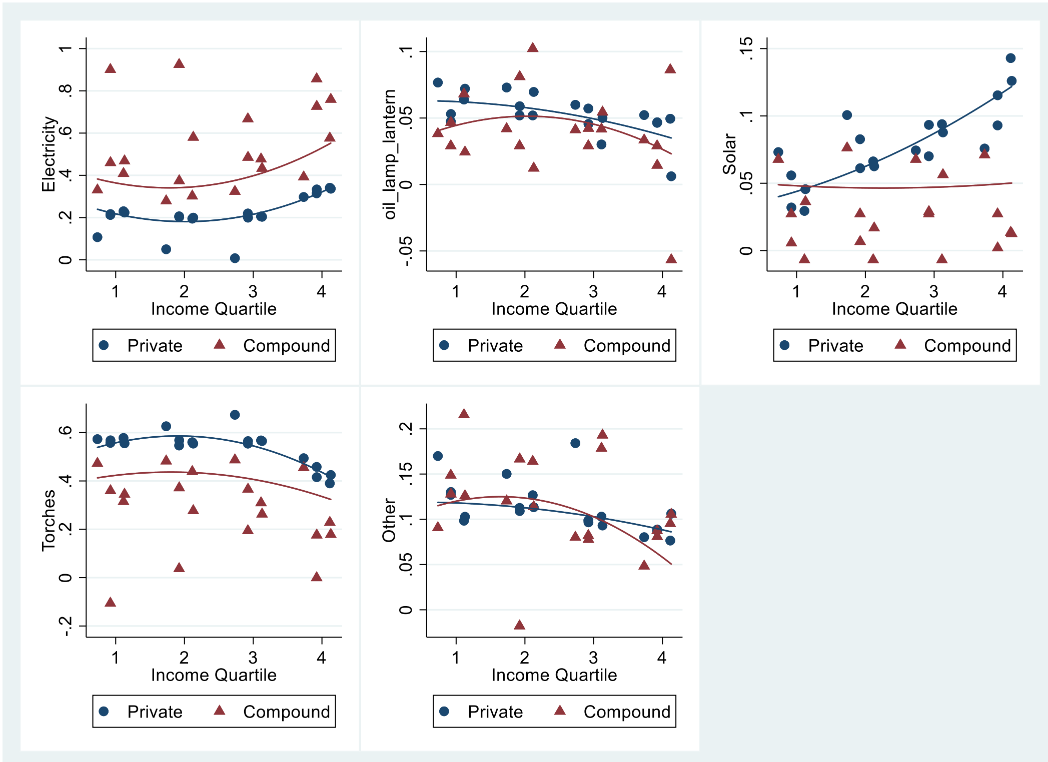

Figure 3: Lighting energy choices and income by dwelling type

We observe a similar relationship between income and lighting fuels for renters and owners (Figure 2) as well as compound and private unit dwellers (Figure 3) except for solar where compound dwellers show a positive relationship compared to the somewhat constant relationship observed for private unit residents. Generally, with increases in income renters and owners are likely to adopt more electricity and solar energy sources but less of oil lamps, torches and "other" sources of lighting energy. Both compound house dwellers and private unit residents also tend to adopt electricity and less of torches, oil lamps and other sources of lighting energy with increases in income. The adoption rates, however, differ between renters and owners as well as compound and private unit dwellers. In income quartile four, renters are likely to increase their electricity use but adopt less of oil lamps, torches and solar lighting sources relative to homeowners. Compound unit occupants compared to private residents in the same quartile use more electricity and less of oil lamps, torches, solar and "other" lighting sources.

Figure 3 depicts the relationship between households cooking energy choices and income by rental (left panel) and dwelling types (right panel). The binscatter plot show more of an inverted U-shape for fuelwood. Thus, at the initial levels of increases in income, renters and owners demand more fuelwood, but with further increases in income, they tend to use less fuelwood. Renters and owners in the second and third quartiles are therefore more likely to use more fuelwood but tend to prefer less fuelwood in the fourth quartile thus depicting an inverted U shape. A similar relationship is observed for compound and private unit dwellers.

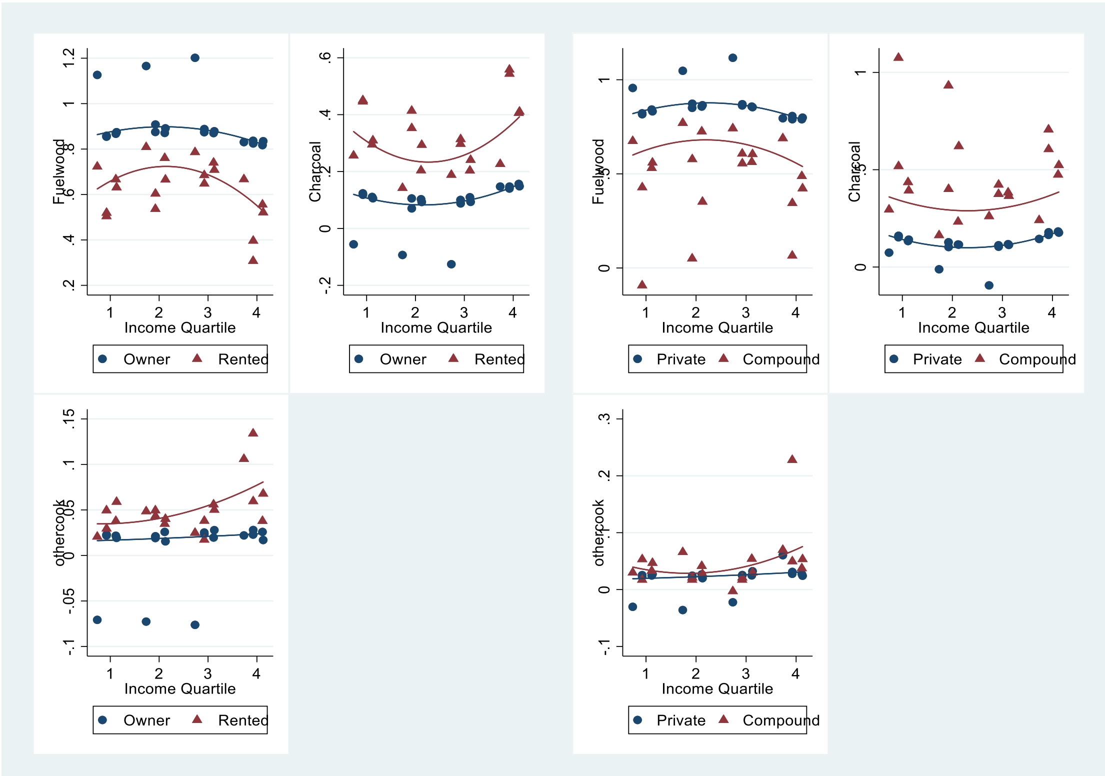

Figure 3: Cooking choices and income levels by rental status and dwelling types

On the other hand, we observe a U-shape relationship for charcoal. The demand for charcoal first decreases with increasing income but does not persist as further increases in income result in higher demand for charcoal. This U-shape relationship is observed for homeowners, renters, as well as private and compound house residents. Renters also prefer “other” forms of cooking energy which include LPG, electricity and biogas as income increases. The relationship between “other” forms of cooking fuels and dwelling types remains inconclusive. For comparison purposes, we additionally present the biprobit results for each quartile in *Appendix C*. Consistent with the above, results also emphasize the importance income for fuel choices.

The importance of income for household fuel choices is studied in most empirical studies. Higher income is often associated with cleaner energy choices. Consistent with Baiyegunhi and Hassan (2014), Lay et al. (2013), Démurger and Fournier (2011), Gupta and Köhlin, (2006) Ouedraogo

(2006) and Hosier and Dowd (1987) our estimates from the biprobit model and the distributional analysis when income is sub-divided into quartiles partly confirms the income-fuel choice relationship and weakly supports the energy ladder hypothesis. This contrasts the study of Martey (2019) who finds a strong support of the energy ladder hypothesis. Our finding, therefore, highlights that evidence does not always provide conclusive support of the energy ladder and that different contexts can yield varied results.

5.2.2 Gender differences

Gender-differentiated impacts are associated with households' energy choices (Choumert-Nkolo et al., 2019; Wickramasinghe, 2011; Narasimha & Reddy, 2007). Evidence shows that female-headed households tend to adopt relatively cleaner fuels compared to male-headed households (Das et al. 2014; Farsi, Fillipinni & Pachauri, 2007; Rao & Reddy 2007). Women are generally caregivers and do most of the household chores (Zambelli et al., 2017). Consequently, they are responsible for household cooking and therefore more exposed to health risks associated with using dirty fuels which further informs their decision for cleaner energy options. Contrary to this argument, existing literature shows that this is not always the case. For instance, Link, Axinn and Ghimire (2012) show that females are more likely to use fuelwood in Nepal. Similarly, Heltberg (2005) show no association between a higher proportion of females and fuelwood usage. To explore this concept in the context of tenancy status and dwelling types, we estimate the biprobit model to examine the effect of tenancy and dwelling types on energy decisions based on the gender of household heads.

Table 10 presents the marginal effects of cooking energy. Consistent with the main findings of the study, household heads who are renters compared to owners tend to rely on charcoal for cooking but are less likely to adopt fuelwood. The degree of magnitude, however, differs for female and male-headed households with female-headed household showing a higher probability of using less fuelwood. Specifically, whereas female-headed households are 12% less likely to adopt fuelwood and 9% more likely to use charcoal, male-headed households are instead 9% less to likely use fuelwood and tend to use more charcoal (5%), when renters are compared to owner-occupants. We formally test the differences between female and male-headed households using the suest post estimation test (Weesie,1999) reported in *Appendix D,* focusing on fuel types for which we observe significant results (Fuelwood and Charcoal). Results show a substantial difference in fuelwood and charcoal adoption by gender of household heads. Consistent with Das et al. (2014), Rao & Reddy (2007) and Farsi et al. (2007) our finding supports the argument that female-headed households tend to adopt cleaner cooking fuel.

Table 10**:** Biprobit estimates of cooking energy choices by household heads gender

	Cooking Energy Sources					
Tenancy/Residency Status	Fuelwood Male	Fuelwood Female	Charcoal Male	Charcoal Female	Other Male	Other Female
Renting	-0.095***	-0.119***	0.065***	0.098***	0.035*	-0.003
	(0.018)	(0.022)	(0.018)	(0.019)	(0.019)	(0.075)
Dwelling type	-0.009	0.0194	-0.005	-0.026**	0.001	0.007
(Compound housing)	(0.011)	(0.016)	(0.009)	(0.013)	(0.006)	(0.016)
Housing variables	YES	YES	YES	YES	YES	YES
Demographic var.	YES	YES	YES	YES	YES	YES
Geographic var.	YES	YES	YES	YES	YES	YES
Wald (df)	5570(55)	1858(55)	5221(55)	1803(55)	3284(55)	1020(55)
P-value	0.00	0.00	0.00	0.00	0.00	0.00
Observations	10,856	3,724	10,856	3,724	10,856	3,724

Notes: Biprobit marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Results for lighting energy choices are presented in Table 11. Consistent with the main findings of the study, household heads who are renting are likely to use more of electricity than owner-occupants. Similar to the results for cooking energy, the magnitude of lighting fuel usage differs across female and male-headed households which are confirmed by the post estimation test in *Table D2 Appendix D.* For female-headed households, renters compared to homeowners are 13% and 11% more likely to use electricity and other lighting sources, respectively. They tend to be 24% less likely to use torch lights. Male headed households who are renters compared owners are only 8% more likely to adopt electricity but 4% less likely to use oil lamps and lanterns.

Table 11**:** Biprobit estimates of lighting energy choices by gender of the household head

	Lighting Energy Sources				
	Female				
Tenancy/Residency Status	Electricity 1(a)	Oil Lamp/lantern 2(a)	Solar 3(a)	Torches 4(a)	Other 5(a)
Renting	0.129***	-0.008	0.0443	-0.245***	0.112**
	(0.034)	(0.039)	(0.036)	(0.051)	(0.046)
Dwelling type	0.013	-0.008	8.59e-05	0.0133	-0.059*
(Compound housing)	(0.021)	(0.024)	(0.025)	(0.049)	(0.034)
Housing variables	YES	YES	YES	YES	YES
Demographic variables	YES	YES	YES	YES	YES
Geographic variables	YES	YES	YES	YES	YES
Wald chi 2 (df)	1927(53)	1068(53)	1078(53)	1636(53)	1232(53)
P value	0.00	0.00	0.00	0.00	0.00
Observations	3,724	3,724	3,724	3,724	3,724
	Male				
Tenancy/Residency Status	Electricity 1(b)	Oil Lamp/lantern 2(b)	Solar 3(b)	Torches 4(b)	Other 5(b)
Renting	0.087***	-0.041**	-0.039	-0.032	0.023
	(0.029)	(0.019)	(0.027)	(0.039)	(0.021)
Dwelling type	0.053***	-0.011	-0.019	-0.116***	-0.019
(Compound housing)	(0.015)	(0.016)	(0.032)	(0.033)	(0.016)
Housing variables	YES	YES	YES	YES	YES
Demographic variables	YES	YES	YES	YES	YES
Geographic variables	YES	YES	YES	YES	YES
Wald chi 2 (df)	5926(53)	2876(53)	3369(53)	4865(53)	2855(53)
P value	0.000	0.000	0.000	0.000	0.000
Observations	10,856	10,856	10,856	10,856	10,856

Notes: Biprobit marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

5.2.2 Rural-urban differences

Given that most Rwandan households are based in rural areas which are likely to affect the role of tenancy status on fuel choices, we sub-divide our sample into rural and urban households to explore these differences. Specifically, we examine the effect of tenancy status and dwelling type on cooking and lighting energy choices by separately estimating the biprobit model for rural and urban households.

Table 12: Rural-urban biprobit estimates for cooking energy choices

Tenancy/Residency Status	**Cooking Energy Sources**					
	Fuelwood Rural	Fuelwood Urban	Charcoal Rural	Charcoal Urban	Other Rural	Other Urban
Renting	-0.119***	-0.064*	0.050***	0.155***	0.029**	-0.052
	(0.015)	(0.033)	(0.017)	(0.054)	(0.014)	(0.046)
Dwelling type	0.004	-0.009	0.016*	-0.031	-0.015	0.026*
(Compound housing)	(0.012)	(0.018)	(0.009)	(0.023)	(0.010)	(0.014)
Housing variables	YES	YES	YES	YES	YES	YES
Demographic var.	YES	YES	YES	YES	YES	YES
Geographic var.	YES	YES	YES	YES	YES	YES
Wald (df)	4864(53)	1561(53)	3162(53)	1567(53)	2112(53)	1107(53)
P-value	0.000	0.000	0.000	0.000	0.000	0.000
Observations	12,054	2,526	12,054	2,526	12,054	2,526

Notes: Biprobit marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Table 12 and 13 present the results for cooking and lighting energy choices, respectively. For cooking energy, findings show that renters compared to owner-occupants in rural and urban areas are less likely to use fuelwood but use more charcoal for cooking. The magnitude of the low usage of fuelwood is greater for rural households than for urban households. Rural households are 12% not likely to adopt fuelwood compared to 6% for urban households. Result for the charcoal adoption is as expected. Renting households compared to owners in urban households are more likely to use charcoal (15%) than in rural areas (5%).

Additionally, renters in rural areas also tend to adopt "other" cooking sources, but no significant effect is observed for urban households. Compound unit residents also tend to use more charcoal and "other" cooking energy in rural households. *Table D3* of *Appendix D* formally confirms the rural-urban differences in the choice of cooking energy.

Table 13: Rural-urban biprobit estimates for lighting energy choices

	Lighting Energy Sources				
	Rural Households				
Tenancy/Residency Status	Electricity 1(a)	Oil Lamp/lantern 2(a)	Solar 3(a)	Torches 4(a)	Other 5(a)
Renting	0.131***	-0.026	-0.023	-0.141***	0.059**
	(0.023)	(0.023)	(0.032)	(0.042)	(0.028)
Dwelling type	0.016	0.009	-0.018	-0.085**	0.017
(Compound housing)	(0.019)	(0.019)	(0.031)	(0.041	(0.023)
Housing variables	YES	YES	YES	YES	YES
Demographic variables	YES	YES	YES	YES	YES
Geographic variables	YES	YES	YES	YES	YES
Wald chi 2 (df)	4795(51)	2314(51)	2854(51)	3637(51)	2435(51)
P value	0.000	0.000	0.000	0.000	0.000
Observations	12,054	12,054	12,054	12,054	12,054
	Urban Households				
Tenancy/Residency Status	Electricity 1(b)	Oil Lamp/lantern 2(b)	Solar 3(b)	Torches 4(b)	Other 5(b)
Renting	0.010	-0.043*	-0.001	0.011	0.036
	(0.037)	(0.022)	(0.008)	(0.044)	(0.031)
Dwelling type	0.057***	-0.033**	0.003	-0.015	-0.035**
(Compound housing)	(0.017)	(0.016)	(0.006)	(0.021)	(0.018)
Housing var.	YES	YES	YES	YES	YES
Demographic var.	YES	YES	YES	YES	YES
Geographic var.	YES	YES	YES	YES	YES
Wald chi 2 (df)	1497(51)	935(51)	836(51)	1223(51)	1066(51)
P value	0.000	0.000	0.000	0.000	0.000
Observations	2,526	2,526	2526	2,526	2,526

Notes: Biprobit marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Results for lighting energy choices (Table 13) show that renters compared to homeowners in rural areas use more electricity and "other" lighting sources but less likely to use torch lights. We find no significant effect for electricity, solar, torch lights and "other" lighting energy use for urban households. However, renters in urban households use less of oil lamps and lanterns. Results for dwelling type also show that whereas compound house dwellers compared to private unit residents are less likely to use torch lights in rural areas; they are more likely to use electricity and less likely to adopt oil lamps and lanterns in urban areas.

Previous studies show that the magnitude of factors influencing fuel choices in urban and rural areas differ (Heltberg, 2004). However, the variation in effect shows that urban households are often more likely to utilize relatively cleaner fuel sources than rural households due to better accessibility of modern fuels and the high opportunity cost associated with collecting and the utilization of dirty fuels (Mekonnen & Kohlin, 2008; Farsi et al., 2007; Heltberg, 2005; Hosier & Dowd, 1987). Our finding supports this assertion as urban households show a tendency of using more transition fuels like charcoal for cooking than in rural areas. Result for lighting energy is, however, inconclusive for rural and urban households.

6. Conclusion

Rwanda has one of the unique house ownership patterns in the SSA region. In this study, we ascertain the heterogeneity effect of the country's house ownership patterns and rental status on energy choices. Specifically, we employ the bivariate probit models to examine the role of tenancy status (rented or owner occupant) and dwelling type (private or compound house residence) on households lighting and cooking choices in the country. To achieve our objective, the study relies on the fifth Integrated Household Living Conditions Survey (EICV 5) - a nationally representative dataset conducted by the Rwandan National Institute of Statistics.

Results show that tenancy status and dwelling types significantly influence households fuel choices in Rwanda. Income, gender of household head and location additionally influence cooking and lighting fuel choices.

Estimates from the biprobit model show higher effects than probit results. Renters compared to owner-occupants use charcoal and "other" fuels but less of fuelwood for cooking. We find no effect for compound house residents compared to private house residents. Results for lighting energy show that renters in comparison to homeowners use more electricity and "other" fuels but fewer oil lamps and torches. Households residing in compound houses tend to use more electricity but fewer torches and "other" lighting energy sources.

A further sub-division of our sample into income quartiles, rural-urban households and female-male-headed households confirm the existence of heterogeneity in energy choices. Specifically, the income-fuel choice relationship shows that for lighting purposes, higher-income quartile groups tend to adopt more electricity and use fewer torches. They, however, use more charcoal and less fuelwood for cooking Although the energy ladder hypothesis is popular in the energy literature (Martey, 2019; Baiyegunhi & Hassan, 2014; Das et al., 2014; Lay et al. 2013; Démurger & Fournier, 2011; Gupta & Köhlin, 2006; Ouedraogo, 2006; Reddy & Reddy, 1994; Hosier & Dowd,1987) our finding only partly supports this hypothesis. This demonstrates the importance the context and how evidence does not always provide conclusive support of the energy ladder hypothesis.

Location of households (urban-rural) also significantly affects energy choices. Renters compared to owner-occupants in urban households show a tendency of using more transition fuels like charcoal for cooking than in rural areas confirming previous findings of Mekonnen and Kohlin (2008), Farsi et al., (2007), Heltberg (2005) and Hosier and Dowd (1987). Consistent with Das et al. (2014), Farsi et al. (2007) and Rao & Reddy (2007). Our results also show that female-headed households are more likely to adopt cleaner cooking energy choices.

The geographical distribution of homeowners resulting from Rwanda's rural resettlement policy could be a significant explanatory factor of our results. Most Rwandan homeowners are poor, reside in rural communities and unable to access modern energy. In effect, most homeowners in Rwanda still rely on traditional fuels. Kigali has the highest number of renters compared to other provinces and has better access to electricity and other forms of transitional energy. The better developmental structures and amenities of urban areas makes it relatively easier for renters living in these communities to adopt cleaner fuels for their cooking and lighting needs. Martey (2019) additionally identifies preferences, ownership rights and building structure as potential mechanisms for the heterogeneity effects.

Our findings reinforce the role of higher socio-economic status on energy choices. Low-income group homeowners in Rwanda who are usually based in the rural areas of the country are more likely to move from dirty lighting and cooking fuels to cleaner options with improvement in income levels. Programs and policies targeted at eradicating poverty will, therefore, enhance cleaner household energy choices. These programs in effect will improve health conditions of households and thus result in positive spillover effects on the environment.

The study is limited by data as a result we were unable to contextualize household's energy decisions by tenancy status. The literature can benefit from future studies that additional include primary and qualitative data as well as highlighting how existing building designs can inform fuel choices. Additionally, national surveys should consider collecting more data on various energy sources to enable researchers to additionally test the fuel stacking hypothesis.

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Appendix A: Additional Descriptive Statistics

Table A1: Composition of other types of cooking fuels

Other cooking Fuels	Frequency
Liquified Petroleum Gas (LPG)	163
Biogas	5
Electricity	8
Oil/Kerosene	4
Crop Waste	90
Others	116
Total	386

Source: Rwandan EICV 5 (2016/2017) data.

Table A2: Summary statistics of Explanatory Variables

Variables	Observation	Mean	SD	Min	Max
Demographic/Socioeconomic					
Male headed households	14580	0.74	0.44	0	1
Age of household head	14580	45.15	15.64	14	109
Education of household head	14580	0.77	0.42	0	1
Household size	14580	4.41	2.11	1	22
Dependency Ratio	14580	0.82	0.76	0	7
Ratio of women to men	14580	1.14	0.76	0	9
Poverty Status	14580	0.33	0.47	0	1
Wage Salary	14580	0.24	0.43	0	1
log per-adult-eq. non- energy expenditure	14580	12.53	0.76	9.87	17.24
log per-adult-eq. energy expenditure	14580	0.82	0.76	0	7
Geographical					
Urban	14580	0.17	0.37	0	1
Kigali City	14580	0.11	0.31	0	1
Southern Province	14580	0.26	0.44	0	1
Western Province	14580	0.23	0.42	0	1
Northern Province	14580	0.16	0.37	0	1
Eastern Province	14580	0.23	0.42	0	1
Housing Characteristics					
Access to Electricity	14580	0.32	0.47	0	1
Number of rooms	14580	3.55	1.24	1	11
Number of Sleeping rooms	14580	2.11	0.88	1	8
Number of households sharing dwelling	14580	0.11	0.57	0	15
Years of inhabitance	14580	9.39	10.51	0	79
Roofing Material	14580	1.37	0.48	1	3
Floor Material	14580	1.38	0.65	1	4
Exterior wall material	14580	1.69	0.93	1	3
Variables of Interest					
Renting	14580	0.21	0.41	0	1
Dwelling type	14580	0.08	0.27	0	1

Source: Authors' own calculations using Rwandan EICV 5 (2016/2017) data.

Appendix B: Probit estimation

Table B1: Probit Estimates of lighting energy choices

	Lighting Energy Sources				
	Panel A				
Tenancy/Residency Status	Electricity 1(a)	Oil Lamp/lantern 2(a)	Solar 3(a)	Torches 4(a)	Other 5(a)
Renting	0.036***	-0.019***	-0.044***	-0.029**	0.024***
	(0.009)	(0.007)	(0.01)	(0.012)	(0.008)
Dwelling type	0.084***	-0.029**	-0.022	-0.118***	-0.044**
(Compound housing)	(0.014)	(0.012)	(0.015)	(0.019)	(0.017)
Housing var.	NO	NO	NO	NO	NO
Demographic var.	YES	YES	YES	YES	YES
Geographic var.	YES	YES	YES	YES	YES
Wald chi 2 (df)	1650(17)	307(17)	579(17)	1767(17)	506(17)
P value	0.000	0.00	0.000	0.000	0.000
Observations	14,580	14,580	14,580	14,580	14,580
	Panel B				
Tenancy/Residency Status	Electricity 1(b)	Oil Lamp/lantern 2(b)	Solar 3(b)	Torches 4(b)	Other 5(b)
Renting	0.017***	-0.007	-0.040***	-0.010	0.029***
	(0.004)	(0.006)	(0.010)	(0.010)	(0.007)
Dwelling type	0.014***	-0.014	-0.025	-0.027	0.0260*
(Compound housing)	(0.005)	(0.011)	(0.018)	(0.028)	(0.016)
Housing variables	YES	YES	YES	YES	YES
Demographic variables	YES	YES	YES	YES	YES
Geographic variables	YES	YES	YES	YES	YES
Wald chi 2 (df)	843(29)	417(29)	766(29)	1352(29)	481(29)
P value	0.000	0.000	0.000	0.000	0.000
Observations	14,580	14,580	14,580	14,580	14,580

Notes: These are marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors based on the cluster divisions of EICV 5 data are in parentheses. Inverse probability sampling weights were used. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Table B2: Probit estimates of cooking energy choices

	Cooking Energy Sources					
Tenancy/Residency Status	Fuelwood 1(a)	Fuelwood 1(b)	Charcoal 2(a)	Charcoal 2(b)	Other 3(a)	Other 3(b)
Renting	-0.066***	-0.040***	0.058***	0.029***	0.012***	0.011***
	(0.006)	(0.006)	(0.005)	(0.006)	(0.004)	(0.004)
Dwelling type (Compound housing)	-0.042***	-0.026***	0.023***	0.001	0.003	0.009*
	(0.009)	(0.009)	(0.009)	(0.010)	(0.005)	(0.005)
Housing variables	NO	YES	NO	YES	NO	YES
Demographic var.	YES	YES	YES	YES	YES	YES
Geographic var.	YES	YES	YES	YES	YES	YES
Wald (df)	1907(17)	2244(29)	1856(17)	1985(29)	587(17)	675(29)
Pvalue	0.000	0.000	0.000	0.000	0.00	0.00
Observations	14,580	14580	14,580	14,580	14,580	14,580

Notes: marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Appendix C: Biprobit estimation by income quartiles

Table C1: Lighting energy choices by income quartiles.

Tenancy/Residency Status	**Lighting Energy Sources** Electricity (1)	Oil Lamp/lantern (2)	Solar (3)	Torches (4)	Other (5)
Renting					
Quartile 2 (n=3644)	-0.018	-0.074*	0.053	-0.040	0.061
	(0.057)	(0.043)	(0.060)	(0.074)	(0.044)
Quartile 3 (n=3648)	0.083	0.006	-0.059	-0.091	0.027
	(0.052)	(0.026)	(0.052)	(0.071)	(0.043)
Quartile 4 (n=3642)	0.137***	-0.049	0.007	-0.124**	0.005
	(0.042)	(0.034)	(0.049)	(0.059)	(0.037)
Dwelling type					
Quartile 2 (n=3644)	0.101***	0.006	-0.036	-0.132*	-0.027
	(0.030)	(0.032)	(0.051)	(0.068)	(0.037)
Quartile 3 (n=3648)	0.039	0.000	-0.018	-0.107	-0.044
	(0.028)	(0.026)	(0.058)	(0.067)	(0.034)
Quartile 4 (n=3642)	0.059**	-0.026	-0.022	-0.028	-0.033
	(0.025)	(0.021)	(0.043)	(0.049)	(0.024)
Housing variables	YES	YES	YES	YES	YES
Demographic variables	YES	YES	YES	YES	YES
Geographic variables	YES	YES	YES	YES	YES

Notes: Biprobit marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Table C2: Cooking energy choices based on income quartiles.

Tenancy/Residency Status	Cooking Energy		
	Fuelwood	Charcoal	Other
	(1)	(2)	(3)
Renting			
Quartile 2 (N=3,644)	-0.116***	0.113***	-0.028
	(0.029)	(0.020)	(0.034)
Quartile 3 (N=3,648)	-0.130***	0.052**	0.097***
	(0.023)	(0.025)	(0.031)
Quartile 4 (N=3,642)	-0.094***	-0.065	0.035
	(0.031)	(0.048)	(0.023)
Dwelling type			
Quartile 2 (N=3,644)	0.009	-0.037**	0.015
	(0.020)	(0.014)	(0.012)
Quartile 3 (N=3,648)	-0.013	0.007	-0.031*
	(0.019)	(0.014)	(0.017)
Quartile 4 (N=3,642)	0.009	0.005	0.007
	(0.017)	(0.018)	(0.009)
Housing variables	YES	YES	YES
Demographic variables	YES	YES	YES
Geographic variables	YES	YES	YES

Notes: Biprobit marginal effect estimates. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights. Housing, Socio-demographic and geographical variables summarized in Appendix A are included.

Appendix D: Post estimation Test

Table D1: Mean differences between female and male household heads cooking energy choices

Suest test	Fuel wood	Charcoal	Other
Chi 2(28)	39.00	39.83	88.49
Prob > chi2	0.0809	0.0684	0.0000

*** p<0.01, ** p<0.05, * p<0.1.

Table D2: Mean differences between female and male household heads lighting energy choices

	Electricity	Oil Lamp/lantern	Torches	Other
Chi 2(27)	79.62	92.69	155.79	67.68
Prob > chi2	0.000	0.000	0.000	0.000

*** p<0.01, ** p<0.05, * p<0.1.

Table D3: Mean differences between rural and urban households' cooking energy choices

Suest test	Fuel wood	Charcoal	Other
Chi 2(27)	138.26	258.32	202.41
Prob > chi2	0.000	0.000	0.000

*** p<0.01, ** p<0.05, * p<0.1.

Table D4: Mean differences between rural and urban households' lighting energy choices

Suest test	Electricity	Oil Lamp/lantern	Torches	Other
Chi 2(27)	520.57	434.56	173.90	230.17
Prob > chi2	0.000	0.000	0.000	0.000

*** p<0.01, ** p<0.05, * p<0.1.

Appendix E: Supplementary Results

Table E1: Full Biprobit Results for cooking energy indicating other determinants

VARIABLES	(1) Fuelwood	(2) Charcoal	(3) othercook
renting	-0.106***	0.0768***	0.0271
	(0.0147)	(0.0146)	(0.0171)
dwellingtype	-0.00196	-0.0107	0.00205
(Compound housing)	(0.00888)	(0.00742)	(0.00544)
male	0.00275	-0.00782	0.00271
	(0.00516)	(0.00520)	(0.00339)
agehhd	0.00121***	-0.00108***	-0.000273**
	(0.000174)	(0.000182)	(0.000120)
hhsize	-0.00254*	0.00208	0.00119
	(0.00137)	(0.00138)	(0.00104)
Hheducation	0.00704	0.00508	-0.00546
	(0.00562)	(0.00647)	(0.00391)
povertystatus	-0.0209***	-0.0557***	0.0346***
	(0.00663)	(0.00747)	(0.00468)
wage_salary	0.0338***	-0.0322***	-0.00184
	(0.00532)	(0.00592)	(0.00369)
log_non_energy_ae	-0.0640***	-0.00243	0.0364***
	(0.00460)	(0.00402)	(0.00358)
log_enerex_ae	-0.00937***	0.0211***	-0.00267***
	(0.000925)	(0.00128)	(0.000575)
depen_ratio	0.00752**	-0.00418	-0.00859***
	(0.00318)	(0.00332)	(0.00269)
ratio_wm	-0.00102	0.00632***	-0.00436***
	(0.00184)	(0.00183)	(0.00148)
Numrooms	0.00537**	-0.00300	-0.000920
	(0.00217)	(0.00219)	(0.00166)
Sleeprms	-0.00154	0.00351	0.000812
	(0.00324)	(0.00322)	(0.00224)
sharedwell	-0.000806	0.00633**	-0.00595***
	(0.00409)	(0.00308)	(0.00209)
AccessElectric	-0.0179***	0.00206	0.00240
	(0.00514)	(0.00549)	(0.00433)
inhabited_yrs	0.000861***	-0.00132***	0.000131
	(0.000284)	(0.000322)	(0.000201)
External walls:			
2.Cement	-0.00722	-0.0153**	0.0106*
	(0.0101)	(0.00748)	(0.00611)
3.Other	0.0144***	-0.0243***	0.00476
	(0.00444)	(0.00475)	(0.00320)
Roof:			
2.Clay tiles	0.0479***	-0.0588***	-0.00852**

	(0.00547)	(0.00581)	(0.00405)
3.Other	0.0500	-0.0582	-0.0152
	(0.0580)	(0.0386)	(0.0153)
Floor:			
2.floormat	-0.0246***	0.0426***	-0.00717
	(0.00609)	(0.00665)	(0.00476)
3.floormat	-0.00969	-0.00789	0.000445
	(0.0111)	(0.00982)	(0.00621)
4.floormat	-0.0191	0.0394**	-0.0157
	(0.0153)	(0.0161)	(0.0110)
ur	-0.0809***	0.0696***	0.00564
	(0.00463)	(0.00473)	(0.00450)
KigaliCity	-0.0556***	0.0479***	-0.00787*
	(0.00665)	(0.00655)	(0.00463)
SouthernProvince	0.0121*	0.0161**	-0.0217***
	(0.00626)	(0.00665)	(0.00497)
WesternProvince	-0.0242***	0.0525***	-0.0360***
	(0.00561)	(0.00594)	(0.00583)
NothernProvince	0.00261	0.0189***	-0.0213***
	(0.00642)	(0.00684)	(0.00479)
Observations	14,580	14,580	14,580

*** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights.

Table E2: Full Biprobit results for lighting energy indicating other determinants

VARIABLES	(1) Electricity	(2) oil_lamp_lantern	(3) Solar	(4) Torches	(5) Other
renting	0.088***	-0.029*	-0.0233	-0.104***	0.049**
	(0.025)	(0.0167)	(0.0238)	(0.0325)	(0.0198)
dwellingtype	0.040***	-0.006	-0.008	-0.069**	-0.026*
	(0.013)	(0.013)	(0.022)	(0.028)	(0.015)
male	-0.00705**	0.00595	0.0190***	0.0131*	-0.0211***
	(0.00351)	(0.00453)	(0.00582)	(0.00794)	(0.00598)
agehhd	-0.000103	0.000175	-0.000576***	0.000468*	-9.26e-05
	(0.000112)	(0.000146)	(0.000182)	(0.000259)	(0.000198)
hhsize	-0.000839	-0.00188	0.0104***	-0.00555**	-0.00554***
	(0.000757)	(0.00132)	(0.00137)	(0.00230)	(0.00187)
Hheducation	0.00822**	-0.00161	0.0205***	0.0152**	-0.0218***
	(0.00378)	(0.00421)	(0.00554)	(0.00743)	(0.00566)
povertystatus	-0.00781*	-0.00121	-0.0347***	0.00546	0.00887
	(0.00404)	(0.00570)	(0.00652)	(0.00998)	(0.00771)
wage_salary	0.00395	-0.00894**	-0.0190***	0.0268***	0.000668
	(0.00361)	(0.00428)	(0.00537)	(0.00728)	(0.00556)
log_non_energy_ae	0.00292	-0.0175***	0.0349***	-0.0152*	-0.0207***
	(0.00289)	(0.00528)	(0.00556)	(0.00919)	(0.00704)
log_enerex_ae	0.00775***	0.0114***	-0.0190***	0.00440***	-0.00297***
	(0.000373)	(0.000879)	(0.000735)	(0.00121)	(0.000958)
depen_ratio	0.00648***	0.00466*	-0.00437	-0.00273	-0.000713
	(0.00184)	(0.00239)	(0.00307)	(0.00439)	(0.00344)
ratio_wm	-0.00122	0.000718	0.00192	0.00420	-0.00628**
	(0.00113)	(0.00168)	(0.00190)	(0.00303)	(0.00245)
Numrooms	-0.000845	0.00500**	0.0108***	-0.00943**	-0.00811***
	(0.00129)	(0.00218)	(0.00231)	(0.00377)	(0.00297)
Sleeprms	0.000604	0.000116	-0.00130	0.000243	0.00109
	(0.00180)	(0.00322)	(0.00342)	(0.00572)	(0.00455)
sharedwell	-0.000614	0.0124**	-0.00134	-0.0102	-0.000264
	(0.00324)	(0.00592)	(0.0134)	(0.0178)	(0.00919)

AccessElectric	0.152***	-0.212***	0.0909***	-0.677***	-0.431***
	(0.00583)	(0.0194)	(0.00533)	(0.0179)	(0.0243)
inhabited_yrs	0.000195	0.000454**	-2.41e-06	-0.000781**	0.000181
	(0.000150)	(0.000224)	(0.000248)	(0.000372)	(0.000284)
2.Cement	0.00898	0.00407	-0.0307***	-0.0694*	0.0212
	(0.00559)	(0.0191)	(0.00938)	(0.0384)	(0.0293)
3.other	0.000724	0.0168***	-0.000442	-0.0470***	0.0173***
	(0.00274)	(0.00394)	(0.00461)	(0.00695)	(0.00549)
2.Claytiles	-0.0137***	-0.0174***	0.00133	0.0347***	-0.0125**
	(0.00362)	(0.00480)	(0.00529)	(0.00807)	(0.00608)
3.other	-0.00310	0.0176	-0.0746***	0.0307	-0.00899
	(0.298)	(0.0622)	(0.00301)	(0.0780)	(0.0562)
2.floormat	0.00881***	0.00227	0.0146**	-0.0675***	0.0219**
	(0.00326)	(0.00668)	(0.00674)	(0.0129)	(0.0103)
3.floormat	0.0200***	0.0303***	0.00854	-0.0539***	-0.0364***
	(0.00608)	(0.00986)	(0.0107)	(0.0176)	(0.0127)
4.floormat	0.0160***	0.0394**	0.00554	-0.0648**	0.00663
	(0.00622)	(0.0188)	(0.0139)	(0.0272)	(0.0205)
ur	0.0347***	0.0387***	-0.127***	-0.133***	0.0866***
	(0.00499)	(0.00675)	(0.0121)	(0.0131)	(0.00914)
KigaliCity	0.0165***	-0.0397***	-0.0804***	-0.141***	0.154***
	(0.00517)	(0.0101)	(0.0154)	(0.0195)	(0.0133)
SouthernProvince	0.00871**	-0.0302***	-0.00382	-0.000969	0.0459***
	(0.00366)	(0.00568)	(0.00654)	(0.0103)	(0.00849)
WesternProvince	0.0178***	-0.0410***	0.0109*	-0.0667***	0.0814***
	(0.00352)	(0.00552)	(0.00609)	(0.00982)	(0.00805)
NothernProvince	0.0141***	-0.0668***	-0.0488***	0.0315***	0.0678***
	(0.00363)	(0.00668)	(0.00722)	(0.0104)	(0.00829)
Observations	14,580	14,580	14,580	14,580	14,580

*** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parentheses. We accounted for probability sampling weights

Chapter 3: Competition and Gender in the Lab vs Field: Experiments with Off-Grid Renewable Energy Entrepreneurs in Rural Rwanda.

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Abstract

Applications of lab experiments to real-world phenomena are limited. We fill the gap by examining how gender attitudes and performance under competitive situations in the lab reflect microenterprise outcomes in the renewable energy sector of Rwanda – a country with progressive gender policies despite its traditional patriarchal setup. We use the standard Niederle and Vesterlund (2007) experimental design in addition to a unique dataset from off-grid microenterprises, managed by entrepreneurs who had been working in mixed and single-sex teams prior to the lab experiments. After a piece-rate and a tournament compensation schemes, participants are offered to the opportunity to choose their compensation scheme between these two options in a third round. We find that female entrepreneurs are not less likely to compete and are not outperformed by male entrepreneurs. This stands in contrast to several studies, mostly conducted on university students of developed countries. Furthermore, we leverage administrative and self-reported business data to show that the female entrepreneurs who chose to compete in the lab perform as well as their male counterparts, providing some external validity to our lab results.

Keywords: Competition, Gender differences, Entrepreneurs, Performance, Renewable Energy
JEL Codes: C91 C92 J16 Q49

1. Introduction

Traditional job markets are mostly male-dominated despite recent efforts by development organisations to close the gender gap. Women often face various social restrictions (including overseeing most household chores, receiving less schooling, and lower returns to their labour) in both developed and developing countries (World Bank, 2015). This problem is more severe in rural areas, where social barriers such as culture and social norms play a significant role.

Despite the well-established advantages associated with the provision of modern energy sources to rural communities, studies in the renewable energy literature have shown that provision of energy sources alone is not enough to achieve the desired empowerment levels and economic freedom for women. Women's journeys towards better welfare opportunities and livelihoods could be fast-tracked if they were well represented at all levels of the energy supply chain (Baruah, 2017; 2015). Entrepreneurship has, therefore, been used as a breakthrough point for women in this sector (Clancy et al., 2012; Clancy, Oparaocha & Roehr, 2004). This has resulted in several initiatives and projects targeted at female entrepreneurship. Typical examples are the Solar Sisters initiative, Women's Integration into Renewable Energy (WIRE) and Women's Entrepreneurship in Renewables (wPOWER) under the Energy4Impact initiative.

Though entrepreneurship is a vital tool for promoting women's empowerment, it is essential to note that a predominant characteristic associated with successful entrepreneurship is the ability to compete (Shane, Locke & Collins, 2003). Women have been shown to be less willing to compete and in some situations outperformed by men under competitive conditions (Dato & Nieken, 2014; Niederle, & Vesterlund, 2011; 2008; 2007; Ergun, Rivas & García-Muñoz, 2010; Croson & Gneezy, 2009; Datta Gupta, Poulsen & Villeval, 2005). This suggests that, apart from the well-established social barriers affecting women's participation in the labour market, females' unwillingness to compete can also influence their performance levels even after taking up entrepreneurial roles. Hence, a deliberate attempt to empower women in the renewable energy industry through entrepreneurship initiatives may have limited potential if due consideration is not given to women's competitiveness and performance abilities.

To date, very little is known about the competitive and performance abilities of women working as sales point entrepreneurs in the renewable energy sector. Our study contributes to the global discussion on women's competitive decisions and performance levels by using lab-in-the-field experiments to first examine how gender attitudes towards competition differ amongst village-level entrepreneurs (VLEs) in Rwanda. The study then demonstrates how performance under competitive situations in the lab reflects microenterprise operations in the field by using a unique dataset from off-grid microenterprises managed by entrepreneurs already working in mixed and single-sex teams since 2016.

Rwanda provides a unique study context for a number of reasons. Though a traditionally patriarchal society, the country is today frequently cited for its commitment towards women's participation and gender equality policies (Burnet, 2011). This comes after the 1994 genocide, which saw the death of at least 500,000 people, the majority of whom were men (Debsscher & Ansoms, 2013). Many women became widows and took over traditional male-dominated social and economic activities. The government of Rwanda has since implemented several gender policies, such as the integration of gender as a fundamental right in the constitution, enforcing a gender quota system for local and national government, and the creation of its first Ministry of Gender Equality. These top-down approaches brought about improved economic and career opportunities as well as higher levels of women's participation in government. Although such policies have substantially improved the postcolonial patriarchal gender roles, rural women are yet to harness the full benefits of the government's women-friendly policies (Burnet, 2011).

Furthermore, the renewable sector of Rwanda is booming as the government of Rwanda is determined to promote private sector involvement, in its quest to accelerate rural electrification to off-grid communities in order to provide energy access to its entire population. However, women's participation in the private energy sector of Rwanda is low, as there are no gender policies governing the private energy sector (Parshotam & van der Westhuizen, 2018). Examining women's competitiveness in this context not only enriches this branch of the economic literature but also provide key insights into women's abilities in the private energy sector of Rwanda.

To implement our objective, we partnered with Nuru Energy – a for-profit social enterprise. Nuru Energy provides low-cost solar mobile phone and light recharging centres to off-grid poor communities in rural Rwanda. They operate by delivering power in the form of rechargeable light-emitting diodes (LEDs) via local village enterprises. LEDs are recharged by a centralised pedaland-solar-powered recharge station, which is operated by community-run microenterprises. As part of a more extensive study (Clarke et al., 2020; Visser et al., 2019) to understand the role of a gender quota business model in empowering women, 136 new microenterprises in Rwanda have been established. Villages were randomised into three treatment arms such that in each village, the enterprise is owned and operated by either an all-male team, an all-female team or a mixed gender team, each consisting of four members, for a total of 544 microentrepreneurs. While such a gender quota-based business model provides an enabling environment for entrepreneurship and self-employment for women, it is essential to further investigate attitudes towards competition in such a context and examine whether performance in the lab reflects microenterprise activities in the field.

This study measures willingness to compete and performance under competition using the standard experimental design of Niederle and Vesterlund (2007) on a subsample of 374 entrepreneurs from the off-grid microenterprises described in the preceding paragraph. Subsequently, field outcomes – sales and self-reported incomes from microenterprise operations – are used to measure the field performances of gender teams. Our study shows that women operating off-grid microenterprises in Rwanda do not shy away from competition and perform as well as men in the lab. This outcome is mirrored in the field: female lab participants who self-selected into competition also have similar business performance as their male counterparts during the first three months of operation. Although our lab sample is broadly representative of the larger RCT sample, we are careful not to generalise our results due to potential selection limitations as there is a possibility that results for the different gender compositions could vary for the larger sample, or over a more extended period of time.

The rest of the paper proceeds as follows. Section 2 presents a review of related literature. The experimental design and data used for the study are detailed in Section 3. This is followed by the empirical strategy of the study in Section 4. Results and discussion of findings are reported in Section 5. Section 6 concludes.

2. Related Literature

A growing experimental literature has explored gender differences in attitudes towards competition with a focus on three broad areas: competition entry decisions, performance levels and gender composition of competing groups.[2] Results show that women are less willing to compete (Zhong et al., 2018; Apicella et al., 2017; Sutter & Glaetzle-Ruetzler, 2015; Booth & Nolen, 2012; Niederle & Vesterlund, 2007) and may have lower performance levels than men when they do compete (eg., Dariel et al., 2017; Dato & Nieken, 2014; Niederle et al. 2013). This may partly explain why women are less represented in the labour market and why, at the subsistence level, female-operated firms are less profitable than those operated by their male counterparts (Buvinic & Furst-Nichols, 2016). In some cases, findings suggest no significant difference in performance between men and women (De Pola et al., 2015, Niederle & Vesterlund, 2007, Barron et al., 2020).

The literature on competition has, however, been skewed towards university student-based experiments in Western societies (*See Appendix A for a summarised review of studies on students and non-students' samples including their respective study area to date).* Developments in the literature show that culture or the context in which these experiments are conducted can influence competitive outcomes. Gneezy et al. (2009) explain this by comparing patriarchal and matrilineal societies. Whereas the observed gender gap in the patriarchal society of Masai in Tanzania emulates most findings in Western countries, the matrilineal society of Khasi in northeast India shows a reversed gender gap. A follow-up study by Andersen et al. (2013) shows that, although no gender gap exists between these two societies at age 7, by age 15, these two communities start exhibiting very different characteristics towards competition. These studies have since paved the way for more society-specific studies (Booth et al., 2018; Bönte et al., 2018; Dariel et al., 2017; Cassar et al., 2016; Apicella and Dreber, 2015).

Although the competition literature is extensive, to date, applications of such experimental studies are limited. Little is known about the extent to which competition measures in the lab relate to real outcomes. Studies have attempted to examine competition in real-world situations or by using natural field experiments (Ors et al., 2013; Paserman, 2007; Lavy, 2012); however, the direct link

[2] For a detailed review on these key areas, see Niederle and Vesterlund (2011) and Croson and Gneezy (2009).

of competition measures to real-world outcomes is still scarce. Zhang (2013) and Buser et al. (2014) directly examine how competition predicts educational choices of students. Both studies show that choices in the lab under competitive incentives correspond to choices of study but were unable to study students' performance outcomes under exam conditions. Berge et al. (2015) argue that an individual's decision to compete does not necessarily imply success in the real world. To test this, they use small-scale entrepreneurs in Tanzania. Findings from Berge et al. (2015) show a positive association between competitiveness in the lab and field choices. Their study, however, did not explicitly examine the gender differences associated with their results.

Our study fills the gap in the competition literature by using a unique dataset from entrepreneurs operating in specific gender groups (all-male, all-female and mixed-gender teams) in rural Rwanda to examine the relationship between lab and field outcomes. The study, therefore, does not only contribute to the competition literature but will also provide insights into the ability and performance of women, which is of relevance to microenterprise development in the renewable energy sector.

3. Experimental Design and Data

Our sample subjects are entrepreneurs operating off-grid microenterprises in the Rulindo and Ruhango districts of Rwanda, as part of a larger randomised control trial (RCT) focused on the use of a gender quota business model to empower women in the renewable energy sector (Visser et al. 2019, Clarke et al. 2020). These entrepreneurs have been operating in randomly assigned gender groups since 2016, with each group consisting of four members. Their core role is to recharge lights for customers at a fee.

Entrepreneurs in the larger randomised control trial study were recruited as follows. First, 272 villages in the Rwanda district of Rulindo and Ruhango were sampled to participate in a new Nuru business model. With the assistance of village leaders, villages were approached about the opportunity of setting up solar recharge stations with each station to be run by a four-person microentrepreneur team. For the purposes of the field experiment, interested villages were randomly sorted into three groups (all-male, all-female, and mixed teams). Community members formed their groups without any restrictions from the research team apart from the gender composition request. Prospective microentrepreneur teams were then requested to raise an investment capital (commitment fees) of 40,000 Rwandan Francs (~50USD) in exchange for their start-up recharging equipment. All 272 villages raised these commitment fees prior to assigning treatment groups. Potential microenterprises were informed that their village had a 50% probability of being selected into the first phase of the new Nuru business. Thus, half of the sample was randomly assigned to a treatment arm. Villages who were selected to a control group had their money returned to team members, while villages who were selected into the treatment group received recharging equipment and 100 lights per each village to commence business. The operations and management decisions were solely up to members of the team. Also, given that community members could form their own gender teams, there is a potential that team members could be familiar with each other before the commencement of business. Clarke et al. (2020) and Visser et al. (2019) provide a detailed account of the randomisation process.

As of March 2017, before conducting the experiments, there were 129 actively working microenterprises (one per village). This provided the study with a total population size of 516 entrepreneurs.[3] Out of the 516 actively working entrepreneurs, 374 participated and completed the experiment.[4]

3.1 Potential Selection Bias

To better understand how the 374 lab participants compare to the larger sample of 516 operational VLEs and to examine any potential selection bias, we compare the socioeconomic and business characteristics of lab participants with those who did not participate in the experiment. *Table B1, Appendix B* report results from the balance test. Results show no significant differences in age, the number of working hours, household income, household expenditure, the probability that an entrepreneur had a household member in wage employment and the likelihood that VLEs had an adequate roof. Besides being not statistically significant, the coefficients are small, and the confidence intervals are narrow. Furthermore, results show that experimental participants and non-participants were equally likely to have been assigned to a male, female or mixed-gender group. We also find that lab participants and non-participants were equally likely to be in either Rulindo

[3] 129 x 4 = 516

[4] Most entrepreneurs who could not make it were not either available during the information stage or had other engagements on the day the experiment was conducted.

or Ruhango district. In addition, there are no significant differences in the proportion of VLEs reported to feel happy and in their level of patience as measured in the survey.

However, there are a few statistically significant differences. First, lab participants had 11.7% more recharges than non-participants. At the mean value of 307 recharges, This difference amounts to 36 additional recharges over the entire three-month period, roughly two additional recharges every 5 days. Despite being statistically significant, this does not amount to an economically significant difference. Second, lab participants were 3.7 percentage points more likely to have secondary education than non-participants. This difference could be a cause for concern if education were a predictor of performance in the field. However, we show this not to be the case in Table 6 below. Lastly, entrepreneurs who participated in the experiment were slightly less dissatisfied about their emotional health than non-experiment participants at the 90% of confidence, but the lack of difference in happiness or patience suggests there are no systematic differences in this regard.

Taken together, the evidence in this table suggests that the sample of participants in the lab experiments is broadly similar to microentrepreneurs who did not participate in the lab experiments, and hence our lab results could plausibly hold for VLEs who did not participate in the lab experiments. At the very least, our results would be informative of the slightly more competitive microenterprises.

3.2 The Experiment

We conducted a series of experiments focused on entrepreneurs' attitudes towards competition, risk aversion and prosocial measures. A total of 24 experimental sessions were conducted by the same experimenter between March and June 2017. The sessions were conducted in school classrooms across 19 sectors (villages are grouped in sectors). Prior to the day of the experiment, individual entrepreneurs were personally invited to participate in the experiment and to additionally indicate their potential availability. Participants who indicated their availability were given further information about the specific venue and the time to arrive at the experiment venue. We made a phone call to remind them about the event the day before the experiment. Given the long distances participants needed to travel to the various experimental venues, we offered to cover the transportation cost of participants who showed up for the event. A minimum of 4 and a maximum of 8 groups were invited to each session depending on their proximity to the experiment venue. The average number of participants per each session was 18, with a maximum number of 30 people. Below, we describe in detail the experimental design and procedures of the two behavioural measures utilised in this study, namely the competition and risk experiment. Detailed instructions used for the experiment can be found in the supplementary material.

The competition games follow the standard experimental design of Niederle and Vesterlund (2007) with minor alterations in the payoffs offered to participants. VLEs solved real problems under piece rate and tournament incentivised schemes. For each session, VLEs were presented with a set of 20 simple addition problems to be solved in five minutes with no performance feedback between tasks. The addition problems were handed to VLEs in a booklet form such that each page had only one problem, as presented below:

75	85	60	15	ANSWER[5]

VLEs were not allowed to use calculators. However, the booklets in which the problems were solved had enough space for scratch work. Instructions and incentives were read out loud to VLEs in Kinyarwanda (the official local language of Rwanda) before the start of each task. Participants performed these tasks (consisting of 20 problems each) under three different incentive schemes, namely: piece rate, tournament and preferred incentive scheme.

In the first round (piece rate), participants earned 50 Rwandan francs (RWF) –approximately 0.055 United States Dollars (USD) – for each correct answer provided. In the second task (tournament), participants competed in randomly assigned gender groups (mixed and single sex) of between two and six members. The study aimed to assign participants to only groups of four consistent with VLEs' group sizes in the field. However, since we had no control over the exact number and gender of participants who showed up for the sessions, we had to assign some participants to groups other than the intended group size of four. Most of our sample (224 out of 374 participants) participated in groups of four members, with 135 participants assigned to groups of 3 or 5 members. *Table B2, Appendix B* shows the group size distribution. The designated groups assigned to participants in

[5] For instance, participants were expected to add these four numbers and provide the answer (235 – for this example) in the space labelled ANSWER, which was left empty on the actual decision sheets for all twenty questions.

the experiment were different from VLEs' actual microenterprise gender groups in the real world. This guaranteed the anonymity of group members and limited any potential informed decisions that could arise when the identity of team members is known to participants. Subjects were, however, informed about the demographic distribution of their respective groups (age, marital status and gender distributions).[6]

In the second round (tournament), participants were requested to solve a second set of addition problems. In contrast to the first task, only the participant with the highest score in each group received a payment. The amount was of 150 RWF (approximately 0.17 USD), which is three times more than the piece rate amount, for each correct answer. Other members of the group received nothing for their effort. In the situation of a tie, earnings were split equally among the top performers of the group.

In the third round (preferred incentive scheme) we offered VLEs the opportunity to choose a preferred payment incentive between the piece rate or the tournament payment scheme. Subjects then solved a third set of addition problems. VLEs who chose the tournament compensation scheme now had their scores from the third round compared to those of their group's opponent's scores from task 2.[7]

We continued with a risk experiment after VLEs completed the competition games. The risk experiments closely follow Brick and Visser (2015), which was based on the earlier design of Gneezy and Potters (1997) as well as Moore and Eckel (2006). This proceeds as follows: VLEs were asked to make twenty-two choices, with each choice providing VLEs with two options. The first option provided VLEs with a sure payoff (increasing from 160 RWF (~ 0.18 USD) in the first choice to 580 RWF (~ 0.64 USD) in the twenty-second choice). The second option offered a lottery with a 30% probability of receiving 1200 RWF (~1.33 USD) and a 70% probability of receiving nothing. A risk-averse VLE will chose the sure pay-off while a more risk-loving VLE will prefer the lottery. A spinning wheel was used to determine the payoffs for VLEs who preferred

[6] This enabled the study to inform participants about the gender distribution of groups in a more subtle way by also including age and marital status.

[7] Thus, if a VLE chose to compete in Task 3, he/she receives RWF150 if his/her score in Task 3 is greater than his/her group members' score in the previous task (Task 2); if not, the VLE receives nothing. This is to ensure that a decision by a group member to choose the piece rate payment incentive does not affect comparison of scores in the third task (Niederle & Vesterlund, 2011).

the gamble. The choices of subjects enabled the study to calculate risk measures using VLEs' switching points between the sure payoffs and the lottery (Booth et al., 2018; Vieider et al., 2015; Brick & Visser 2015).

Participants were provided with feedback about their performance at the end of the experiment after all tasks were completed (including the risk task). Also, participants were paid for all tasks according to their performance with earnings ranging from 2000RWF (~2.09 USD) to 12500 RWF (~13.09 USD). The average earning received by participants was of 6000RWF (~6.28 USD). The experiment lasted for approximately 2 hours.

3.3 Descriptive Statistics

Table 1 provides details of entrepreneurs' backgrounds and an overview of field outcomes used in the analysis. VLEs' background information is obtained from survey data conducted as part of the larger RCT study detailed in Clarke et al. (2020) and Visser et al. (2019). The average village-level entrepreneur is married, 42 years of age, risk-averse, and has at least primary education (7 years of schooling) and household size of 11 people.

Table 1: Background and Field Variables

Variable	Observation	Mean	Min	Max
Background				
Age	374	42.19	18	76
Education	374	6.9	1	16
Female	374	0.49	0	1
Marital Status	374	0.90	0	1
Household size	343	11	1	12
Household Head	336	0.59	0	1
District = Rulindo	374	0.35	0	1
Risk measure (Switching Point)	374	6.33	1	22
Business Outcomes				
Number of recharges in 3-month period (Sales)	374	307.62	40	640
Income from Business	335	946.62	0	9000

Note: Age is the age of the VLE in years, education is in years of schooling, Female is a dummy showing whether the VLE is male or female, Marital status indicates whether VLE is married. Household size is the number of people living in VLE's household. Household head shows whether the VLE is a household head. Risk measure shows the level of VLEs' attitudes towards risk-taking, ranging from 1 (highly risk-averse) to 22 (risk-seeking). For the microenterprise outcomes, recharge frequency, which is used as a proxy for sales, is the number of times VLEs recharge lights for customers. Income is VLEs' self-reported income (in RWF) from operating the microenterprise. Source: Authors’ own calculations using survey data

For field outcomes, we use administrative data on the number of recharges during the first three months of business operations and complement this information with self-reported incomes of VLEs, which measures the performance levels of microenterprises. Nuru Energy has a centralised server that regularly receives recharge data from the various enterprises. The centralised data station provides the study with the sales information for each microenterprise. Self-reported incomes from business operations are obtained from the survey data to complement the administrative information. Specifically, we consider the total number of recharges of lights for the three first months of business operations and the average income per month. A Nuru microenterprise on average has a total of 307 recharges in those three months, with the average VLE reporting an income of 946 RWF per month.

Table 2: Gender Group Composition

Gender groups	Observation	Proportion
Experimental group composition		
All-male teams (%)	131	35.03
All-female teams (%)	130	34.76
Mixed gender teams (%)	113	30.21
Microenterprise group composition		
All-male teams (%)	127	33.96
All-female teams (%)	128	34.22
Mixed gender teams (%)	119	31.82

Source: Authors' own calculations using experimental and survey data

Table 2 shows the gender distribution of teams in the experiment and the field. In the experiment, 131 (35%) participants were assigned to all-male teams, 130 (34.8%) participated in all-female teams, and 113 (30%) were allocated to in mixed gender teams. For the microenterprise gender group compositions, 127 (34%) were in all-male teams, 128 (34%) operated in all-female teams and 119 (32%) worked in mixed-gender teams. This shows an approximately equal gender distribution for both entrepreneurial and experimental groups with no significant difference between the two distributions.

4. Empirical Strategy

The study aims at examining entrepreneurs' attitudes towards competition and comparing entrepreneurs' performance levels in the lab to performance in business. For entrepreneurs' attitudes towards competition, we estimate a standard probit model depicted in equation 1:

$$\Pr\,(Competition_{entry} = 1)_i = \Phi(\gamma_0 + \gamma_1\ Female_i + \gamma_3 X_i + \gamma_4 V_i + \mathcal{E}_i)\ \ \ldots (1)$$

where the dependent variable is a dummy variable measuring the willingness of entrepreneurs to participate in a competition such that $Competition\_entry_i$ = 1 if the VLE chooses the tournament and 0 if the VLE chooses piece rate in the third round of the experiment. $Female_i = 1$ indicates that a participant is female. Other explanatory variables X_i include scores from round 2, susceptibility to time pressure and response to competition against peers,[8] risk preferences, number of VLEs per session, and group size, are standard explanatory variables included in estimations of willingness to compete (Booth et al., 2018, Dariel et al., 2017, Niederle & Vesterlund, 2007). We also control for VLEs' background indicators V_i (age, education, marital status, household size, household head, geographical districts of operation, and gender composition of the VLE teams in the field).

To examine how entrepreneurs' performance levels compare to field outcomes, we estimate equation 2 using an Ordinary Least Squares (OLS) estimation approach:

$$Perfomance_i = \gamma_0 + \gamma_1\ Gender\_Teams_i + \gamma_3 X_i + \mathcal{E}_i \qquad (2)$$

Equation 2 is estimated for lab and field outcomes. For lab outcomes, the dependent variable $Perfomance_i$ is VLEs' scores under competition, calculated as the number of correct answers in task 3. *Gender_Team* is the real-world gender teams in which entrepreneurs are working all-male, all-female or the mixed gender teams. Each team consist of four members such that the all-male and all-female teams have four males and four females respectively per gender group, while the mixed gender teams have two males and two females working together in a group. Individual background characteristics remains the same as in equation 1. For field outcomes, we use the recharge frequency of lights (sales) and the inverse hyperbolic sine transformation of self-reported incomes from VLEs to measure performance. We face the problem of some VLEs reporting zero income when considering the self-reported incomes. The inverse hyperbolic sine transformation approximates the natural logarithm of that variable and allows retaining observations with zero self-reported income. Standard errors for the field estimation are clustered at the village level since

[8] Susceptibility to time pressure measures the difference between competition scores (task 2) and piece rate scores (task 1). Including this variable is a standard practice in all competition studies (see Booth et al., 2018, Dariel et al., 2017, Niederle & Vesterlund, 2007).

the gender composition of VLE teams in the field was randomly assigned at the village level.

5. Results and Discussion

5.1 Performance in the Lab Under Piece Rate, Tournament and Preferred Incentive Treatments

Table 3 shows the performance levels of VLEs in the lab for all treatments. In the first two rounds (Piece rate and Tournament), VLEs scored an average of 7.73 and 9.83 correct answers, respectively. This performance varies from 7.54 to 8.16 for single and mixed gender groups under the piece rate incentive. Men significantly perform better in the all-male groups, with an average score of 8.23 than females in the all-female groups, who scored 6.85 on the average (P-value = 0.003). In the mixed-gender groups, both men and women show no performance differences under the piece rate incentive (P-value = 0.262)

For the tournament incentive, performance ranges from 9.49 to 10.64 for single and mixed gender groups, with the all-male groups performing better than the all-female groups (P-value = 0.023). Performance under the tournament also improved significantly despite a high correlation between piece rate and tournament scores of approximately 0.73 and 0.72 for men and women respectively. On average, all gender groups solved two more problems under the tournament compensation scheme compared to the piece rate scheme with no significant difference (P-value = 0.488). This suggests no gender difference associated with improvement in performance after moving from the piece rate (task 1) to the tournament round (task 2). Improvement in performance from task 1 to task 2 may be due to the initial learning effect, as explained by Niederle and Vesterlund (2007).

Table 3: Performance Levels of VLEs in the Lab

Variable		**Obs**	**Whole Sample**	**Male**	**Female**	**Diff**	**P-value**
Piece rate *(Task 1)*	Overall	374	7.73	8.38	7.06	1.32	0.002***
	Single- sex	261	7.54	8.23	6.85	1.39	0.003***
	Mixed	113	8.16	8.69	7.57	1.12	0.262
Tournament *(Task 2)*	Overall	374	9.83	10.56	9.09	1.47	0.004***
	Single- sex	261	9.49	10.12	8.85	1.28	0.023**
	Mixed	113	10.64	11.52	9.66	1.86	0.062*
Task 2–Task 1	Overall	374	2.10	2.17	2.03	0.15	0.488
	Single- sex	261	2.0	1.89	2.0	-0.11	0.793
	Mixed	113	2.48	2.83	2.09	0.74	0.292
Preferred incentive (Task 3):							
Tournament	Overall	172	11.7	12.19	11.22	0.98	0.256
	Single- sex	119	11.18	11.69	10.57	1.11	0.204
	Mixed	53	13	13.35	12.6	0.75	0.872
Piece rate	Overall	201	10.39	11.06	9.78	1.28	0.015**
	Single-sex	141	10.34	11.07	9.72	1.35	0.021**
	Mixed	60	10.5	11.03	9.93	1.10	0.353
Task3 – Task 2	Overall	172	1.02	1.03	1.02	0.01	0.730
(Tournament	Single -sex	119	1.03	1.07	0.98	0.09	0.788
Choosers)	Mixed	53	1.02	0.92	1.12	-0.19	0.899

Note: P-values are from the Mann Whitney U tests. Values in the "whole sample", "male" and "female" columns are averages for the full sample and each group, respectively.

We also present average scores for the third task under the preferred incentive treatment. VLEs who chose to compete solved an average of 11.7 problems, with performance varying from 11.18 to 13 for single and mixed gender teams respectively. There is no significant difference in performance for all-male and all-female teams (11.69 for men and 10.67 for women) with a corresponding P-value of 0.204. Similarly, men and women in mixed gender groups have identical performance levels (13.35 and 12.6, respectively, P-value = 0.872). Comparing performance in task 2 (tournament) to task 3, Table 2 shows a slight increase in performance for VLEs who chose to compete and those who did not. Both men and women solved an average of one more problem in Task 3, but this difference is not statistically significant (P-value = 0.730). The improvement in performance under the preferred incentive treatment cut across all gender groups, with no gender group improving more than the other.

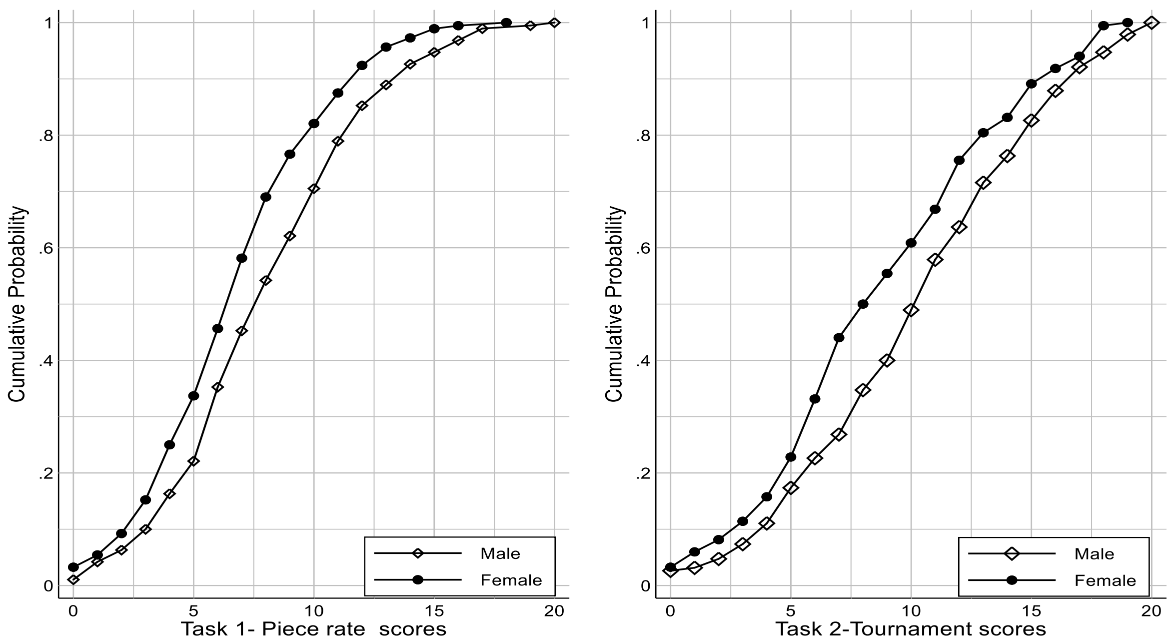

Figure 1: CDF of Correctly Solved Problems (Task 1: Piece Rate & Task 2: Tournament)

In Figure 1, we show the cumulative distributions for piece rate and tournament treatments by gender. This shows the cumulative probability of correctly solving a given number of problems. The figure clearly emphasises the existing gender gap reported in Table 2 under the first two tasks (Piece rate and Tournament). In both incentive schemes, women show a higher chance of solving a lower number of problems than men. This indicates higher performance levels for men than women.

Figure 2 shows the cumulative distributions of VLEs who chose to enter the competition under the preferred incentive scheme (task 3). In the first graph, we show the cumulative probability of solving a given number of problems for VLEs assigned to mixed gender teams during the competition games. The cumulative distributions for single-sex teams are shown in the second graph in the right panel. The third graph in Figure 2 shows the distribution for all VLEs (combined) irrespective of their gender group assignment.

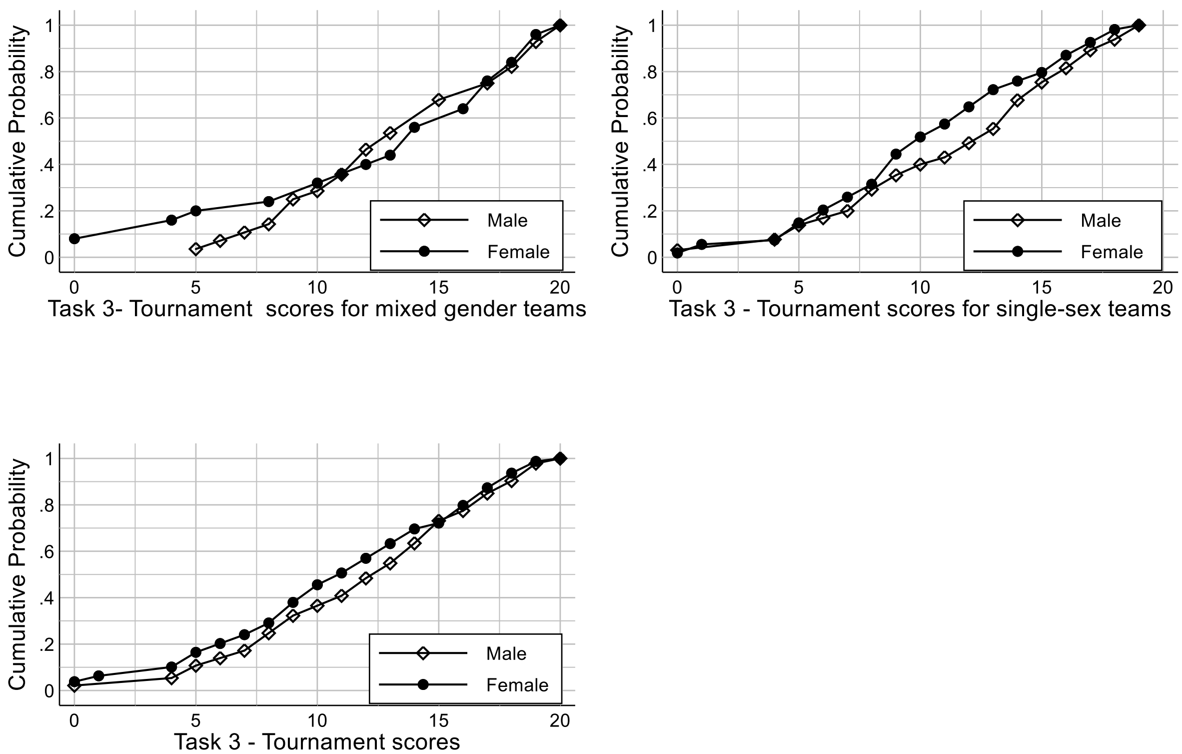

Figure 2: CDF of Correctly Solved Problems (Task 3: Tournament)

We find no substantial difference in the cumulative distributions either men or women. Mixed and single-sex teams show similar performance trends for both men and women. However, in the single-sex teams, women show a slightly higher cumulative probability distribution for lower scores than men. The probability of correctly solving a given number of problems under the tournament in task 3 overall is similar for both men and women.

5.2 Entrepreneurs' Willingness to Compete

This section first analyses competition entry decisions of VLEs. Out of the 374 VLEs who participated in the experiment, 172 (46%) chose to compete in the third experimental round. Comparing the 46% of participants who chose to compete in our sample to other tournament entry rates (29.6% to 54%) from previous studies (Dariel et al., 2017; Apicella et al., 2017; John, 2017; Khachatryan et al., 2015; Gneezy et al., 2009; Niederle & Vesterlund, 2007)[9] we see that, while our reported competition entry rate generally falls within the topmost percentile, it does not deviate from previously reported rates. Female entrepreneurs select into competition 43% of the time, while men select into competition 49% of the time. The Fischer exact test (P=0.299) indicates that this difference between women's and men's competition entry is not statistically significant. While there is a possibility that high-ability participants may self-select into the competition, subjects in our study did not receive any form of performance feedback between experimental rounds, enabling the study to hedge against such potential selection bias. We, however, acknowledge that participants are still likely to have beliefs about their ability, but this caveat is inherent to all experiments of this type.

Table 4 shows the results for tournament entry decisions of entrepreneurs based on experimental gender group composition. Columns 1 – 3 show that females are not less likely to compete than males. Instead, there are a number of predictors of competition that we analyse in turn. For instance, education and risk-taking are more important predictors of competition entry decisions in the single-sex teams than in the mixed gender teams. Risk preferences (being risk-loving) is an important predictor of competition entry in the all-female groups (Column 4), whereas it does not play a significant role in mixed gender teams. Males with higher education levels in the all-male experimental groups are more likely to compete. Married women are more likely to enter competition in the all-female groups than in the mixed-gender groups, as shown in column 4.

[9] We detail many more studies in Appendix A

Table 4: VLE's Competition Entry Decisions

VARIABLES	(1) Whole Sample	(2) Mixed	(3) Single	(4) Female	(5) Male
Females	**0.0461**	**0.0478**	**0.0253**		
	(0.108)	(0.180)	(0.128)		
Experimental single-sex teams	0.0285				
	(0.0706)				
Scores from round 2	0.0178**	0.0400***	0.0069	0.0051	0.0049
	(0.0079)	(0.0112)	(0.0104)	(0.0160)	(0.0139)
Tournament - Piece rate	-0.0192*	-0.0412***	-0.0087	0.0127	-0.0146
	(0.0104)	(0.0156)	(0.0141)	(0.0217)	(0.0185)
Number of participants per session	-0.0036	-0.0274**	0.0012	0.0021	0.0052
	(0.0052)	(0.0112)	(0.0061)	(0.0094)	(0.0085)
Risk taking (Switching Point)	0.0089**	0.0104	0.0109***	0.0117*	0.0049
	(0.0036)	(0.0067)	(0.0042)	(0.0064)	(0.0063)
Education	0.0252**	0.0201	0.0315**	0.0350	0.0313*
	(0.0109)	(0.0169)	(0.0141)	(0.0219)	(0.0188)
Household head	0.0213	-0.0600	0.0746	0.160	-0.204
	(0.0811)	(0.141)	(0.0923)	(0.118)	(0.194)
Household size	-0.0219	-0.0412	-0.0167	-0.0210	-0.0098
	(0.0152)	(0.0267)	(0.0181)	(0.0270)	(0.0262)
Age	-0.0017	0.0082	-0.0038	6.41e-05	-0.0048
	(0.0027)	(0.0049)	(0.0030)	(0.0048)	(0.0041)
Rulindo District	0.0281	-0.0297	0.0489	0.0740	0.0423
	(0.0780)	(0.098)	(0.122)	(0.185)	(0.190)
Married	0.0542	0.176	0.0056	0.234*	-0.229
	(0.0920)	(0.140)	(0.115)	(0.141)	(0.228)
Field Gender Composition					
2.All- Females	-0.0233	0.0985	0.0057		
	(0.110)	(0.173)	(0.136)		
3.Mixed	0.0309	0.220*	-0.0035	0.0357	0.0088
	(0.0788)	(0.122)	(0.0949)	(0.109)	(0.0966)
Group Size					
2	0.268		0.229		0.244
	(0.241)		(0.258)		(0.272)
3	-0.144	-0.0424	-0.191	-	0.181
	(0.0995)	(0.191)	(0.118)		(0.200)
5	0.0122		-0.0228	-0.0793	0.0597
	(0.0738)		(0.0757)	(0.108)	(0.114)
6	0.172		0.124		0.224
	(0.144)		(0.154)		(0.162)
Observations	335	102	233	109	115
Log pseudolikelihood	-212.92	-57.19	-147.87	-68.45	-70.55

Results are marginal effects from a Probit estimation. Heteroskedasticity-robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Controlling for the different gender compositions in the field, we find that entrepreneurs operating mixed gender microenterprises and assigned to a mixed gender team in the lab are more likely to choose into competition. We find no significant effect for other field gender teams. We additionally control for the differences in group sizes encountered during the experiment. *Appendix B, Table B4* further reports estimations when we restrict the analysis to only groups sizes of four, with similar results. In both cases, results show that differences in group sizes do not significantly impact the choice into tournament. Overall, findings suggest no gender gap in competition entry amongst entrepreneurs operating off-grid microenterprises in rural Rwanda.

Although our finding of no gender gap in competition entry contradicts a large body of literature which shows that women are reluctant to make competition entry decisions (Croson & Gneezy, 2009), it is perhaps not surprising in the context of Rwanda given its history and progressive gender mainstreaming policies implemented subsequently. Following the 1994 genocide which mainly targeted men and boys, 70% of Rwanda's population were women.

This forced the country to involve women in the rebuilding of the nation. As a result, traditionally male-dominated positions were offered to women. These national gender policies have gradually permeated the perceptions of the younger generation, which is evident in the baseline survey data collected as part of the larger RCT study. In the survey, children of VLEs were asked questions about their general gender perceptions. Their beliefs suggest that wives should be equally educated as husbands, boys should not get more resources for education, and daughters should have similar rights as sons in terms of inheriting property (*as reported in Appendix B, Table B3*).

In line with these beliefs, Burnet (2011) also identifies that the deliberate gender policies implemented by the government have translated into notable successes at the local level. These successes include increased levels of respect from village members and family, improved decision making at the household level, women's access to education, and enhanced capacity for women to freely speak and be heard at village meetings. This is an indication that the gender equality agenda in Rwanda is gradually changing perceptions and empowering women to take on challenging roles irrespective of the entrenched cultural barriers still existing in the country. It is likely that the progressive women's empowerment policies in Rwanda may be a contributing factor to explain why we see no significant gender difference in VLEs' decision to perform tasks under competitive situations.

Further, the original business model of Nuru before the current gender quota system under study also demonstrates how women expressed great interest in the entrepreneurship prospects of the Nuru program. Thus, the willingness of women to take on entrepreneurship roles despite its associated competitive characteristics could be an additional explanatory factor as to why no gender differences exist in the tournament entry decisions of VLEs. A more recent study by Dariel et al. (2017) supports our finding by showing that women in the United Arab Emirates are willing to participate in competition. Their results were also obtained in the context of a very entrenched patriarchal society after several policies towards women's empowerment and women's participation in the labour market were put in place.

Risk-taking and competitiveness, though different concepts, can be related in nature. Niederle and Vesterlund (2007) explain that competition involves uncertainty in earnings, such that any gender gap associated with risk preferences can influence decisions to compete. Our results show that VLEs with more risk-taking orientations are more likely to choose competition in single-sex teams, particularly in the all-female teams, but this is not the case for the mixed and all-male teams. The relationship between risk attitudes and competition entry decisions is well established in the literature. For instance, van Veldhuizen (2017) and Bartling (2009) show that less risk-averse individuals self-select into competition. As a result, the gender gap observed in competition entry decisions is significantly driven by differences in risk attitudes. Similarly, Cardenas et al. (2012) explore this concept by comparing results from two countries: Sweden and Colombia. They find a positive relationship between risk-loving individuals and competitiveness in Sweden but find no such relationship amongst Colombian boys and girls. In line with Niederle and Vesterlund (2007), they conclude that, whereas risk-taking is a key driver of competition entry decisions, other factors such as overconfidence could also influence decisions to compete. Our results that risk-loving VLEs are more likely to choose competition is widely supported by these previous studies.

5.2 Performance in the Lab vs Field

In this section, we compare business performance in the field of women who decided to compete in the lab to their male counterparts. We further discuss how performance levels of gender teams in the lab compare to the performance in the field. Table 5 reports performance of entrepreneurs who chose to compete in the third round of the experiment. These are the main results in this study. Column 1 shows that the gender composition of teams in the lab experiment did not affect performance in the lab. All-female and mixed gender teams perform as well as all-male teams in the lab. Next, columns 2-4 show no gender differences in performance controlling for different sets of covariates, including the gender composition of field teams (Columns 3 and 4). Our preferred specification is Column 4, which also includes group size fixed effects.

A large body of literature finds that opponents' gender influences performance under competition, such that women tend to perform better in single-sex environments than in co-gender environments (Delfgaauw et al., 2013; Booth & Nolen 2012; Niederle & Vesterlund, 2008; Gneezy et al., 2003). These studies suggest that the gender gap increases when women compete with men – the basis for the continuous debate about single-sex schools relative to mixed gender schools. However, Lee, Niederle and Kang (2014) test the gender composition of teams by examining whether single-sex schooling reduces the gender gap in performance. Contrary to other studies, their study reveals that single-sex schools do not necessarily reduce the gender gap in competitiveness. This is consistent with our finding that performance of women does not improve under single-sex tournaments. A subsequent study by De Paola et al. (2015) is also consistent with our finding that the gender of one's opponent does not affect competitiveness.

Table 5: Performance in the Lab

Variables	(1)	(2)	(3)	(4)
Females		**-1.219**	**-1.088**	**-0.616**
		(1.187)	(1.565)	(1.596)
Experimental gender group:				
All-Female Teams	-0.820			
	(1.088)			
Mixed Teams	1.053			
	(1.162)			
Mixed Teams x Male		1.704	1.676	1.645
		(1.396)	(1.420)	(1.452)
Mixed Teams x Female		1.385	1.189	0.891
		(1.220)	(1.258)	(1.298)
Field gender Composition:				
All-Female Teams			**-0.087**	**-0.318**
			(1.543)	(1.558)
Mixed Teams			**0.801**	**0.695**
			(1.043)	(1.051)
Age	-0.031	-0.026	-0.021	-0.018
	(0.038)	(0.038)	(0.038)	(0.038)
Education	0.772***	0.764***	0.765***	0.765***
	(0.094)	(0.094)	(0.094)	(0.094)
Rulindo District	0.250	0.092	0.117	-0.140
	(0.990)	(1.023)	(1.027)	(1.175)
Household head	0.153	-0.406	-0.429	-0.381
	(0.971)	(1.142)	(1.141)	(1.139)
Household size	0.365*	0.330	0.306	0.352
	(0.214)	(0.211)	(0.219)	(0.225)
Married	1.532	1.604	1.469	1.424
	(1.430)	(1.400)	(1.386)	(1.327)
Risk taking (Switching Point)	-0.021	-0.026	-0.027	-0.033
	(0.052)	(0.053)	(0.054)	(0.054)
Constant	3.749	4.331	4.069	3.649
	(2.755)	(2.842)	(2.833)	(5.338)
Group Size	**No**	**No**	**No**	**Yes**
Observations	154	154	154	154
R-Squared	0.303	0.308	0.314	0.322

Heteroskedasticity-robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Consistent with Lee et al. (2014) and De Paola et al. (2015), we find that competing in single-sex teams does not improve performance in the lab. While the gender of VLEs and the gender composition of teams does not affect performance under competition, education is a significant predictor of VLEs' performance under competition. This is expected given the nature of the tasks that participants were asked to perform.

Previous studies demonstrate the importance of education as a key driver of performance when evaluating outcomes such as labour productivity and economic competitiveness (Cabrera & Le Renard, 2015; Sahlberg, 2006). In Rwanda, significant progress has been made by the government to ensure universal education access. For instance, the National Gender Policy (2010) and Girls' Education Policy (2008) address gender gap issues through affirmative quota systems. More women after the genocide now have access to education, with many rural families convinced about the importance of educating girls (Burnet, 2011). The World Bank indicators show that between 1990 and 1992 (before the genocide) 14,000 fewer girls than boys accessed primary education; however, by 2008, approximately 16,000 more girls than boys were in primary schools. The increase in access to education for women could be a contributing factor for the high competitiveness levels of Rwandan women.

Results also show a weak significant level for household size in Column 1, which might originate from competition within the household for limited resources. Downey (1995) explains that household heads and parents have finite resources such as time, energy, and money. They are forced to share these limited resources with children and other members as the household increases in size, which can result in the dilution of resources. The fact that VLEs from larger households perform better compared to smaller households may be due to the urgent need to provide for household members, which increases their desire to perform well in return for higher experimental payoffs.

In Table 6 (Columns 1-4), we report results related to performance in the field. The dependent variable in columns 1 and 2 is the number of recharges in the first three months of business operation. The dependent variable in columns 3 and 4 is self-reported business income. The sample in this table is formed by the VLEs who self-selected into competition in the third round of the lab experiments. As with the experimental results, field outcomes indicate no significant differences in performance based on the gender composition of teams. An important caveat to keep in mind is that business performance data refers to the first three months of operation only, so subsequent differences in business performance could arise with the pass of time.

Married men and women also tend to have lower sales performance levels, although married women are more likely than unmarried women to choose competition in our experiment. This finding contradicts studies in the entrepreneurship literature (Fairlie & Robb, 2009; Wickramasinghe & De Zoyza 2008), which suggest a positive relationship between marriage and business performance. These studies also explain that married women tend to have lower business performance levels than men. Our finding that married people do not perform as well as single people in business might be explained by a number of factors, including the additional time married people invest in maintaining their families, which may reduce hours of work and in effect, reduce business performance.

Table 6: Performance in the field

VARIABLES	(1) Log (Sales)	(2) Log (Sales)	(3) Income	(4) Income
Females		**-0.338**		**0.463**
		(0.224)		(2.099)
Field Gender Composition:				
All-Female Teams	**0.048**		**0.550**	
	(0.142)		(1.191)	
Mixed Teams	**0.018**		**-0.128**	
	(0.151)		(0.911)	
Mixed Teams x Male		-0.012		0.396
		(0.166)		(1.016)
Mixed Teams x Female		0.033		-1.506
		(0.181)		(1.193)
Age	0.001	0.000	-0.038	-0.034
	(0.004)	(0.004)	(0.038)	(0.038)
Education	0.010	0.007	-0.138	-0.152
	(0.012)	(0.012)	(0.105)	(0.108)
Rulindo District	-0.218	-0.294**	-0.540	-0.947
	(0.142)	(0.148)	(0.857)	(1.002)
Household head	0.138	0.142	0.914	0.294
	(0.091)	(0.120)	(0.902)	(1.094)
Household size	0.026	0.022	-0.166	-0.169
	(0.029)	(0.029)	(0.214)	(0.217)
Married	-0.262**	-0.260**	-0.319	-0.310
	(0.128)	(0.125)	(1.332)	(1.320)
Risk taking (Switching Point)	0.005	0.006	0.061	0.060
	(0.007)	(0.007)	(0.044)	(0.045)
Experimental gender groups	**No**	**Yes**	**No**	**Yes**
Constant	5.524***	6.006***	6.701***	5.017***
	(0.271)	(0.319)	(2.198)	(0.707)
Observations	154	154	149	154
R-Squared	0.0816	0.131	0.0512	0.139

Village clustered standard errors for all field estimations. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Business performance of women has been constantly underestimated (Brush and Cooper 2012; Minniti and Naude 2010; de Bruin et al. 2007; Ahl 2006) based on broader characteristics and context-related factors such as industry type, field experience and business size (Baker and Welter, 2017). Sappleton (2018) shows that the underestimation of women and the observed differences between female and male-owned businesses is due to the unequal comparison of business models in a given industry. For instance, women often engage in retail businesses focused on serving local markets. Such businesses are smaller in size, have lower growth rates and yield lower profits despite their high competition levels. Emerging management literature demonstrates how measures of business performance such as business sizes and growth rates of industry tend to favour men, whereas no performance differences are associated with more specific indicators such as profitability, number of employees, number of orders and closure rates (Zolin 2013; Robb & Waston 2012). Among the lab participants who self-selected into competition, who are a selected subset of villages in the study by Clarke et al. (2020), male-owned enterprises did not outperform female-owned enterprises during the first three months of operation. This resonates with Zolin (2013) and Robb & Waston (2012), given that we compare the performance of entrepreneurs working in the same industry under the same business model with similar terms and conditions.

The external validity of experiments is often low and continuously criticised by empirical researchers. The artificiality under which lab experiments are conducted makes it difficult for real-world generalizability (Schram, 2005). Roe and Just (2009**)** argue that the best way to overcome the limitations associated with a single research method is to apply multiple approaches to the same phenomenon. Showing that similar results can be achieved when experimental results are compared to real-world operations of microenterprises corroborates the external validity of our findings.

Recent years have also seen the government of Rwanda depend heavily on the private sector's participation in implementing off-grid solutions due to the fast pace at which the state wishes to attain 100% electricity access. As a result, national policies have contributed substantially to the rapid growth of the private sector, especially for solar companies. The government has also taken steps towards increasing gender equity energy policies in the country, yet private companies are still not required to include gender mainstreaming in their operations (Parshotam & van der

Westhuizen, 2018). Despite the support from the government, women's participation in the private sector is limited, as some companies potentially see the inclusion of women as a limitation for the maximisation of revenue (Parshotam & van der Westhuizen, 2018).

6. Conclusion

A large body of literature investigates gender differences in competition among student subjects in the lab. Yet, the application of such studies to a real-world phenomenon is scarce. This study examines competitiveness from the perspective of gender inclusivity in the renewable energy value chain in a context where the government of Rwanda is determined to promote private sector involvement, in their quest to accelerate rural electrification to off-grid communities.

Our study adds to the existing literature on competitiveness and gender by being the first to test these concepts in the renewable energy sector, using a unique subject pool of entrepreneurs operating off-grid gender-focused microenterprises in rural Rwanda – a country globally known for its progressive gender policies. Further, the extent to which competition results in the lab reflect real-world situations has not received much attention in previous studies. This study provides new evidence to support the extent to which experimental results are consistent with profitability in the field, to corroborate the external validity of our findings.

Our findings show that, under competitive situations in the lab, women operating off-grid microenterprises in Rwanda are not less willing to enter competition; female VLEs perform as well as men when they work in both all-female and mixed gender groups, and gender of opponents does not affect their performance. Results also show that, in single-sex groups, education and risk-taking are key drivers of the decision to compete; in the all-female teams, risk-loving women are more likely than risk-averse women to compete. Consistent with our experimental results, field findings also show no statistically significant differences in business performance between male and female VLEs that self-selected into competition in the lab experiments. One important caveat is that we use only the first three months of operations, so we cannot reject that differences in business performance could appear later on. Furthermore, this result is informative only of the VLEs more prone to competition, not for the average VLEs.

While the study unleashes the applicability of experimental results by adding to the competition literature, our research also provides insights into the private energy sector. Currently, women's participation in the private energy sector of Rwanda is low, as some companies potentially see the inclusion of women as a limitation for revenue maximisation (Parshotam & van der Westhuizen, 2018). By showing that women entrepreneurs can be as competitive as men entrepreneurs, and that women who self-select into competition can perform as well as males that do so, our study provides an impetus for private energy companies in Rwanda to reconsider the involvement of more women in this sector.

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Appendix A: Compiled Studies

Table I: List of Studies Based on Niederle–Vesterlund (2007) Experimental Design

Student Subjects

Studies	Country	Task	Sample Size	Tournament Entry	
				Male	Female
Addition tasks					
Zhong et al. (2018)	Singapore	Addition	197	49%	25%
Dariel et al (2017)	UAE	Addition	147	50%	54%
Apicella et al. (2017)	USA	Addition	100	58%	38%
Halko & Saaksvuori (2017)	Finland	Addition	80	74%	54%
Reuben, Wiswall & Zafar, (2017)	USA	Addition	257	54%	27%
Buser, Dreber & Mollerstrom, (2017)	USA	Addition	104	52%	28%
Berlin & Dargnies (2016)	France	Addition	228	63%	35%
Brandts, Groenert & Rott, 2014)	Spain	Addition	112	59%	30%
Wozniak et al. (2014)	USA	Addition	128	54%	31%
Niederle et al. (2013)	USA	Addition	84	74%	31%
Cadsby et al. (2013)	Canada	Addition	132	36%	9%
Price, (2012)	USA	Addition	310	66%	49%
Mueller & Schwieren (2012)	Germany	Addition	127	42%	26%
Kamas & Preston (2012)	USA	Addition	310	41%	23%
Dargnies (2012)	France	Addition	76	85%	51%
Balafoutas, Kerschbamer & Sutter (2012)	Austria	Addition	134	59%	31%
Balafoutas & Sutter (2012)	Austria	Addition	72	64%	30%
Healy & Pate (2011)	USA	Addition	192	81%	28%
Niederle & Vesterlund (2007)	USA	Addition	80	73%	35%
Other tasks					
Buser, Gerhards & van der Weele, (2018)	Denmark	Mix	297	42%	26%
Banerjee, Gupta & Villeval (2018)	India	Memory task	168	22%	16%
Wozniak et al. (2014)	USA	Verbal	128	54%	31%
Gupta, Poulsen & Villeval, (2013)	France	Mazes	100	60%	34%
Shurchkov (2012)	USA	Verbal	128	39%	30%
Buser et al. (2017b)	Denmark	Mix	297	42%	26%
Banerjee et al. (2017)	India	Memory task	168	22%	16%

Non-student Subjects

Studies	Country	Task	Sample Size	Tournament Entry	
				Male	Female
Adults					
Bönte et al. (2017)	Germany	Math	225	56%	45%
Cassar, Wordofa & Zhang (2016)	China	Addition	358	36%	26%
Apicella and Dreber (2015)	Tanzania	Skipping rope Bead collection Handgrip strength	191 88 70	45% 52% 67%	30% 37% 29%
Gneezy et al. (2009)	Tanzania (patriarchal) India (matrilineal)	Bucket toss Bucket toss	172 146	50% 39%	26% 54%
Children					
(Zhang, 2015)	China (Han) China (Yi) China (Mosuo)	Addition Addition Addition	96 96 80	63% 60% 75%	48% 38% 48%
Buser, Peter & Wolter (2017)	Switzerland	Addition	249	68%	51%
Alma°s et al. (2016)	Norway	Addition	483	52%	32%
Sutter et al. (2016)	Austria	Addition	246	44%	21%
Khachatryan et al. (2015)	Armenia	Addition Word search	824	54% 57%	52% 56%
Sutter & Glaetzle-Ruetzler, (2015)	Austria	Addition	717	40%	19%
Lee, Niederle & Kang (2014)	South Korea	South Korea	640	30%	22%
Dreber, von Essen & Ranehill (2014)	Sweden	Addition Word search	216 216	36% 33%	17% 28%

Appendix B: Additional Estimates

Table B1: Difference in characteristics between experimental and non-experimental Sample

Variables	Lab Indicator
Age	-0.0007
	(0.0017)
Number of Working hours	3.77 e-08
	(3.14e-08)
Household Income	-3.55e-07
	(8.96e-07)
Household Expenditure	-3.48-07
	(6.76e-07)
Household Wage Employment	4.93e-08
	(1.28e-07)
Household roof	0.0016
	0.0215
Female Teams	0.0313
	(0.062)
Mixed Teams	-0.0186
	(0.0659)
District	0.0076
	(0.0615)
Happiness level	-0.0121
	(0.009)
Patience Level	-0.0057
	(0.010)
Sales	0.117***
	(0.0086)
Education	0.0378***
	(0.0106)
Emotional Health	-0.00881*
	(0.0043)
Constant	0.1607
Observations	504
R- Squared	0.2236

Village-level clustered standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Notes: This table compares characteristics of lab participants to the VLEs who did not participate in the experiment in terms of business and socioeconomic characteristics. The dependent variable is a dummy that takes the value of 1 if the VLE participated in the lab experiments and 0 otherwise.

Table B2: Distribution of Groups and Number of People per Experimental Group

Number of people per group	Female Group	Male Group	Mixed-gender Group	Total Number of Groups
2	---	2	---	2
3	3	4	3	10
4	14	16	26	56
5	13	8	---	21
6	---	2	---	2

Table B3: Baseline Differences in Expected Gender Behaviours by Children

Variable	Male	Female	Difference	P-value
Wives should be less educated than their husbands	3.44	3.6	-0.3.6	0.34
Boys should get more resources/opportunities for education than girls	3.92	3.98	-0.05	0.64
Girls should be allowed to study for as long as they like - as high as they want	1.57	1.57	0.00	0.99
Daughters should have a similar right in terms of inheriting property as sons	1.72	1.82	-0.10	0.48
Women should get equal opportunities in all areas of life	1.6	1.59	0.00	0.92

Notes: Responses ranges from 1- strongly agree, 2- agree, 3- neither agree nor disagree, 4 - disagree and 5-strongly disagree. Children of VLEs agreed to the following statements: girls should be allowed to study for as long as they like, daughters should have similar rights in terms of property as sons and women should get equal opportunities in all areas of life, responses. It is worth noting that children gave a neutral response to the following statement wives should be less educated than their husbands but disagreed with the statement boys should get more resources/opportunities for education than girls. These answers demonstrated the extent to which perceptions about women are changing among younger generations living in rural areas of Rwanda.

Table B4: VLE's competition entry decisions for group sizes of four only

VARIABLES	(1) Combined	(2) Mixed	(3) Single	(4) Female	(5) Male
Dummy for Females	0.0102	0.0833	-0.132		
	(0.131)	(0.171)	(0.156)		
Scores from round 2	0.0195**	0.0436***	0.00238	0.0147	-0.00804
	(0.00962)	(0.0107)	(0.0158)	(0.0229)	(0.0238)
Tournament - Piece rate	-0.0236**	-0.0481***	-0.0128	-0.00850	-0.0130
	(0.0120)	(0.0154)	(0.0199)	(0.0292)	(0.0296)
Number of participants per session	-0.0116	-0.0282**	-0.00797	-0.0145	-0.00319
	(0.00709)	(0.0112)	(0.0119)	(0.0175)	(0.0170)
Risk taking (Switching Point)	0.00842*	0.0136**	0.00439	0.00588	-0.00592
	(0.00466)	(0.00639)	(0.00726)	(0.00954)	(0.0133)
Education	0.0360***	0.0324**	0.0415**	0.0312	0.0518**
	(0.0128)	(0.0160)	(0.0205)	(0.0340)	(0.0252)
Household head	-0.0533	-0.0622	-0.101	-0.0563	-0.0768
	(0.102)	(0.133)	(0.146)	(0.218)	(0.278)
Household size	-0.0469**	-0.0457*	-0.0479*	-0.0668*	-0.000202
	(0.0199)	(0.0268)	(0.0266)	(0.0405)	(0.0425)
Age	-0.00121	0.0114**	-0.00679	0.000838	-0.0102*
	(0.00371)	(0.00484)	(0.00445)	(0.00757)	(0.00589)
Rulindo District	-0.0277	-0.0913	-0.0342	-0.119	0.0660
	(0.0929)	(0.0963)	(0.188)	(0.241)	(0.323)
Married	0.0128	0.105	-0.163	0.221	
	(0.122)	(0.153)	(0.154)	(0.233)	
Dummy for experimental single-sex teams	0.0393				
	(0.0748)				
Field Gender Composition					
2.All- Females	0.125	0.180	0.228		
	(0.137)	(0.166)	(0.203)		
3.Mixed	0.186**	0.311***	0.200	0.000740	0.280**
	(0.0942)	(0.111)	(0.125)	(0.191)	(0.141)
Observations	197	94	103	52	47
Log pseudolikelihood	-117.96	-48.06	-61.17	-32.18	-25.28

Results are marginal effects from a Probit estimation. Heteroskedasticity-robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Appendix C: Experimental Instructions

Introduction

Welcome!

"Thank you for coming. My name is [NAME], I am a doctoral fellow at the University of Cape Town, South Africa. These are my colleagues [NAMES]. We have invited you here to play simple economic games.

You will earn money for participating in today's experiment. For your participation, you will be paid F1000. This means you are starting the day with F1000.

You will play today's games in 3 parts

You can make additional money based on your decisions.

How much money you make **solely** depends on the decisions you make during the games. This means it is very important you pay attention and understand the rules of the games, which I am going to explain at the beginning of every game.

At the end of the day, the amount you earned will be paid to you **IN CASH**.

Please do not talk to anyone when we start playing the games. If at any stage of the game, you have ANY question just raise your hand and someone will come to you in private to answer your question.

Participating in the games is voluntary. If you decide not to continue with the games, you may leave at any stage even after we have started playing the games but note that you will not earn any money for participating.

At this point, if you wish to continue with the experiment, you may sign the consent form that my assistants are bringing around right now. [HAND OUT THE CONSENT FORMS AND READ TO THEIR UNDERSTANDING]

Do we have anyone who needs assistance? [IF YES, WE ASSIST WHERE NECESSARY]
Has everyone finished signing? Alright, one of us is coming around to collect the forms from you.
[COLLECT FORMS]

We are going to share a second form to capture some demographic details before we continue with the various games. Under no circumstance will this information be used to identify the decisions you make in the games. [HANDOUT IDENTIFICATION FORMS]

Your experiment number is written on the topmost part of your tables. Is everyone done with filling out the forms? [GIVE ASSISTANCE WHERE REQUESTED] Okay, someone is coming around to collect the forms. [COLLECT FORMS WHILES CHECKING THAT ALL FIELDS HAVE BEEN PROPERLY FILLED]

Part 1: Game 1

You will play three games in this part. In the first game, you are asked to add simple numbers together. All you must do is to write down the answers to as many problems as possible in 5 minutes.
Example: [POINT TO THE POSTER AND DO AN EXAMPLE]

We will time you throughout the tasks. After 5 minutes, I will ask you to stop. Each correct answer to the problem will earn you RWF 50. This means if you solve three problems correctly, you earn 3X RWF 50 = F150, if you solve four problems correctly you will earn 4X RWF 50= RWF 200 and so forth. There are 20 questions in total to be solved. That means if you get all 20 problems correct you will earn a maximum of 20 X RWF 50 = F1000 for this game.

Now, your decision sheets for this game comes in the form of a booklet: one problem on each page. So, after solving a question, you turn to the next page and continue solving until the 5 minutes is up.
The use of mobile phones/calculators are not allowed in this session.

Once again, do not talk to anyone during the games.

After you finish with all the games, your results for this part will be given to you individually at the end of the day.

Any questions?
[DISTRIBUTE BOOKLETS] Do not open your booklets until asked to do so.

[AFTER EVERYBODY HAS GOTTEN THEIR BOOKLETS] Now, write down your experimental number which was given to you at the start of the day in the blank space on your booklets. [POINT TO POSTER]

Okay! Let's continue, Solve as many problems as you can in 5 minutes. You can now open your booklets and start!
After 5 minutes, stop solving! Pencils Down! [COLLECT BOOKLETS]

Game 2

Again, in this game, you are asked to add as many numbers as you can in 5 minutes. The difference now is that for this game, you will be part of a group. The people in your group will be randomly picked from this room. We will hand over to you some basic information about your group members. However, you will never know the names of the other people in your group, and they will never know your name.

Your performance in this round will be compared to the other members of your group. Only the person with the highest score in each group will be paid for this round. The amount paid to the person who solved the highest number of problems for each group is now RWF 150 for each problem solved correctly. That is the winner of this game for each group earns RWF 150 for each correct problem.

This means if the highest score in the group is 10, the person who had the 10 will earn RWF 150 X 10 = RWF 1500

Once again there are 20 problems in total to be solved so the highest amount, the winner for each group can make 20 X RWF 150 = RWF 3000

If two or more people have the same score in a group, the earnings will be split among the top performers of the group equally.

For example: If in a group, two people have the same score, which is also the highest score of the group, let's say their score was 5. Then it means the earnings become 5 X RWF150=RWF750. In this case, the F750 will be shared equally between these two winners. This means they will receive F375 each.

Remember if you are not the winner of your group you earn **NOTHING for this game**.

Any question? Great! Now let's start with the game.

[DISTRIBUTE BOOKLETS WITH THE BASIC INFORMATION OF GROUP MEMBERS] Do not open your booklets until asked to do so.

[AFTER EVERYBODY HAS GOTTEN THEIR BOOKLETS] Now, write down your experimental number which was given to you at the start of the day and your group numbers [SHOW THEM WHERE THEY ARE] in the blank space on your booklets. [POINT TO POSTER]. ASSISTANTS GO ROUND TO EXPLAIN THE BASIC INFORMATION OF GROUP MEMBERS TO PARTICIPANTS

Okay! Let's continue, Solve as many problems as you can in 5 minutes. Remember, you are now in groups. You can now open your booklets and start!

After 5 minutes, stop solving! Pencils Down! [COLLECT BOOKLETS]

Game 3

In this game, you will go through the additions again in 5 minutes as done in previous games. But now you can choose which way you want to be paid. Do you want to be paid by your individual performance like in **GAME 1,** or do you choose to be compared to your group performance as done in **GAME 2**?

As I said in Game 1, you are paid RWF **50** for each correctly solved problem. In Game 2, if you are the winner of your group, you get three times higher the amount paid for each correct problem. That is, you earn RWF **150** for each correct problem.

Since we have a total of 20 problems, it means if you choose to be paid by your own performance as done in Game 1 the maximum amount you can make is RWF **1000** but if you choose to play in a group as done in Game 2 the maximum amount you can earn is RWF **3000 if you are the winner.** If you choose to play in a group and **you are not the winner, you earn nothing for this game.**

So, if you choose to play the individual performance task, you will be paid RWF **50** for each problem solved correctly. However, if you choose to compare your performance to your group, you will earn RWF **150** for each correct problem **if you are the winner of your group**.

Any questions?

Now, write your experimental number and choose how you want to be paid for this round on sheets in front of you [POINT TO POSTER]

Experiment Number ________________________________

[TICK]

[ ] – **Individual task payment**

[ ] – **Group task Payment**

[ASSIST PARTICIPANTS]

[DISTRIBUTE DECISION BOOKLETS WHILES COLLECTING PREVIOUS SHEETS GIVEN OUT]

[AFTER EVERYBODY HAS GOTTEN THEIR BOOKLETS]

Now, write down your experimental number (given at the start of the day) and group numbers [IN THE CASE OF THOSE WHO CHOSE TO PLAY IN GROUPS] in the blank space on your booklets
Okay! Let's continue, Solve as many problems as you can. You can start!

After 5 minutes, stop solving! Pencils Down! [COLLECT BOOKLETS]"

Chapter 4: Risk attitudes, gender and business performance among off-grid renewable energy entrepreneurs in rural Rwanda.

Rebecca A. Klege

Abstract

Theory predicts that entrepreneurs' ability to take risks positively affect business success. Yet, empirical findings are mixed, with no available experimental evidence. We fill the gap by conducting a lab-in-the-field experiment among 374 entrepreneurs operating off-grid renewable energy recharge stations in assigned gender teams, to examine risk attitudes among entrepreneurs and the effect of risk aversion on business performance in rural Rwanda. Experimental results are additionally compared to subjective risk measures. Findings show a strong risk aversion among entrepreneurs. Results also reveal a negative relationship between risk aversion and business performance. Thus, entrepreneurs with high risk-taking abilities tend to record better sales. Contrary to experimental results, we find no significant relationship between risk attitudes and business performance for subjective risk measures. Women reveal higher risk aversion levels than men for both experimental and survey risk measures. Despite the gender differences in risk aversion, women are not outperformed by male entrepreneurs. Additional factors influencing the risk attitudes of entrepreneurs' and the implications of results are discussed.

Keywords: Risk aversion, Entrepreneurs, Gender, Business Performance, off-grid energy

1. Introduction

Risk-taking and uncertainty are essential drivers of entrepreneurial success and can be traced back to the early works of Knight (1921) and Kihlstrom and Laffront (1979). Economic theory predicts that business owners tend to be less risk-averse than others (Koudstaal, Sloof & Praag, 2016). In effect, entrepreneurs' risk attitudes are expected to affect business performance. Whereas economic literature has actively studied entrepreneurs risk-taking abilities by comparing them to non-entrepreneurs using both empirical and experimental techniques (Koudstaal et al., 2016; Holm, Opper & Nee, 2013; Graham, Harvey & Puri, 2013; Djankov, Roland & Zhuravkaya, 2007), literature examining the effect of risk attitudes on business performance has been dominated by psychological and management studies (e.g. Boermans & Willebrands, 2017; Willebrands, Lammers & Hartog, 2012; Kraus et al.,2012; Naldi et al.,2007). As a result, previous studies that examine the relationship between risk and business performance has been reliant on psychometric and hypothetical measures of risk.

The study extends the existing literature by conducting a lab-in-the-field experiment among 374 entrepreneurs in rural Rwanda to examine the relationship between risk attitudes and business performance. These entrepreneurs have been operating off-grid renewable energy recharge stations since 2016 in assigned gender teams, as part of a more extensive randomized control trial (RCT) study focused on women empowerment in the renewable energy sector.

Unlike previous studies, our study context is an interesting one. First, the government of Rwanda is promoting private sector participation in the energy sector as a pathway to achieve its target of providing electricity access for all. As a result, several entrepreneurship activities are springing up in the renewable energy sector, with many focused on using community members as sales agents. The entrepreneurs used for this study comes from the business model of Nuru energy – one of the leading solar energy providers in Rwanda. Examining the relationship between risk-taking and business performance in such a model will provide key insights into the abilities of sales agents which will better inform future community recruitment processes in the private renewable energy sector. Second, previous studies that have attempted studying the relationship between risk and business success relied on entrepreneurs operating different models in various industries. Sappleton (2018) argues that differences in business operations can lead to varied performance levels which could explain the mixed findings reported in the literature. Our study context provides us with a subject pool of entrepreneurs working in the same sector, operating the same business models, with a similar number of customers as well as the same operational years in business. Given that entrepreneurs operate in gender teams, the study further explores the relationship between risk and business performance from a gender perspective.

Experimentally, the multiple price list design, following notable studies such as Booth et al. (2018), Tanaka, Camerer and Nguyen (2016), Brick and Visser (2015), Brick, Visser and Burns (2012) and Holt and Laury (2002) is used to elicit entrepreneurs risk attitudes. Survey risk measures were based on entrepreneurs self-reported ability to take risks on a scale of 1 (never take risks) to 5 (always take risks). Following the Willebrands et al. (2012) and Daniel and Mead (1998), the study employs sales levels as a measure for business performance.

Our experimental evidence reveals a strong risk aversion among entrepreneurs. Comparing our results to similar risk measures, we find that the risk aversion levels of our sample is not any different from small-scale farmers in Ethiopia and South Africa (Brick & Visser 2015; Akay et al., 2012). Thus, entrepreneurs from this study are like ordinary farmers in other developing countries. Second, our study shows high-risk aversion negatively affects business success. As such, entrepreneurs in our sample with better risk-taking abilities tend to record better sales.

Contrary to our experimental results, we find no significant relationship between risk and business performance when survey risk measures are used. However, women reveal higher risk aversion levels than men for both risk measures. Despite the gender differences in risk aversion, women are not outperformed by male entrepreneurs. Additional factors influencing the risk attitudes of entrepreneurs' and the implications of results are discussed. Given that our experimental evidence confirms the general theoretical assertion that risk is vital for business success, there is a need for more future experimental studies to resolve the inconclusiveness of empirical findings.

The study proceeds as follows. Section 2 review existing studies. Section 3 describes the experimental design, survey measures of risk and the measurement of business performance. The sample and data of the study are presented in Section 4. Section 5 presents the results and discussion of findings. Section 6 concludes.

2. Literature Review

Every economic decision requires some level of risk-taking, explaining why the study of risk continues to dominate economic literature. Standard theory predicts that risk-taking is vital for entrepreneurship, which in turn propel the successfulness of a business (Kihlstrom & Laffont 1979; Kirzner 1973; Knight 1921; Cantillon 1755). Previous studies that examine risk attitudes of entrepreneurs compare them to non-entrepreneurs using both empirical and experimental approaches (*see Appendix D for a comprehensive list of papers and methods*). The most recent of such studies was by Koudstaal et al. (2016). Using a lab-in-the-field experiment, they compared entrepreneurs to both managers and employees in the Netherlands. They find that entrepreneurs risk attitudes were similar to managers but tend to be more risk-loving than employees.

The relationship between risk attitudes and business success has instead been mixed and skewed towards psychological and management studies (see a review by Rauch et al., 2009). While some studies show a positive relationship between risk and firm performance (Boemans & Willebrands, 2017; Wang &Yen, 2012; Ma et al., 2012) others find a negative relationship (Rezaei et al., 2018; Kollmann & Stockman, 2014; Lechner & Gudmundsson, 2014; Naldi et al., 2007; Tang et al., 2007), a few found no effects (Thapa, 2015; Zhao, Seibert & Lumpkin, 2010) and even some show a U-shape relationship (Diez Esteban et al., 2017; Begley & Boyd, 1987). Rauch and Freeze (2000) in a meta-analysis of six studies, find a negative relationship between risk-taking and business performance. Using data from Swedish firms, Naldi et al. (2007) report a negative association between risk-taking and business success. Caiendo, Fossen and Kritikos (2010) reveal that the relationship is rather non-linear as entrepreneurs with medium risk are more likely to survive compared to those with higher or lower risk-taking abilities.

In developing economies, findings also seem to be inconclusive. Koop, Reu de and Frese (2000) examined the relationship between risk-taking and business success among entrepreneurs in Uganda and found a significant positive effect. A similar study looking at microenterprises in Southern Africa by Krauss et al. (2005) also show a positive effect. A study by Willebrands et al. (2012) based on small scale enterprises in Nigeria, analysed the relationship between risk-taking and business performance. Results from their study suggest that risk propensity negatively affect business success. A more recent study by Boermans and Willebrands (2017) using Tanzanian data on 611 entrepreneurs demonstrate that risk propensity and risk perceptions are two different concepts. They conclude that while risk perceptions positively affect business performance, high-risk propensity shows a negative effect. The inconclusiveness in previous studies has primarily been informed by psychometric and hypothetical measures of risk, based on survey data. Our study fills the gap by conducting a lab-in-the-field experiment among 374 entrepreneurs in rural Rwanda to examine the relationship between risk attitudes and business performance.

3. Experimental and Survey Design

Similar to the sample group used in Chapter 3, entrepreneurs in the larger randomised control trial study were recruited as follows. First, 272 villages in the Rwanda district of Rulindo and Ruhango were sampled to participate in a new Nuru business model. With the assistance of village leaders, villages were approached about the opportunity of setting up solar recharge stations with each station to be run by a four-person microentrepreneur team. For the purposes of the field experiment, interested villages were randomly sorted into three groups (all-male, all-female, and mixed teams). Community members formed their groups without any restrictions from the research team apart from the gender composition request. Prospective microentrepreneur teams were then requested to raise an investment capital (commitment fees) of 40,000 Rwandan Francs (~50USD) in exchange for their start-up recharging equipment. All 272 villages raised these commitment fees prior to assigning treatment groups. Potential microenterprises were informed that their village had a 50% probability of being selected into the first phase of the new Nuru business. Thus, half of the sample was randomly assigned to a treatment arm. Villages who were selected to a control group had their money returned to team members, while villages who were selected into the treatment group received recharging equipment and 100 lights per each village to commence business. The operations and management decisions were solely up to members of the team. Also, given that community members could form their own gender teams, there is a potential that team members could be familiar with each other before the commencement of business. Clarke et al. (2020) and Visser et al. (2019) provide a detailed account of the randomisation process.

3.1 Experimental Design

The study adopts the multiple price list (MPL) choice tasks following the design closely by Brick and Visser (2015) and Moore and Eckel (2006) which is a variation of the original Holt and Laury

(2002) design. The MPL is a widely used design, employed by notable studies including Booth et al. (2018), Tanaka, Camerer and Nguyen (2016), Brick, Visser and Burns (2012).

Our experiment starts by presenting participants with a set of twenty-two paired lotteries with each decision pair consisting of two options: Option 1 – a certain payoff and Option 2 – a gamble. *Appendix A* presents the decision sheet used for the experiment. Detailed instructions are included as *Appendix E*[10]. Similar to Brick and Visser (2015) and Moore and Eckel (2016), the sure payoffs in option one increases from RWF[11] 160 (0.18 USD) to RWF 580 (0.64 USD) with RWF 20 increments as participants move from the first choice (row one) to the last choice (row twenty-two). The second option offers participants a constant payoff of 30% probability[12] of receiving 1200 RWF (1.33 USD) and a 70% probability of earning nothing for all twenty-two decision rows. It is expected that extremely risk-averse individuals will prefer the sure payoff in the first decision row, whereas extreme risk-loving subjects will prefer the gamble in the last row. A risk-neutral individual will, however, switch from option two to one when the expected value of both options is the same (Harrison 2005). In our case, this will be at decision row 11. Thus, a rational decision-maker who starts by choosing option one or switches from option two to option one at any given decision row is expected to continue choosing option one till the last decision row (twenty-two). The switching points provide the study with the certainty equivalent measures of participants.

A common concern associated with multiple price list design is the presence of multiple switching points (Vieder et al., 2015; Brick et al., 2012; Galarza, 2009; Jacobson & Petrie, 2009; Harrison 2005; Holt and Laury, 2002). Detailed instructions were provided to participants before the start of the experiment to minimize this potential problem. These instructions were read out loud in the official local language of Rwanda – Kinyarwanda – to the understanding of participants. The use of visual aids enables better comprehension amongst participants with low levels of education (Akay et al., 2012; Carlson et al., 2004; Corso, Hammitt & Graham, 2001). Posters, spinning wheels and coloured balls were therefore used to explain better the different choices and

[10] Experimental instructions were obtained from Brick and Visser 2015 and revised to suit of our study

[11] Rwanda Francs

[12] We maintained a constant probability throughout the experiment because participant had low educational levels and were not no familiar with such experimental procedures.

probabilities associated with each pay-off. A series of practise rounds before the start of the game[13] were played to confirm participants' understanding of instructions before proceeding to the actual experimental sheets for the study. As a result, no multiple switching behaviour was recorded, and participants did not feel pressurized to switch or stick to specific choices. At the end of the experiment, a ball was drawn from a bag to determine which of the twenty-two rows will be played for real money. A spinning wheel was used to determine the payoffs of subjects who chose the lottery (option two).

3.2 Survey design

We also rely on an extensive survey questionnaire designed to study the impacts of gender quota business model as part of a large RCT study. The questionnaire was carefully designed after a series of stakeholder interviews and piloting phase. Sections from the questionnaire used in this study include entrepreneurs general self-perceived risk preferences, demographic and socio-economic indicators of participants which includes gender, age, marital status, geographical location, education, income and household size. Entrepreneurs were also asked to provide information on their competitive abilities as well as their general happiness levels. Participants self-perceived risk ranged from a scale of 1 (never take risks) to 5 (always take risks). Happiness, on the other hand, ranges from 1 (not happy) to 10 (very happy). Entrepreneurs also either considered themselves as competitive (1) or not competitive (0).

4. Sample and Data

The study was conducted with a sample of 374 participants located in 129 villages of Rwanda. Our participants are entrepreneurs – energy service providers, recharging Nuru LED lights for community members off the national grid at a fee. These entrepreneurs have been working in uniquely assigned gender teams (all-female, all-male and mixed-gender teams) of four members per team as part of a more extensive RCT study since 2016. Before conducting the experiment, a personal invitation was sent out to all entrepreneurs in the Rulindo and Ruhango districts of Rwanda operating the Nuru off-grid microenterprises. Participants were allocated into different sector groups based on the distance to their respective villages with a total of 25 conducted lab-in-

[13] The practice rounds used different scenarios similar to actual games played

the-field experimental sessions. Self-perceived risk measures, as well as entrepreneurs background and household's information, are obtained from a more extensive survey conducted as part of the randomized control trial study, as discussed in Barron et al. (2019).

Table 1 report the descriptive statistics profile for survey variables. The average entrepreneur is 42 years of age with a low education level. For instance, most participants (87.43% of the sample) had only primary education with an average of seven years of schooling. Only 1% of the sample reported higher education in the form of diploma or degrees. Approximately 11 % of the sample had secondary or technical education (between 11-13 years of schooling). Given that the criteria for participation include the ability to read and write[14] as an entrepreneur, all subjects had some form of education.

Table 1: Survey variables

Variables	Observation	Description	Mean/ Proportion	Standard Deviation
Age	374	Age of entrepreneur	42	10.83
Education	374	Education of the entrepreneur (in years)	7	6.94
Household size	342	Number of members living in the entrepreneur's household	5	0.79
Female (%)	374	1=female, 0= male	0.49	0.50
Married (%)	374	1= married, 0 = otherwise	0.90	0.29
District	374	1= Ruhango, 2 = Rulindo	1.35	0.48
Income	342	Income of entrepreneur	14,709	28917
Happiness	342	Happiness level (0= not happy; 10= very happy)	6	2.15
Competitiveness	342	1 = competitive, 0= not competitive	0.96	0.18
Survey Risk	342	Self-reported risk (1 = never take risks; 5 =always take risks)	3.12	1.21

Source: Authors' own calculations using survey data

The average household size of participants is five. Most subjects are from the Ruhango district of Rwanda (64%) with the remaining 34% located in Rulindo district. The gender distribution of our subjects is almost equal. Precisely, 49% of the sample are females, and the remaining 50.8% are males. Participants are mostly married (90%) with monthly personal income approximately RWF

[14] The nature of the study requires participants to be able to read and write as we wanted to limit any human interference during the decision-making process.

14,709 (15.48 USD) on the average. Overall, most entrepreneurs (97%) self-reported high levels of competitiveness and are relatively happy. The average self-reported risk measure shows that entrepreneurs sometimes take risks.

4.1 Measuring experimental risk attitudes

Entrepreneurs' risk attitudes were informed by the number of safe choices. This enables the study to observe the associated switching points for each entrepreneur. The switching points provide a straightforward interpretation of risk attitudes without invoking assumptions surrounding the theory of utility maximization (Jin et al., 2017; Koudstaal et al., 2015; Brick & Visser, 2015). Using the switching points, we directly observe participants corresponding certainty equivalents. *Appendix B* presents the distribution of the number of safe choices made by participants and the associated switching points. Choices reveal that 54% of entrepreneurs are extremely risk-averse, 10% are extremely risk-loving, and only 2% are risk-neutral.

Following Brick and Visser (2015), Sutter et al. (2013) and Akay et al. (2012), the certainty equivalents of participants are used to create entrepreneurs' risk aversion measures. This is done by converting the certainty equivalent to values ranging from 0 to 1. The risk measure is calculated as follows: $\frac{CE-CE_U}{CE_l-CE_U}$ where CE is the certainty equivalent of participants, CE_U denote the highest possible certainty equivalent and CE_l is the lowest possible certainty equivalent. When the value of the calculated risk measure (certainty equivalent ratio) is 0 it signifies risk-seeking behavior 0.5 implies risk neutrality, and 1 indicates risk aversion.

Table 2: Implied constant relative risk aversion (CRRA) ranges and risk classification

Switching row	Number of safe choices	CRRA ranges	Risk classification
10-11	11-13	0.00< r < 0.09	Risk neutral/ slightly risk averse
6-9	14-17	0.09< r < 0.25	↓ Increasing risk aversion
2-5	18-21	0.25 < r < 0.40	
1	22	0.40 < r	

Source: Authors' own calcution using experimental data

Although we avoid the reliance on the utility maximization theory, to enable successful comparison with notable studies such as Brick et al. (2012), Andersen et al. (2010), Andersen et al. (2008), Harrison and Ruström (2008), and Holt and Laury (2002) we present the implied risk bounds in Table 2 with focus on risk-averse choices. Assuming a constant relative risk aversion (CRRA) utility function: $U(x) = (x^{1-r})/ (1 - r)$ an entrepreneur who for instance switches from option two to option one between row six to nine reveals an implied CRRA range of 0.09 to 0.25.

4.2 Measuring business performance

Various indicators can be used to measure the success of a business. For instance, Krauss et al. (2005) used a single index based on an aggregation of sales, profit, and the number of customers to measure the success of a business. On the other hand, Koop, Reu de, and Freese (2000) measure business performance as the number of employees in a firm. Profitability seems to be a more attractive measure of business success; however, Daniels and Mead (1998) identify 1) incorrect reporting of profits among entrepreneurs, 2) improper records keeping, 3) seasonality and 4) recall bias as challenges associated with using profit to measure business success. They, however, identified sales as a relatively uncontroversial measure which can be easily remembered by entrepreneurs. Following Daniels and Mead (1998) and the fact that sales information (recharge frequency) from the Nuru model are directly transmitted to a centralized data hub eliminating any potential human errors, we use sales information as a measure for business performance.

Table 3: Microenterprise variables

Microenterprise Variables		Mean/ Proportion	Standard Deviation	Minimum	Maximum
Recharge Frequency	374	209	119.17	1	576
Gender Teams:					
All-male teams (%)	127	0.34	-	-	-
All-female teams (%)	128	0.34	-	-	-
Mixed gender teams (%)	119	0.32	-	-	-

Source: Authors' own calculations using survey data

Table 3 presents the descriptive statistics of microenterprise variables. The light recharges range from 1 to 509, with an average of 209 recharges. Each village has one microenterprise. This enterprise is either owned together by an all-female team, an all-male team or a mixed-gender team consisting of four members. From our sample, 127 (34%) participants work in all-male teams, 128 (34%) of our subjects operates in all-female teams and 119 (32%) work in mixed teams. This indicates an approximately equal distribution of the assigned entrepreneurial teams.

5. Results and Discussion

5.1 Self-perceived risk attitudes

We first estimate the ordered probit regression to identify factors influencing entrepreneurs self-reported risk attitudes in Table 4. We include age and gender, argued in the literature as exogenous determinants of risk (Dohmen et al., 2011). Like previous studies, (e.g. Kerri & Visser, 2015; Maart-Noelck & Musshoff, 2014; Akay et al. 2012; Dohmen et al., 2011; Tanaka et al. 2010) additional variables such as education, income, marital status and household size are included in the estimation. We also control for business characteristics – gender teams of operations as well as the location of the enterprise. In addition, we control for two self-reported behavioural measures: competitiveness and happiness. Previous studies neglect the relationship between individual's happiness levels and risk-taking, although anecdotal evidence of such a relationship exists[15]. For instance, Goudie et al. (2014) show that happy people are less likely to take risks. Thus, accounting for happiness enables the study to further comment on the relationship between risk and happiness

[15]The two studies that explicit examine risk taking and happiness levels are Gouldie et al. (2014) and Jin et al. (2017) with both relying on survey data. Experimental relationship between these two attitudinal measures is yet to be examined.

Table 4: Determinants of entrepreneurs self-perceived risk attitudes

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Female	**-0.314*** **	**-0.466*** **	**-0.485*** **	**-0.477*** **	**-0.484*** **	**-0.479*** **	**-0.458*** **	**-0.503*** **	**-0.503*** **	**-0.462*** **
	(0.116)	(0.172)	(0.171)	(0.170)	(0.172)	(0.176)	(0.166)	(0.172)	(0.173)	(0.177)
Female Teams		0.240	0.232	0.223	0.230	0.224	0.260	0.231	0.229	0.256
		(0.202)	(0.201)	(0.200)	(0.202)	(0.206)	(0.196)	(0.203)	(0.203)	(0.205)
Male Teams		0.226	0.207	0.209	0.206	0.197	0.208	0.198	0.192	0.185
		(0.160)	(0.159)	(0.159)	(0.159)	(0.159)	(0.156)	(0.156)	(0.157)	(0.161)
Married					0.017					0.076
					(0.198)					(0.203)
Age			-0.009	-0.008	-0.009	-0.007	-0.007	-0.007	-0.006	-0.002
			(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
HH_size			0.021		0.020	0.020	0.019	0.023	0.021	0.011
			(0.030)		(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.032)
Education						**0.044***				**0.042***
						(0.023)				(0.022)
Income							**0.041*** **			**0.036*** *
							(0.013)			(0.014)
Happiness								**0.072*** *	**0.070*** *	**0.053***
								(0.029)	(0.029)	(0.027)
Competitiveness									**0.734*** *	**0.844*** *
									(0.348)	(0.337)
Rulindo District										0.141
										(0.125)
Log-likelihood	-521	-520	-518	-518	-518	-516.	-514	-515	-512	-506
Wald Chi(df)	7.37(1)	9.51(3)	11.86(5)	11.36(4)	11.89(6)	15.57(6)	20.02(6)	19.82(6)	25.94(7)	36.20(11)
P-value	0.006	0.023	0.036	0.023	0.065	0.016	0.003	0.003	0.000	0.000
Observations	342	342	342	342	342	342	342	342	342	342

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

The resulting coefficients from Table 4 are robust across all estimations (Columns 1- 10). First, results show an apparent gender effect. Women self-report to be less willing to take risks than men. This finding is in line with previous studies that employ survey risk measures as dependent variables. For instance, Jin et al. (2017) in their study asked farmers in rural China about their willingness to take risks on a scale of 0 to 10 and found that men consistent with our result were more willing to take risks than women. Similarly, Dohmen et al. (2011) using a panel survey of the German adult population, show that women were less willing to take risks than men. A survey study conducted by Shema and Mutarindwa (2017) in Rwanda (our study context) also confirms our results by showing that 61% of women self-report low risk-taking abilities than men.

Consistent with Dohmen et al. (2011), we find that entrepreneurs with high income and high education levels are more likely to take risks. Happy people are also more likely to take risks. Whereas our finding on happiness is consistent with Jin et al. (2017) conducted in China, it contradicts the conclusion of Goudie et al. (2014) which was based on an American study sample. Findings also show a positive relationship between competitiveness and risk taking.

5.2 Lab results

Figure 1 presents the certainty equivalents distribution of participants. In line with *Appendix B*, a greater proportion of entrepreneurs show high risk-aversion levels and therefore reveal the lowest certainty equivalent. The top panel shows that at a 30% probability level of winning RWF 1200, about 55% of entrepreneurs prefer the safe option. A comparable study by Brick and Visser (2015) using a sample of 82 South African small-scale farmers with a gambling probability of 30% observe similar high-risk aversion proportion of 51%. Akay et al. (2012) also based on small-scale farmers in Ethiopia, find that 60% of their sample were highly risk averse. Thus, contrary to expectations risk attitudes of entrepreneurs operating the Nuru energy business model in Rwanda, to a larger extent are not any different from non-entrepreneurs such as ordinary farmers in South Africa and Ethiopia.

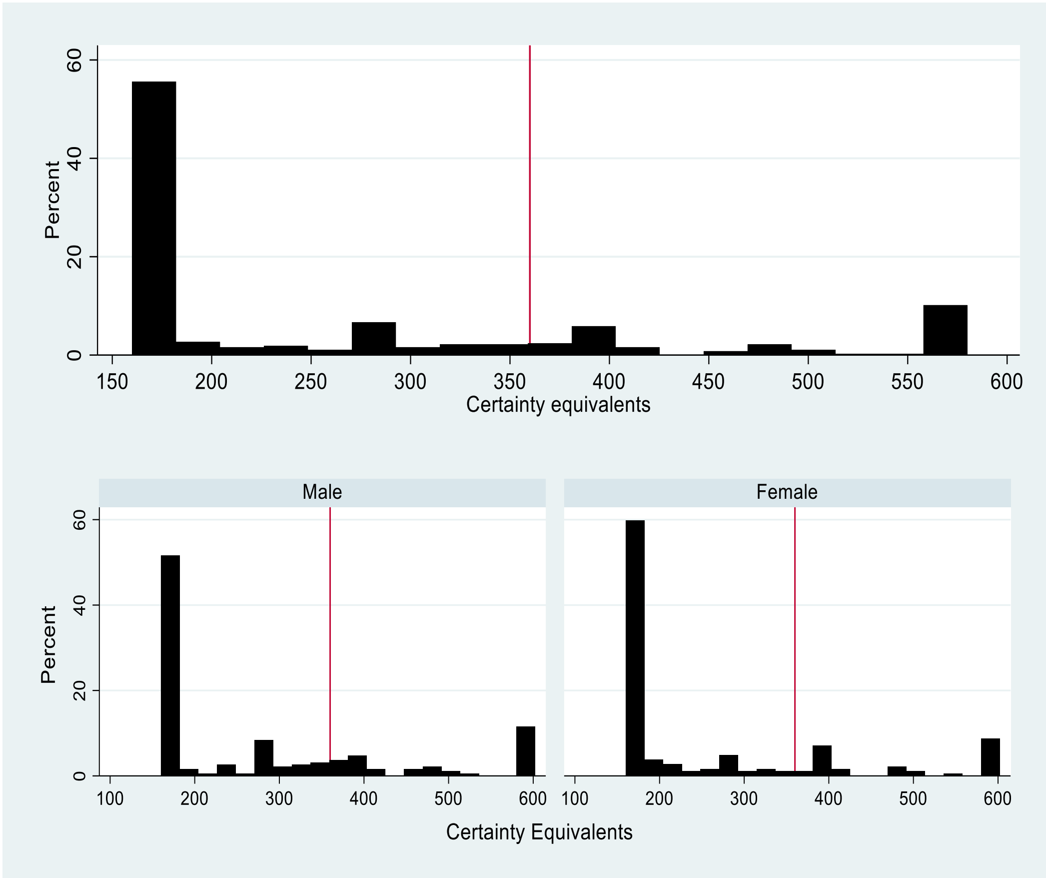

Figure 1: Certainty equivalents frequency distributions. The reference line (in red) reflects the expected value of the gamble.

Studies distinguishing entrepreneurs from others are extensive and mixed. Two notable studies Koudstaal et al., (2016) and Holm et al., (2013) using lab-in-the-field -experiments addressed the inconclusiveness in this body of literature. Precisely, Koudstaal et al., (2016) comparing entrepreneurs to two control groups: managers and employees in the Netherlands, show that entrepreneurs tend to have similar risk aversion levels with managers, but show lower risk aversion levels than employees. Hom et al., (2013), on the other hand, compared entrepreneurs to a sample of non-entrepreneurs in China. They find that entrepreneurs were more likely and willing to take a strategic risk but not so willing to take risks that do not require any strategy.

Although our finding of strong risk aversion among entrepreneurs contradicts the find of Koudstaal et al., (2016) and Holm et al., (2013), results are not surprising. The recruitment process of the Nuru business model targeted ordinary community members who were willing and able to raise the commitment fees with focus on gender, poverty alleviation as well as access to modern energy.

Commitment fees were therefore set at the barest minimum – RWF 10,000 (USD 10) per person to reduce entry barriers. In effect, most entrepreneurs operating the Nuru recharging stations were also into subsistence farming, indicating why we find high-risk aversion among our sample. A disaggregation of the sample by gender for the experimental risk measure in the lower panel of Figure 1 reveal that women are more likely to choose the safer option (60%) than men (50%). Women, therefore, show higher risk aversion levels than men.

Table 5: Risk aversion among entrepreneurs

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Female	0.155	0.289*	0.305*	0.302*	0.288*	0.297*
	(0.098)	(0.159)	(0.159)	(0.160)	(0.160)	(0.160)
Female Teams		-0.193	-0.186	-0.157	-0.155	-0.156
		(0.183)	(0.182)	(0.183)	(0.183)	(0.182)
Male Teams		0.061	0.094	0.106	0.114	0.115
		(0.143)	(0.143)	(0.143)	(0.143)	(0.143)
Age			0.010*	0.011**	0.010*	0.010*
			(0.005)	(0.005)	(0.005)	(0.005)
HH_size			-0.035	-0.038	-0.036	-0.038
			(0.028)	(0.029)	(0.029)	(0.029)
Rulindo District				0.193*	0.208*	0.213*
				(0.110)	(0.111)	(0.111)
Married				-0.119	-0.151	-0.143
				(0.182)	(0.186)	(0.186)
Education					-0.013	-0.012
					(0.018)	(0.018)
Income					-0.010	-0.008
					(0.013)	(0.013)
Happiness						-0.018
						(0.024)
Competitiveness						0.045
						(0.289)
Constant	1.021***	1.002***	0.761***	0.771***	0.983***	1.031**
	(0.072)	(0.087)	(0.239)	(0.274)	(0.345)	(0.477)
Log likelihood	-337.75	-308.81	-306.57	-304	-304	-303
LR Chi 2(1)	2.53	4.98	9.47	13.01	14.11	14.70
Observations	374	342	342	342	342	342

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the CE- ratio with increasing values denoting risk-aversion.

Given that most participants reported the lowest possible certainty equivalent, which causes our data to be censored on the right, we use a Tobit regression model. Table 5 reports the results of risk aversion based on the same set of explanatory variables used for the self-reported risk analysis in Table 4. Corresponding OLS results are presented in *Appendix C.*

Confirming the findings of Figure 1 and Table 4, we find a clear gender effect for risk-aversion across model specifications from Column 2 to 6. Female entrepreneurs tend to show higher risk-aversion levels than men. We also find a weak relationship between age and risk aversion. Older people are more risk-averse relative to younger people. Comparing experimental results to the self-reported risk results, we find that gender is a major driving factor of both risk measures. Interestingly, entrepreneurs in Rulindo seems to more risk averse than those from the Ruhango district. In the two cases, women are more risk-averse than men. Unlike the survey results, we find no significant effect for income, education, happiness and competitiveness for the experimental risk measure.

Gender differences in risk-taking is a widely researched subject. Previous studies have either actively examined differences between male and female risk attitudes or partially explored the topic (Nelson, 2016; Booth, Cardona-Sosa, & Nolen,2014; Hardies, Breesch & Branson, 2013; Booth & Nolen, 2012; Charness & Gneezy,2012; Gneezy & Croson, 2009; Byrnes, Miller & Schafer; 1999). Most studies find differences in risk aversion between men and women with a few finding no strong effects. Charness and Gneezy (2012) based on 15 experimental studies in line with our finding, observed strong evidence of gender differences in risk-taking with women showing higher risk-aversion levels than men. Consistent with our finding Sutter et al. (2012) and Brick et al. (2012) studying risk-attitudes among children and small-scale fishermen respectively also find that women are more risk-averse than men.

5.3 Risk aversion and microenterprises performance

Table 6 report the OLS results of the effect of entrepreneurs' degree of risk-aversion on business performance based on different model specifications (Columns 1 – 4). In Column 3, the relationship between self-perceived risk measure and performance is further examined. Additional variables: business characteristics of microenterprises, household size, age, education and marital status of entrepreneurs are controlled for in columns 2 to 4.

Table 6: Relationship between risk aversion and business performance

	Log (Sales)			
Variables	(1)	(2)	(3)	(4)
CE-ratio		**-0.382****		**-0.333***
		(0.179)		(0.200)
Female	0.132	0.266	0.219	0.353
	(0.219)	(0.177)	(0.165)	(0.296)
Self-reported risk			**-0.009**	
			(0.055)	
Female X CE				-0.110
				(0.349)
Constant	4.897***	5.493***	5.253***	5.474***
	(0.167)	(0.463)	(0.549)	(0.471)
Observations	373	342	342	342
R-Squared	0.003	0.092	0.082	0.0920

Village level clustered standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Increasing CE- ratio implies higher risk-aversion. Business characteristics and individual demographic indicators are included.

Results show that risk aversion based on the certainty equivalent ratio negatively affects business performance, indicating that low performing entrepreneurs tend to have higher risk-aversion levels. The subjective risk measure, however, does not significantly affect business performance (Column 3). Risk-taking is among the five key attributes[16] identified in the entrepreneurial orientation (EO) literature as factors influencing successful business performance (Wiklund & Shepard, 2003; Lumpkin & Dess, 1996). Theories suggest that risk-loving individuals are more likely to succeed in business compared to risk-averse individuals yet empirical evidence examining the relationship between risk-taking and firm performance are however mixed and inconclusive (Rauch et al., 2009). Although our finding that high risk-aversion based on experimental indicators is associated with low business performance resonates with the theoretical assertions and empirical findings of Boermans and Willebrands (2017) Wang and Yen (2012) and Yoon-joo Ma et al. (2012) it contradicts the findings of Rezaei et al. (2018), Kollmann and Stockman (2014) and Lechner and Gudmundsson (2014).

[16] The other attributes are innovativeness, proactiveness, autonomy and competitiveness.

Given our earlier finding (Table 5) that women are more risk-averse than men, one would have expected a lower business performance for women. Findings from Table 6, however, show no significant difference between female and male entrepreneurs. It is possible that working in teams could provide entrepreneurs with the leverage to hedge against personal risk aversion levels, therefore reducing the observed high risk-aversion amongst women. Although the study is unable to test the difference in performance levels for individual and group business models, in a related paper, Barron et al. (2020) show that even under a solo business model, women are more likely to outperform men.

Existing evidence suggests that men tend to make more revenue in business than women (Boermans & Willebrands,2017; Willebrands et al., 2012, Robb & Waston, 2012; Klapper & Parker, 2010). Such findings support the widely debated female-underperformance hypothesis in management studies (Yousafzai et al., 2018; Baker & Welter, 2017; Zolin et al., 2013; Robb & Watson, 2012; Du Rietz & Henrekson, 2000). Sappleton (2018) argues that most of the studies supporting the female-underperformance hypothesis are based on different business models operating in various industries. Our finding of similar performance between men and female could also because we study enterprises operating similar business models on the same scale and with similar start dates. However, we use only the first three months of operations, so we cannot reject that differences in business performance could appear later on when a more extensive data of the intervention is evaluated

Our findings raise important insights for the inclusion of more women in the private energy sector of Rwanda. Women participation as entrepreneurs in the energy sector, is associated with several benefits. For instance, Pailman (2016) show that entrepreneurs operating solar-powered charging kiosk are likely to depend on this role for their primary or supplementary income. Such incomes are used to supplement household and agricultural activities (Pailman, 2016). These income-generating opportunities result in spillover effect on pro-social household spendings such as food, health and education expenditures and can enable women to engage in other investment opportunities (Iyiola & Azuh 2014; Sigalla & Carney 2012). Existing studies also identify that through entrepreneurial activities women often gain access to social networks where best practices are shared, and support systems are built to enhance performance (Baruah, 2016; Soria et al., 2016). Our study show risk-aversion can negatively impact business success. Given the many benefits associated with the inclusion of more women in the energy sector, policies geared towards hedging against risk aversion in entrepreneurial programs can be vital in reducing gender gaps in business performance. Working in teams is a possible way of reducing the risk burden as we find equal performance levels despite the gender difference in risk aversion.

6. Conclusion

Entrepreneurs are generally stereotyped as more willing and able to cope with risks. Whereas economic literature has actively sought to understand the risk attitudes of entrepreneurs by comparing them to non-entrepreneurs, the question of how risk attitudes impact business performance has somewhat been neglected. Findings from existing studies examining the relationship between risk attitudes and performance remain inconclusive and rely on subjective measures of risk.

In this paper, we conduct a lab-in-the-field experiment among 374 off-grid renewable energy entrepreneurs working in assigned gender teams as energy sales agents in rural Rwanda, to examine risk attitudes among entrepreneurs and the effect of risk aversion on business performance. The distinguishing features of our study are as follows. The study is conducted with entrepreneurs in the renewable energy sector of Rwanda – a country relying on entrepreneurship through the private sector to speed up the provision of energy access to rural areas. These entrepreneurs, unlike previous studies, operate in the same business model, have a similar number of customers and start dates, therefore providing the study with a better tool for comparison. Second, given that entrepreneurs operate in gender teams, the study can additionally explore the relationship between risk and business performance from a gender perspective. The study further employs both incentivized experimental and subjective risk measures which allow the study to compare results from both measures.

Experimental results reveal a strong risk aversion among entrepreneurs. The risk aversion levels found in our study is, however, not any different from small-scale farmers in Ethiopia and South Africa (Brick & Visser 2015; Akay et al., 2012). Thus, entrepreneurs from our study are similar to ordinary farmers in developing countries. Women also tend to show higher risk aversion levels than men. Comparing survey results to experimental results, we find that whereas gender is a significant determining factor for both risk measures, subjective risk measures are additionally driven by income, education, competitiveness and happiness.

Further, results show that risk aversion negatively affects business success. As such, entrepreneurs with high risk-taking abilities tend to record better sales. Comparing experimental results to the survey result, we find no significant relationship between risk and business performance for subjective risk measures. Despite the gender differences in risk aversion, women are not outperformed by males in business. A potential explanation for this could be the fact that individuals are likely to hedge against their self-limitations when they operate in teams. One important caveat is that we use only the first three months of operations, so we cannot reject that differences in business performance could appear later on.

Given that our experimental evidence confirms the general theoretical assertion that risk-taking is vital for business success, there is the need for more future experimental studies to resolve the inconclusiveness in the literature. Future studies testing differences in the impact of risk attitudes on business success for solo and team business models will also be a useful extension to our study.

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Appendix A – Decision sheet

Experiment number: _________

	Option 1	✓		**Option 2**	✓
[1]	F160 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[2]	F180 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[3]	F200 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[4]	F220 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[5]	F240 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[6]	F260 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[7]	F280 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[8]	F300 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[9]	F320 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[10]	F340 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[11]	F360 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[12]	F380 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[13]	F400 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[14]	F420 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[15]	F440 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[16]	F460 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[17]	F480 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[18]	F500 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[19]	F520 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[20]	F540 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	

[21]	F560 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	
[22]	F580 for sure		**OR**	Spin the wheel: ○F0 / ●F1200	

Appendix B: Lottery Distribution

Table B1: Distribution of choice of lottery

Number of safe choices	Switching Points	Number of Participants
22	Always option 1	205 (54.81%)
21	2	3 (0.8%)
20	3	10 (2.7%)
19	4	6 (1.6%)
18	5	7 (1.87%)
17	6	3 (0.8%)
16	7	1 (0.27%)
15	8	25 (6.68%)
14	9	6 (1.6%)
13	10	8 (2.14%)
12	11	8 (2.14%)
11	12	9 (2.41%)
10	13	22 (5.88%)
9	14	6 (1.60%
8	15	0 (0%)
7	16	3 (0.80%)
6	17	2 (0.53%)
5	18	6(1.60%)
4	19	4 (1.07%)
3	20	1 (0.27%)
2	21	1 (0.27%)
1	22	0 (0%)
0	Always option 2	38 (10.16%)

Appendix C: Additional Estimation

Table C1: Determinants of risk aversion (OLS estimates)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Female	**0.062***	**0.106****	**0.114****	**0.111****	**0.108****	**0.111****
	(0.035)	(0.050)	(0.049)	(0.049)	(0.049)	(0.050)
Female Teams		-0.066	-0.065	-0.057	-0.057	-0.057
		(0.060)	(0.060)	(0.059)	(0.060)	(0.061)
Male Teams		0.017	0.025	0.029	0.030	0.031
		(0.050)	(0.050)	(0.050)	(0.050)	(0.050)
Age			0.003*	0.003*	0.003*	0.003*
			(0.002)	(0.002)	(0.002)	(0.002)
HH_size			-0.015	-0.015	-0.015	-0.015
			(0.011)	(0.012)	(0.012)	(0.012)
Rulindo District				0.045	0.048	0.051
				(0.040)	(0.040)	(0.040)
Married				-0.044	-0.049	-0.045
				(0.060)	(0.060)	(0.060)
Education					-0.004	-0.003
					(0.007)	(0.007)
Income					-0.002	-0.001
					(0.005)	(0.005)
Happiness						-0.009
						(0.009)
Competitiveness						0.006
						(0.100)
Constant	0.724***	0.718***	0.655***	0.669***	0.720***	0.760***
	(0.025)	(0.033)	(0.099)	(0.115)	(0.138)	(0.183)
R-squared	0.008	0.015	0.028	0.033	0.034	0.037
Observations	374	342	342	342	342	342

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the CE- ratio with increasing values denoting risk-aversion.

Appendix D: Supplementary Material

Literature overview: Risk attitudes among entrepreneurs' vs non-entrepreneurs

	Focus Group	Comparison Group	Region	Method
Koudstaal et al. (2016)	Entrepreneurs	Managers and Employees	Netherlands	Experiment
Holm et al (2013)	Entrepreneurs	Population at large	China	Experiment
Graham et al. (2013)	US Chief executive officers	Non -US executives	United States	Experiment
Burmeister Lamp et al. (2012)	Entrepreneurs	Students	Germany	Experiment
List and Mason (2011)	Entrepreneurs	Students	Costa Rica	Experiment
Sandri et al. (2010)	Entrepreneurs	Students/nonstudents	Germany	Experiment
Macko and Tyszka (2009)	Entrepreneurs	Students	Poland	Experiment
Caliendo et al. (2010)	Individuals who transfer into self-employed	Individuals who remain employ	Germany	Survey
Djankov et al. (2007)	Entrepreneurs	Non-entrepreneurs	Russia	Survey
Djankov et al. (2006)	Entrepreneurs	Non-entrepreneurs	China	Survey
Elston et al. (2006)	Entrepreneurs	Non-entrepreneurs	United States	Experiment
Cramer et al. (2002)	Self-employed at some point in life	Never self-employed	Netherlands	Survey
Uusitalo (2001)	Self-employed	Not self-employed	Finland	Survey
Van Praag & Cramer (2001)	Ever been self-employed	Never been self-employed	Netherlands	Interviews
Stewart et al. (1999)	Entrepreneurs	Corporate mana	United States	Survey
Sarasvathy et al. (1998)	Entrepreneurs participating in education program	Bankers participating in same education program	United States	Survey
Koh (1996)	Entrepreneurially inclined MBA students	Not entrepreneurially inclined MBA student	Hong Kong	Survey

Begley (1995)	Firm founders	Business managers	United States	Survey
Caird (1991)	Owner managers	Professional groups	United States	Survey
Hull et al. (1980)	Owner-managers	Business school alumni	United States	Survey
Brockhaus (1980	Start-up entrepreneurs	Business Managers	United States	Survey

Appendix E: Experiment instructions

Note: Instructions were adopted from Brick and Visser (2015) to suit our purposes. Full citation can be found in the reference section of the main paper

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"In this part, you will play three games: Game 1, 2 and 3.

For each game, you have 22 different decisions to make. You will be asked to choose between two options; Option1 and Option 2 in all the 22 cases. [POINT TO POSTER]

You will be paid for only one of your choices: that is only one out of the 22 choices you make will be paid for. You will only know which of these choices you will be paid for at the end of the day.

So, how are we going to determine the choice for which you will be paid?

I have in this bag 22 numbered balls [TOSS THE BALLS IN BAG FOR THEM TO SEE]. Once you have made a choice between Option 1 and Option 2 for each row, **we** will use this bag to decide which row will be played for money **AT THE END OF THE DAY**. One of you will draw a ball from this bag. If the ball has the number 1 on it, we will play row 1 for money. If the ball has a 2 on it, we will play row 2 for money. If the ball has a number 22 on it, we will play row 22 for money.

Okay, let's try it! **[SEND THE BAG AROUND FOR A FEW PEOPLE TO DRAW FROM IT] TO DEEPEN THEIR UNDERSTANDING]**

So, since we do not know which of the 22 choices you make will be paid for, it is important to think carefully before you choose between option 1 and Option 2 for each row since real money is as stake.

Any questions so far? Great. I will explain in detail how you will make your decisions as we go along

Risk Aversion

30% probability of earning RWF 1200

In this game, you must choose between 2 options: Option 1 and Option 2. [POINT TO POSTER].

You must show on the answer sheet in front of you, **<u>for each row</u>**, whether you choose Option 1 or Option 2. [POINT TO POSTER]

This is very important: if you choose Option 1, you will earn a sure amount of money!

If you choose Option 2, the amount of money you earn depends on this spinning wheel. And, it depends on whether the arrow lands on white or black.

Because this is SO important, let me say it again: if you choose Option 1, you will earn a sure amount of money. But, if you choose Option 2, the amount of money you earn depends on this spinning wheel. And, it depends on whether this arrow lands on white or black [DEMONSTRATE BY MOVING THE SPIN].

This is what will happen if you choose <u>Option 2</u>:

One of you will come up and spin the arrow. If your arrow lands on white, you will earn nothing. If the arrow lands on black, you will earn RWF1200. DEMONSTRATE BY SPINNING THE WHEEL: the arrow has landed on [white, black], this means you would have earned [nothing, RWF 1200].

[SPINNING WHEEL REPRESENTING 30%]: Now as you can see, the white area is much bigger than the black area. So, this means that if you choose Option 2 and spin the wheel, there is a bigger chance of the arrow landing on white than there is of it landing on black. So, there is a bigger chance of you earning nothing than there is of you earning RWF 1200.

OK, let's look at the POSTER:

<u>In row 1:</u>

If you choose Option 1 [POINT TO OPTION 1 ON POSTER], you will earn RWF 160 for sure. You won't have to spin the arrow.

But, if you choose Option 2 [POINT TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn RWF 1200.

<u>In row 2:</u>

If you choose Option 1 [POINT TO OPTION 1 ON POSTER], you will earn RWF 180 for sure. You won't have to spin the arrow.

If you choose Option 2 [POINT TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn RWF 1200.

In row 3:

If you choose Option 1 [POINT TO OPTION 1 ON POSTER], you will earn RWF 200 for sure. You won't have to spin the arrow.

If you choose Option 2 [POINT TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn RWF 1200.

In row 10:

If you choose Option 1 [POINT TO OPTION 1 ON POSTER], you will earn RWF 340 for sure. You won't have to spin the arrow.

If you choose Option 2 [POINT TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn RWF 1200.

In row 15:

If you choose Option 1 [POINT TO OPTION 1 ON POSTER], you will earn RWF 440 for sure. You won't have to spin the arrow.

If you choose Option 2 [POINT TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn RWF 1200.

In row 20:

If you choose Option 1 [POINT TO OPTION 1 ON POSTER], you will earn RWF 540 for sure. You won't have to spin the arrow.

If you choose Option 2 [POINT TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn RWF 1200.

In row 22:

If you choose Option 1 [POINT TO OPTION 1 ON POSTER], you will earn RWF 580 for sure. You won't have to spin the arrow.

If you choose Option 2 [POINT TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn RWF 1200.

[IMPORTANT TO STRESS:]

OK, now this is very important! As you can see, the sure payoff you earn from Option 1 **increases** as you go down the rows. It has increased from RWF 160 in row 1 to RWF 580 in row 22 [POINT TO THE POSTER AS YOU SAY THIS].

But, the payoff to Option 2 **stays the same throughout the whole game!** In the first row, if you choose Option 2, you will **either** earn nothing if the arrow lands on white, or you will earn RWF 1200 if the arrow lands on black. In row 10, if you choose Option 2, you will **either** earn nothing if the arrow lands on white, or you will earn RWF 1200 if the arrow lands on black. In row 22, if you choose Option 2, you will **either** earn nothing if the arrow lands on white, or RWF 1200 if the arrow lands on black. [POINT DOWN POSTER WHILE SAYING THIS]

Let's do an example: [**NOW, YOU DRAW ON THE POSTER]**

In row 1, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn F160 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn RWF 1200. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

In row 2, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn RWF 180 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn RWF 1200. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

In row 3, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn RWF 200 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn RWF 1200. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

In row 4, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn RWF 220 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn RWF

1200. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].
In row 5, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn RWF 240 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn RWF 1200. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

Let's pretend you choose Option 2 all the way down to row 8. ***TICK UP TO ROW 8.***

Now, in row 9, you choose Option 1. [NOW MAKE A TICK IN THE LEFT COLUMN]

So, in row 9, you **switch to** Option 1. Remember that you always get a sure return with Option 1, so you will have a sure payoff of RWF 320. So, at row 9, you prefer the sure payoff of RWF 320 you get with Option 1 as opposed to taking a chance with Option 2 on where the arrow lands and earning either RWF 0 or RWF 1200. Then when we go to row 10, you will now earn RWF 340 if you pick Option 1 – the sure payoff is now even higher. And in row 11 you will earn even more with Option 1 – you will earn RWF 360. In row 12, Option 1 will give you even more money – you will get a sure payoff of RWF 380. So, your earnings from Option 1 are getting higher and higher as you go down the rows. But with Option 2, you always have the **same chance** of earning F0 or RWF 1200 **depending** on where the arrow lands.

So going back to your choice, if you liked Option 1 more in row 9 when you had a sure payoff of RWF 320, then you would also like Option 1 in rows 10, 11, 12, 13, 14, all the way to 22 as the payoffs get more and more.

<u>So **(this is VERY important)** once you pick Option 1, you will pick Option 1 for the rest of the rows!</u> [REPEAT THIS POINT A FEW TIMES]

[*Note: Important they know that once they pick Option 1, they must stay with Option 1 for the rest of the rows. Once they have filled in the practice sheet, we will go around and check that respondents have not made a mistake.*]

[IMPORTANT] Remember you are not going to be paid for all 22 choices made, so let's try how the payment will work in this game. [INVITE SOMEONE TO COME DRAW FROM THE BAG HAVING THE 22 BALLS]. Let's say ball number 18 is picked. So for all those who choose Option 1 will get the sure amount and for those who choose option 2 one of you will come to spin the wheel [INVITE ONE PERSON TO SPIN THE WHEEL] based on the colour it lands on, that becomes the earning for option 2 choice. [REPEAT THIS A FEW TIMES]

After we know which row we are playing for money, one of you will then come up and spin the arrow.

Does anyone have any questions before we start?

Because this is the first game, we are going to first do a practice round. So, this round won't count for money – but is just to make sure that you understand how the game works.

Ok, let's start. Please write the number we gave you at the start of the experiment on the sheet where it says experiment number [POINT TO WHERE THEY MUST PUT THEIR NUMBER].

For **each** row in the sheet in front of you, indicate whether you would like to choose Option 1 and receive a sure amount of money, or whether you would like to choose Option 2 and spin the arrow.

[GO AROUND TO CHECK DECISIONS OF PARTICIPANTS TO MAKE SURE IT CORRESPONDS WITH THE ABOVE INSTRUCTIONS]

[COLLECT THE PRACTICE SHEETS]

Ok, now we are going to play the game for real. Please write the number we gave you at the start of the experiment on the sheet where it says experiment number [POINT TO WHERE THEY MUST PUT THEIR NUMBER].

For **each** row in the sheet in front of you, indicate whether you would like to choose Option 1 and receive a sure amount of money, or whether you would like to choose Option 2 and spin the arrow".

The End.

Chapter 5: The power of nudging: Using feedback, competition and responsibility assignment to save electricity in a non-residential setting

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Abstract

Can behavioural interventions achieve energy savings in non-residential settings where users do not face the financial consequences of their behaviour? Using high-frequency data, our paper addresses this question by leveraging social comparison and responsibility assignment aimed at reducing electricity consumption in a large provincial government office building with 24 floors, a total of 1008 occupants. Floors were divided into two treatments arms. Both treatment groups received regular emails encouraging recipients to turn off appliances and lights before leaving the office, as well as weekly ranked energy consumption results by floors. Additionally, weekly "energy advocates" were assigned to each floor in treatment group two. Findings show that floors that participated only in the inter-floor competitions reduced energy consumption by 9%, while those additionally assigned floor-wise "energy advocates" reduced energy consumption by 14%. A further investigation of the sustainability of our results shows that, although the intervention effect we find in the first month of the post-intervention period attenuates monthly, by the fifth month, these initial declines in the intervention effect completely dies out. Our five months of intervention reveal that financial consequences are not necessarily a pre-requisite for reducing energy consumption when using behavioural nudges.

Keywords; Energy Conservation, Behavioural Nudges, Social Competition, Randomized Control Trials

1. Introduction

Commercial buildings are significant consumers of energy and account for a substantial amount of the world's greenhouse gas emissions. For large economies such as the United States, United Kingdom and Europe, commercial buildings account for 18% and 11%[17] of total energy respectively (Perez-Lombard, Ortiz & Pout, 2008). In South Africa, the commercial sector accounts for 15% of energy use (Eskom, 2017).

Historically, technological modification has been the most common intervention used to address the high energy demand in the commercial sector. Among these technological solutions have been the installation of energy-efficient appliances, proper insulation, sensors and intelligent controls. Previous studies on the residential sector have also identified behavioural interventions as a cost-effective way of reducing energy consumption (Kandul, Lang & Lanz 2020; Myers & Souza, 2019; Alcott & Kessler, 2019; Torres & Carlsson, 2018; Sudarshan, 2017; Jessoe, Lade et al., 2017; Allcott & Rogers 2014; Costa & Kahn, 2013). Yet, the application of behavioural interventions in the non-residential sector is limited.

Unlike the residential sector, implementing behavioural interventions in non-residential or office environments poses additional challenges. Employees do not have any direct financial incentives to reduce energy consumption at work. Even when the will to conserve energy exist, they are unaware of their energy use due to the absence of utility bills. Also, while the average residential household has four members, office floors can have between 50-200 individuals, making coordination much more challenging. Despite these challenges, the high levels of wastage in the work environment cannot be neglected. Masoso and Grobler (2009) documented employees attitudes towards energy use in six commercial buildings located in Botswana and South Africa. Findings from their study show that office buildings used more energy (56%) during non-working hours compared to working hours (44%). Mahdavi et al., (2008) also show that during working hours, workers on the average spend 50% of the time away from their desks without turning off equipment. This suggests the need to implement behavioural interventions in the office environment, although workers are not financially liable for their energy use.

[17] Both Europe and United Kingdom have the same level energy consumption

The few studies that have tackled the subject have been limited to buildings in the United States (Onarghi et al., 2018; Gulbinas & Taylor, 2014; Carrico & Riemer, 2011) except for Brown et al. (2013) which was conducted in the OECD building in France. Our paper directly contributes to the limited literature on the applications of behavioural interventions in the non-residential sector by examining the effectiveness of nudges for energy conservation in a single large provincial office building in the City of Cape Town. The City of Cape Town is in the Western Cape province of South Africa – the country's second-largest economy. The city accounts for more than half of the provincial energy consumption with the commercial sector accounting for 44% of the total energy used (Cape Town State of Energy, 2015). Given the numerous energy pressures on the city due to rapid urbanization and energy insecurity resulting in periodic "load-shedding", examining the energy conservation potential of behavioural nudges in such a context will be beneficial to policymakers while informing future global studies.

Further, studies examining the effect of behavioural interventions on energy consumption in the workplace focused on social comparison feedback and thermostat default setting, with interventions lasting only for a few weeks. We expand the interventions used in this study by assigning each floor with a peer leader in the form of an "energy advocates" (responsibility assignment) with interventions conducted over five months. The study therefore additionally contributes to the literature by introducing a new behavioural intentions where we combine reminders and and responsibility assignment.

Prior to the start of our study, smart meters were installed on all floors of the building to track the daily (30 minutes interval) electricity consumption of each floor. Floors were assigned to two treatment arms and a control group, with seven floors in each group. Floors in the first treatment arm received repeated general energy conservation information emails and participated in weekly inter-floor competitions where floor occupants received ranked electricity consumption results. Meanwhile, floors in the second treatment arm received both energy conservation information, participated in weekly inter-floor competitions and were also assigned a weekly floor "energy advocate".

Findings show significant declines in energy use after the rollout of interventions, with our preferred estimates indicating a 9% reduction due to the first treatment, and a 14% reduction for the second treatment. A follow-up interview with employees revealed that most major behaviour changes occurred at the close of the day as part of a conscious initiative by occupants to switch of appliances after work. A further investigation of the sustainability of our results shows that, although the intervention effect we find in the first month of the post-intervention period attenuates monthly, by the fifth month (October 2016), these initial declines in the intervention effect completely dies out. Our findings, consistent with previous studies, reveal the potency of nudging employees to achieve energy use reductions in office spaces. We conclude that financial consequences are not necessarily a pre-requisite for reducing energy consumption when using behavioural nudges.

The paper proceeds as follows. Section 2 review related literature on the applications of behavioural interventions. Section 3 presents the experimental overview and design of the study. We present data and estimation techniques in Section 4. Section 5 discusses the results of our study. Section 6 concludes.

2. Related literature

Policymakers seeking to dampen the demand for energy typically use traditional policy instruments such as price interventions (raising tariffs, taxes on electricity, and peak-load pricing to affect the timing of consumption). In the last two decades, studies within the residential sector have shown the cost-effective nature of using behavioural interventions to achieve energy conservation. Typical interventions used in the literature include the provision of educational information, real-time feedback, social comparison feedbacks, peer leaders and default settings (Kandul et al., 2020; Alcott & Roger, 2014, Costa & Kahn, 2013; Alcott 2011; Alcott & Mullainathan, 2010; Schultz, Nolan, Cialdini, Goldstein, & Griskevicius, 2007).

Asensio and Delmas (2015) compare the effectiveness of price and behavioural interventions. Their results show that feedbacks are a more effective way of reducing energy use. A review by Fisher (2008) also shows that implementing feedback interventions can lead to energy reductions with savings ranging from 1.1% to 20% depending on the type of feedback (indirect or direct feedback). Among the feedback family, social comparisons where energy consumptions of occupants are compared to peers or neighbours is shown to be the most effective. Allcott and Mullainathan (2010) reveal that households can reduce their energy consumption by 2% after receiving letters containing social comparison feedback. In a study involving school children, Agarwal et al. (2017) also demonstrate the effectiveness of peer comparison. They show that children were able to influence their families to conserve energy. More recently, Kandul et al. (2020) provided households with social comparison feedback on indoor heating temperature relative to others. Their intervention led to 0.28 degrees Celsius reduction in indoor temperature. While evidence shows that behavioural interventions have been largely successful, there are also discussions about the long-run impacts and welfare implications of such results. Ferraro, Miranda and Price (2011) examined the persistence of treatment effects associated with norm-based instruments by running field experiments within residential households to reduce water demand. They conclude that social comparisons have a long-run impact on water demand.

The non-residential sector is yet to fully benefit from the extensive literature on the effect of a behavioural intervention to reduce energy consumption. Ornaghi et al. (2018) using different types of information framing examined how behavioural interventions can be used to reduce energy consumption in university buildings. Their interventions aimed at asking participants to close their windows after working hours. Results from their study revealed that the percentage of windows left open reduced by half for treatment groups compared to control groups. Similary, Dixon et al. (2015) show that university buildings can reduce energy consumption by 6.5% through social comparison feedback. Gulbinas and Taylor (2014) find that comparing employees historical and current energy consumption with peers can yield a significant reduction in energy use. Based on a group level feedback and peer education interventions, Carrico and Riemer (2011) show that energy consumption at the workplace can be reduced by 7% when using feedbacks and 4 % when only peer education is used. Brown et al. (2013) also addressed the question of "how much does changing the default setting in office thermostats affect the chosen settings in offices?" They find that an effective way to prevent overheating is to reduce the thermostat settings to a default mode by 1-degree celsius.

Although evidence shows that studies on the non-residential sector are gradually being expanded, most of the action has been limited to developed countries. Also, to date, no existing studies have examined the effectiveness of responsibility assignment in the office context. Our paper contributes to the limited literature on implementing behavioural interventions in the office context by testing the effect of social competition and responsibility assignment in a large provincial building in South Africa.

3. Experimental overview

3.1 Study building

The study was conducted in a 24-floor provincial office building located on 4th Dorp street in the City of Cape Town, South Africa (see Figure 1) where four provincial government departments are headquartered namely; Department of Health, Department of the Premier, Department of Transport and Public Works and Department of Treasury. At the time of the study,1008 employees were working in the building. The regular working hours for employees start from 8 am to 4 pm. After these hours the building is close to the public. The building had two installed smart meters on each floor which provided real-time energy consumption data every 30 minutes, making it possible for randomization to occur at the floor level. All storeys operated an open floor policy which housed several workstations. Apart from lighting, typical appliances available on each floor were, computers, printers, photocopy/fax machines, air conditioners, projectors, space heaters, fridge, water boilers, microwaves and electronic chargers.

Figure 1: 4 Dorp Street Office Building, Western Cape Government, Cape Town

3.2 Intervention

Before the commencement of the study, we interacted with employees in the building through interviews, focus groups, and site visits to enable us to understand major setbacks impeding energy-efficient behaviour in the building. This enabled us to design interventions that aligned with specific challenges faced by employees. Our interactions revealed six major bottlenecks impeding energy-efficient behaviours. The six bottlenecks include 1. *Diffused Responsibility*: Employees were often unsure about whose responsibility it was to turn off appliances and lights at the close of the day. 2. *Moral Justification*: Employees considered public service as their sole contribution to the environment, rather than reducing personal energy consumption in the office space. 3. *Unit Confusion*: It was unclear to employees how small individual behaviours can translate into energy efficiency. 4. *Limited Attention*: Employees sometimes forgot to turn off devices. 5. *Identity*: While at work, employees do not think about translating their energy-efficient behaviours at home to the office. 6. *Social Norms*: Employees do not know how much energy their colleagues use and therefore have no reference point for how energy efficient they are.

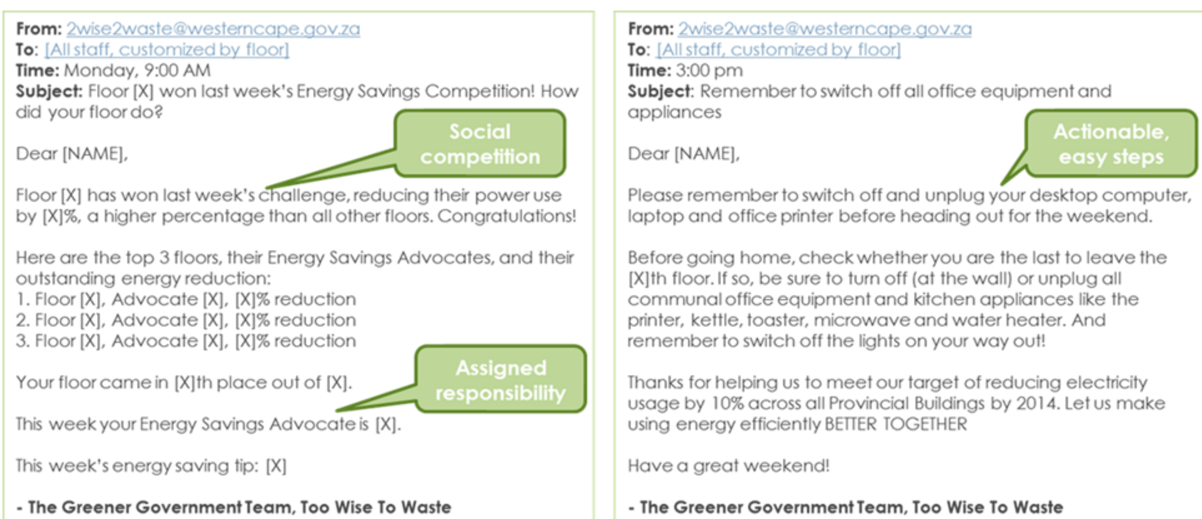
Subsequently, the study designed various intervention components to mitigate the observed bottlenecks by using an automated email system to test the effect of different isolated messages that incorporate the following intervention components: 1. Providing information – Giving easy-to-understand information regarding energy use that employees can easily translate into action and also place specific behaviours into a context familiar to them. 2. Social Competition – A program that compares employees' energy use with other floors to foster a sense of competition and provide regular feedback. 3. Responsibility assignment – where one person is chosen every week as a peer leader to champion energy-saving initiatives on each floor. For example, one employee is randomly singled out on a weekly basis as the "energy champion" for specific floors. This employee is subsequently given specific tasks throughout the week (e.g., "turn off lights at the end of the day", "turn off the water heater" and "unplug the printer").

3.2 Design

Out of the 24 floors in the 4th Dorp street office building, the study was implemented on only 21 floors. The three exempted floors include the ground floor, which served as a security checkpoint and access area for visitors while the other two floors were empty due to renovations at the start of the experiment. The 21 floors were randomly assigned to a control group and two treatment groups with seven floors in each group based on specific feedbacks as follows:

- *Treatment I group –315 employees*: Employees on floors assigned to this group received regular actionable steps emails (reminders to turn off lights every Friday, information on how to conserve electricity every first Monday of the month, kitchen tips every third Wednesday of the month) and weekly ranked inter-floor competition energy consumption feedback.
- *Treatment II group – 281 employees*: Employees in this group received the same emails as floors in the first treatment group. Additionally, each floor in this group was assigned a peer leader serving as an energy advocate for a week.
- *Control group (305 employees)*: Members of floors assigned to this group did not receive any form of emails or feedback on their energy use.

Figure 2 shows sample emails received by employees whose floors were assigned to treatment groups. Additional emails on actionable steps to reduce energy consumption are presented in *Appendix A.*


From: 2wise2waste@westerncape.gov.za
To: [All staff, customized by floor]
Time: Monday, 9:00 AM
Subject: Floor [X] won last week's Energy Savings Competition! How did your floor do?

Dear [NAME],

Floor [X] has won last week's challenge, reducing their power use by [X]%, a higher percentage than all other floors. Congratulations!

Here are the top 3 floors, their Energy Savings Advocates, and their outstanding energy reduction:
1. Floor [X], Advocate [X], [X]% reduction
2. Floor [X], Advocate [X], [X]% reduction
3. Floor [X], Advocate [X], [X]% reduction

Your floor came in [X]th place out of [X].

This week your Energy Savings Advocate is [X].

This week's energy saving tip: [X]

- The Greener Government Team, Too Wise To Waste

From: 2wise2waste@westerncape.gov.za
To: [All staff, customized by floor]
Time: 3:00 pm
Subject: Remember to switch off all office equipment and appliances

Dear [NAME],

Please remember to switch off and unplug your desktop computer, laptop and office printer before heading out for the weekend.

Before going home, check whether you are the last to leave the [X]th floor. If so, be sure to turn off (at the wall) or unplug all communal office equipment and kitchen appliances like the printer, kettle, toaster, microwave and water heater. And remember to switch off the lights on your way out!

Thanks for helping us to meet our target of reducing electricity usage by 10% across all Provincial Buildings by 2014. Let us make using energy efficiently BETTER TOGETHER

Have a great weekend!

- The Greener Government Team, Too Wise To Waste

Fig.1. Emails depicting social comparison, responsibility assignment and actionable steps

The study was conducted within one year, starting from June 2015. This includes the pre-intervention period, which lasted for five months (June – October 2015). We spent November 2015 to May 2016 fine-tuning and monitoring the automated email system. During this period, occupants of both treatment I and II floors only received actionable steps on ways to reduce electricity consumption. The full roll-out of our study referred to here as the "full fidelity period" (June-October 2016) lasted for five months. During this time Treatment, I floors received general information and weekly ranked inter-floor competition results while Treatment II floors received general information, weekly ranked inter-floor competition results and assignment of a weekly floor energy advocate which lasted for five months.

4. Data and estimation procedure

The experimental set up provided the study with a panel of energy use data for all 21 floors at a high daily frequency interval of 30 minutes. Table 2 presents pre-intervention checks for the experiment. Electricity usage for floors in the 4 Dorp office building ranges from 2.49 to 2.59 kilowatts (kW) for every thirty minutes on the average. This implies the daily electricity consumption per floor ranges from 119.52– 124.32 kWh. Table 2 shows no significant energy use difference between control and treatment floors, as depicted in column 5.

We also present a balance test for the number of people occupying these floors (headcount). Results show that the number of floor occupants during the baseline period is balanced between the control and treatment floors. Given that the number of people occupying a floor can largely influence the amount of electricity a floor will use, we include the headcount variable as a covariate in our subsequent analysis.

Table 1: Pre-intervention Randomization Checks

Variables	Control	Treatment 1	Treatment 2	$\overline{kW_o}$ (kW/30mins)	$kW_0^T - kW_0^c$ Difference
Energy Consumption	2.49	2.59	---	2.54	0.10
	(0.34)	(0.34)		(0.24)	(0.48)
		-	2.49	2.49	-0.003
			(0.38)	(0.26)	(0.52)
Headcount	41.34	42.96	---	42.15	1.61
	(5.96)	(5.96)		(4.21)	(8.43)
		-	34.94	38.36	-6.41
			(6.61)	(4.49)	(9.01)

Standard errors in parentheses, clustered at floor level. Pre-intervention period: June – October 2015

4.1 Estimation

The difference-in-difference (DiD) approach is adopted to evaluate the impact of routine behavioural interventions on energy consumption. This is done by comparing electricity consumption levels of Treatment I and II floors to control floors. The equation of interest is specified below:

$$kw_{it} = \alpha_i + \delta_0 A_{it} + +\delta_1 T_{it}^1 + \delta_2 T_{it}^2 + \gamma_1 T_{it}^1 A_{it} + \gamma_2 T_{it}^2 A_{it} + X_{it}'\beta + \varepsilon_{it} \quad (1)$$

Where kw_{it} is the amount of electricity consumed by individual meters *i* on each floor at time *t* in kilowatts/30minutes, $T^1=1$ if meter readings are from Treatment I floors at time *t*, $T^2=1$ if meter readings are from Treatment II floors at time *t*. $A=1$ is the post-intervention indicator, δ_0 is the time trend common to control and treatment floors, δ_1 and δ_2 are Treatment I and II specific effects which account for average time-invariant differences between the treatment and control floors, γ_1 measures the average Treatment I effect, γ_2 measures the average Treatment II effect, X_{it} represent the covariates: headcount and monthly fixed effects. ε_{it} is the error term.

The average treatment effect which is the difference-in-difference estimate, therefore, compares the difference between the treatment floors before and after they received intervention emails and the difference between the before-and-after outcomes of the control floors which did not receive the intervention emails but shared similar consumption characteristics (Khandker et al., 2010). The average impact of social competition and assigned responsibility is estimated as follows:

$$DD_1 = E[kw_{i1}^{T1} - kw_{i0}^{T1}] - \left[kw_{i1}^{C} - kw_{i0}^{C}\right] \quad (2)$$

$$DD_2 = E[kw_{i1}^{T2} - kw_{i0}^{T2}] - \left[kw_{i1}^{C} - kw_{i0}^{C}\right] \quad (3)$$

To account for the unobserved heterogeneity, we use the standard panel fixed effect estimator with robust standard errors. These standard errors are clustered at the meter level, given that electricity consumption data is obtained from two single meters installed on each floor.

5. Results and discussion

Table 2 presents estimation results and their corresponding aggregated percentage reductions for the intervention period for different configurations of monthly dummies[18]. Our primary estimation is column two, which includes the monthly dummies. Even though we validated 21 floors during the pre-intervention period of June 2015 – October 2015, at the time of starting our interventions, one of the floors had a malfunctioning meter and was subsequently dropped from the study, explaining why our estimations report on only 20 floors.

Table 2: Fixed effect regression estimates for energy consumption.

Variables	(1) kW/30mins	(2) kW/30mins	(3) kW/30mins
	(0.0576)	(0.0777)	(0.125)
Treatment 1 X Post	**-0.116**	**-0.119**	**-0.215***
	(0.168)	(0.169)	(0.123)
Treatment 2 X Post	**-0.324***	**-0.349***	**-0.351****
	(0.180)	(0.179)	(0.179)
headcount	0.0148***	0.0171***	0.0173***
	(0.00458)	(0.00470)	(0.00472)
Constant	1.928***	1.846***	1.799***
	(0.190)	(0.190)	(0.184)
Monthly Fixed effects	No	Yes	Yes
Observations	528,928	528,928	502,030
R-squared	0.010	0.014	0.017
F(P-Value)	0.00	0.00	0.00
Control	185,521	185,521	185,521
Treatment1	182,840	182,840	155,942
Treatment 2	160,567	160,567	160,567
Number of floors	20	20	19
Number of meters	40	40	38
Percentage Reduction:			
Treatment 1		5%	9%
Treatment 2		14%	14%

Fixed Effects Regressions. Robust standard errors in parentheses clustered at meter level *** p<0.01, ** p<0.05, * p<0.1. Pre-intervention period: June – October 2015

[18] As a robustness check, we also estimate a pooled panel OLS regressions which includes both monthly and floor fixed effects using the "xtreg" command in Stata. Results are consistent with the presented results in Table 3 as shown in Appendix B.

Results in Column (2) show that for every 30 minutes, meters on Treatment II floors consume about 0.349 kilowatts less than control floors. From the average treatment effect reported, we further calculate the aggregated percentage reduction for the intervention period using the pre-intervention average electricity consumption values. This implies a 14% reduction (at 10% level of significance) for Treatment II floors (general energy conservation information + inter-floor competition with weekly feedback + advocates). However, the reduction in electricity consumption for Treatment I floors in Column (2) appears to be insignificant.

In column 3, we present regression results without floor 22. This floor was allocated to the Treatment group one. However, meter readings indicated that unlike other floors, floor 22 reported increases in energy consumption during the intervention period. Further investigation through site visits and qualitative interviews with floor occupants show that an additional water heater, an appliance that consumes a significant amount of power, was installed on this floor during the intervention period while no corresponding equipment installations took place on other floors. We, therefore, show the regression results in column 3 by excluding floor 22 from the analysis. Given this preferred model specification, floors assigned to treatment II resulted in the same level of 14% reduction in electricity consumption but now at a 5% significance level. Further, Treatment I floor who received only general energy conservation information and inter-floor competition with weekly feedback subsequently show a reduction of 9%[19] (at a 10% significance level).

Previous studies have shown the possibility of conserving energy in buildings using comparative feedback. For instance, Carrico and Riemer (2011) examined the effect of group-level feedback on energy conservation for university buildings in the United States. They found a 7% reduction in energy use. Dixon et al. (2015) in a similar context of University buildings also find that comparative feedback compared to individual feedback, generate a higher energy conservation rate of 6.5%. Our finding that behavioural interventions can yield significant reductions in the non-residential setting is consistent with existing studies such as Onargi et al. (2018), Dixon et al. (2015), Gulbinas &Taylor (2014) and Carrico and Remier (2011).

[19] Energy consumption trends for all floors are presented in Appendix C

5.1 Attenuation effects

To investigate the sustainability of our results over the intervention period, we systematically run regressions monthly by adding on to the initial start month (June 2016) when both treatments were running. Table 3 shows an initial decline in the percentage reduction for the combined intervention effect of the provision of general energy conservation information, inter-floor competition and assignment of floor energy advocate as we add more months to the estimation, with the treatment effect becoming less significant as more time elapsed (from 5% to a 10% level of significance). Results show that on the average, Treatment II floors reduced electricity consumption by about 0.36 - 0.49 kW for every 30 minutes depending on the period of estimation. Specifically, in Column 1 for June, Treatment II floors recorded a 0.63kW decline in electricity consumption relative to control floors. Using pre-intervention average consumption values, this indicates a 28% reduction.

Interestingly, the rate at which the percentage reductions attenuate slows down as we continue to add more months. For instance, a movement from June to the period June-July (two months post-intervention) saw about a 7.1% reduction from the initial 28% reduction in electricity use achieved in June to 20.9% in June-July. Further, moving from the period June- July to the period June-August (three-month post-intervention) an attenuation effect of 5.6% is recorded, which is below the previously reported 7.1%. As we move to four months post-intervention period (June-September), the attenuation effect dropped to only about 1%. By the fifth month of the post-intervention period (June- October), these declines completely die out, as shown in figure 3. This implies that despite the decline in our treatment effect size in the initial months, the decline gradually fades out and eventually stabilizes by the fifth month of intervention, as seen in figure 3.

Table 3: Long-term effects of intervention

Variables	(1) June	(2) June- July	(3) June- August	(4) June- September
Treatment 1 X Post	-0.359	-0.314	-0.213	-0.167
	(0.259)	(0.197)	(0.188)	(0.172)
Treatment 2 X Post	**-0.630****	**-0.511****	**-0.371***	**-0.347***
	(0.294)	(0.224)	(0.219)	(0.192)
headcount	0.0250***	0.0184***	0.0159**	0.0163***
	(0.00804)	(0.00621)	(0.00615)	(0.00465)
Constant	1.579***	1.814***	1.894***	1.879***
	(0.282)	(0.228)	(0.230)	(0.186)
Monthly Fixed Effects	Yes	Yes	Yes	Yes
Observations	88,189	201,570	320,176	432,528
R-squared	0.015	0.011	0.010	0.011
Control	30,721	70,386	111,787	151,580
Treatment 1	30,725	70,223	111,716	149,715
Treatment 2	26,743	60,961	96,673	131,233
F (P-Value)	0.007	0.002	0.000	0.000
Number of Floors	20	20	20	20
Number of meters	40	40	40	40
Percentage Reduction:				
Treatment 2	28%	20.9%	15.3%	14.1%

Fixed Effects Regressions. Robust standard errors in parentheses clustered at meter level *** p<0.01, ** p<0.05, * p<0. Pre-intervention period for each estimation comparable with that of previous years. The percentage reduction for June- October 2016 is already established in Table 3 (main regression) to be 14

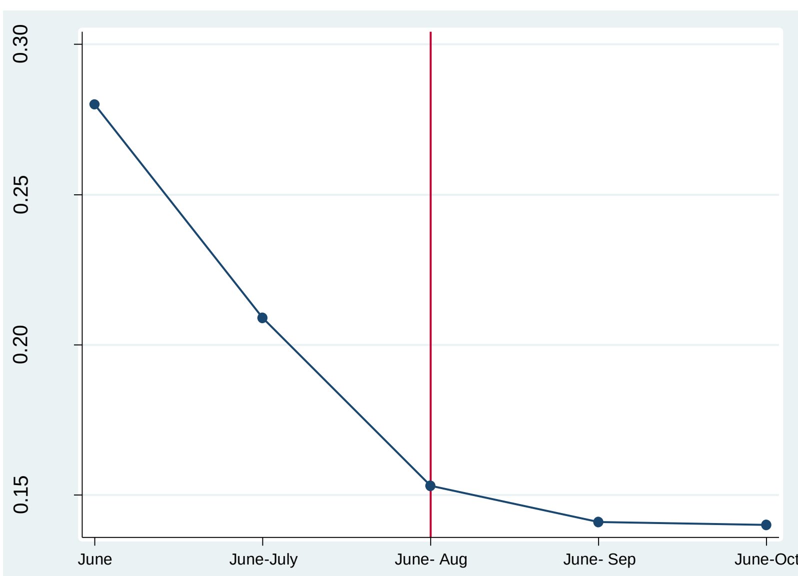


Figure 3: Attenuation effect of the intervention

The long-term effects of behavioural interventions in achieving conservation behaviours have often been raised. While several attempts have been made in the residential context to address this question for both energy and water use (e.g. Allcott & Rogers, 2014; Ferraro et al., 2011), the few existing studies on commercial buildings are yet to contribute to the discussion. Our results show that although the high initial conservation rate (28%) recorded in June systematically declined, the attenuation only lasted for first three months with effect sizes remaining constant in subsequent months at 14%. Thus, consistent with Allcott and Rogers (2014), it is likely to sustain conservation for additional months.

5.2 Intervention effect at different periods within the day

Table 4 presents the intervention effect for working and non-working hours. Results show that a significant amount of reduction in energy use occurred after working hours. No substantial reductions were recorded during working hours. Of the two feedback interventions implemented, floors assigned to treatment group two showed higher reductions (at 5% significance level) implying that the main way this group of floors seems to have worked better than Treatment I floors is by empowering the floor advocates to either turn off or ask people to turn off appliances at the end of the workday. Our results confirm the findings of Masoso and Gobler (2010) which show that high waste among office occupants in Botswana and South Africa is likely to occur after working hours and suggest the tendency to achieve significant reductions if behavioural interventions are applied.

Table 4: Energy conservation and working hours.

VARIABLES	(1) Working hours	(2) Non-working hours
Treatment1 X Post	-0.0650	-0.149
	(0.203)	(0.172)
Treatment 2 X Post	**-0.201**	**-0.440****
	(0.207)	(0.183)
headcount	0.0232***	0.0135***
	(0.00600)	(0.00434)
Constant	2.899***	1.206***
	(0.258)	(0.162)
Observations	198,836	330,092
R-squared	0.029	0.019
F (P-Value)	0.00	0.00
Control	69,704	115,817
Treatment 1	68,977	113,863
Treatment 2	60,155	100,412
Number of floors	20	20
Number of meters	40	40

Fixed Effects Regressions. Robust standard errors in parentheses clustered at meter level *** p<0.01, ** p<0.05, * p<0. Pre-intervention period: June – October 2015

To further understand the mechanism through which interventions led to the reduction in energy use, post-intervention qualitative interviews were conducted. The follow-up interviews revealed two major sets of findings. First, the impressive overall reductions in electricity use due to Treatment II (14%) mask considerable variation in how occupants on different floors responded to the intervention. While some employees on treatment floors worked as a team to reduce energy consumption, others were lukewarm towards the routine emails they received. Although the net effect of such behaviours resulted in an ultimate decline in electricity use for treatment floors, such differences in behaviour must be considered in the event of a scale-up.

Secondly, interviews with floor occupants confirmed our empirical results about effects being concentrated outside office hours, as major initiatives by floor advocates were implemented after working hours. For instance, unlike before the interventions, floor occupants became conscious of unplugging office equipment, heaters and lights at the end of the day.

6. Conclusion

Nonresidential buildings are significant consumers of energy. The effort to reduce energy consumption in this sector has led to the adoption of advanced technologies such as energy-efficient appliances, sensors and intelligent remotes. Despite these efforts, there still exists high energy waste in the workplace with a greater proportion of wastage occurring after working hours (Masoso & Gobler, 2010). This wastage is largely driven by workers attitudes towards energy conservation at the workplace.

Although behavioural interventions are often used in the residential setting to achieve energy reductions, workplace applications of such interventions are limited. In this paper, we ascertain the effect of behavioural interventions on energy consumption in a nonresidential context (office building) where occupants are not financially liable for their energy use. Two main interventions were used consisting of a range of emails which includes providing general conservation information, social comparison feedback and the assignment of responsibility to employees.

Our findings show that behavioural interventions are valuable and effective tools for conserving energy in the workplace. Although consistent with Ornarghi et al. (2018) and Cialdini and Goldstein (2008) result show that provision of social comparison feedback to workers can yield significant reductions in energy consumption, we find a higher effect when floors are additionally assigned weekly "energy advocates" to spearhead the energy conservation campaign. Results also show that the main way in which floors that received both the weekly ranked floor consumption feedback and the assigned weekly energy advocates (Treatment II) seems to have worked better than those who only received the social comparison feedback (Treatment I) was by empowering floor advocates to either turn off or ask people to turn off appliances at the end of business hours.

Several factors contribute to the effectiveness of behavioural interventions. For instance, simple and easy to understand interventions tailored to specific needs and behaviour is more effective (Steg &Vlek, 2009). This is clearly the case for our study as emails were designed based on initial discussions with employees on factors limiting them from reducing energy use at the workplace. Also, the emails provided to employees were simple, actionable steps which are found in the literature as a great source of conservation behaviours (Abrahamse et al.,2005). Given the reductions achieved during the intervention period, there is a potential for employers, in our case, the Western Cape Government to implement behavioural nudges in response to high energy consumption in the non-residential centre.

The sustainability and the efficacy of behavioural interventions over time; are major concerns (List & Metcalfe, 2014). Indeed, our month-by-month estimates show a gradual decline in the treatment effect, implying that energy reductions are likely to decline; however, this decline in energy reductions dwindles with time and stabilizes by the fourth month. Allcot and Rogers (2014) examined the persistent levels of treatment effect arising from social norms and other behavioural nudges by continuing interventions for two further years. They found that about two-thirds of the initial treatment effect remained and concluded that reduction in energy consumption declines somewhat over time but does not disappear. As we are unable to estimate the long-run effect of our interventions, research to establish the durability of the effects we find would be a critical input into efforts towards the sustainable and effective use of nudges in the commercial sector.

In the context of maintaining behavioural results from competition feedback, our interventions could be recalibrated or incentivized anew by awarding prizes, the announcement of advocates' names for winning floors on the screens in the foyer of the building and even media releases recognizing the "winners" to keep competing floors motivated. Given the duration and focus of the study, we did not experiment with such measures, but it is an avenue for future research. Overall, our study presents additional evidence which suggests there may be a large scope for implementing behavioural nudges in the non-residential sector.

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Appendix A: Sample Emails

1. Tips for Kitchen

From: 2wise2waste@westerncape.gov.za
To: [All staff, customized by floor]
Time:…

Subject: Reduce electricity use in the kitchen
Dear [name]
The kitchen is a room filled with electrical equipment. Help reduce your building's / floor's electricity use by following the following tips:

- Use hot water sparingly form the tap / hydro boil
- Boil the amount of hot water required
- Switch-off kitchen appliances not in use
- Close the fridge door as soon as possible after opening it, ensure the seal is intact, and that it closes properly.
- Very often fridges are unnecessarily set too cold. Turn the temperature setting dial up a notch.

The 2Wise2Waste Electricity Savings Project

Western Cape Government
BETTER TOGETHER.

2. Tips/ Information Provision

From: 2wise2waste@westerncape.gov.za

To: All staff, customized by floor
Time: Monday, 9:00 AM
Subject: How to save electricity on your floor
Dear [name]
Here are some easy things you can do to save electricity on your floor:
1. [Tip 1]
2. [Tip 2]
3. [Tip 3]

Good luck. Let us make saving electricity BETTER TOGETHER!
- The 2Wise2Waste Electricity Savings Project

Western Cape Government
BETTER TOGETHER.

3. Weekly Friday Afternoon Reminder

From: 2wise2waste@westerncape.gov.za
To: [All staff, customized by floor]
Subject: Remember to switch off all office equipment and appliances
Time: 3:00 pm

Dear [name]

Please remember to switch off your desktop computer, laptop and office printer before heading out for the weekend.

Before going home, check whether you are the last to leave the [X]th floor. If so, be sure to turn off (at the wall) all communal office equipment and kitchen appliances like the printer, kettle, toaster, microwave and water heater. And remember to switch off the lights on your way out!

Thanks for helping us to meet our target of reducing electricity usage by 10% across all Provincial Buildings by 2015. Let us make using electricity efficiently BETTER TOGETHER! Have a great weekend!

- The 2Wise2Waste Electricity Savings Project

Western Cape Government
BETTER TOGETHER.

Appendix B: Additional Estimates

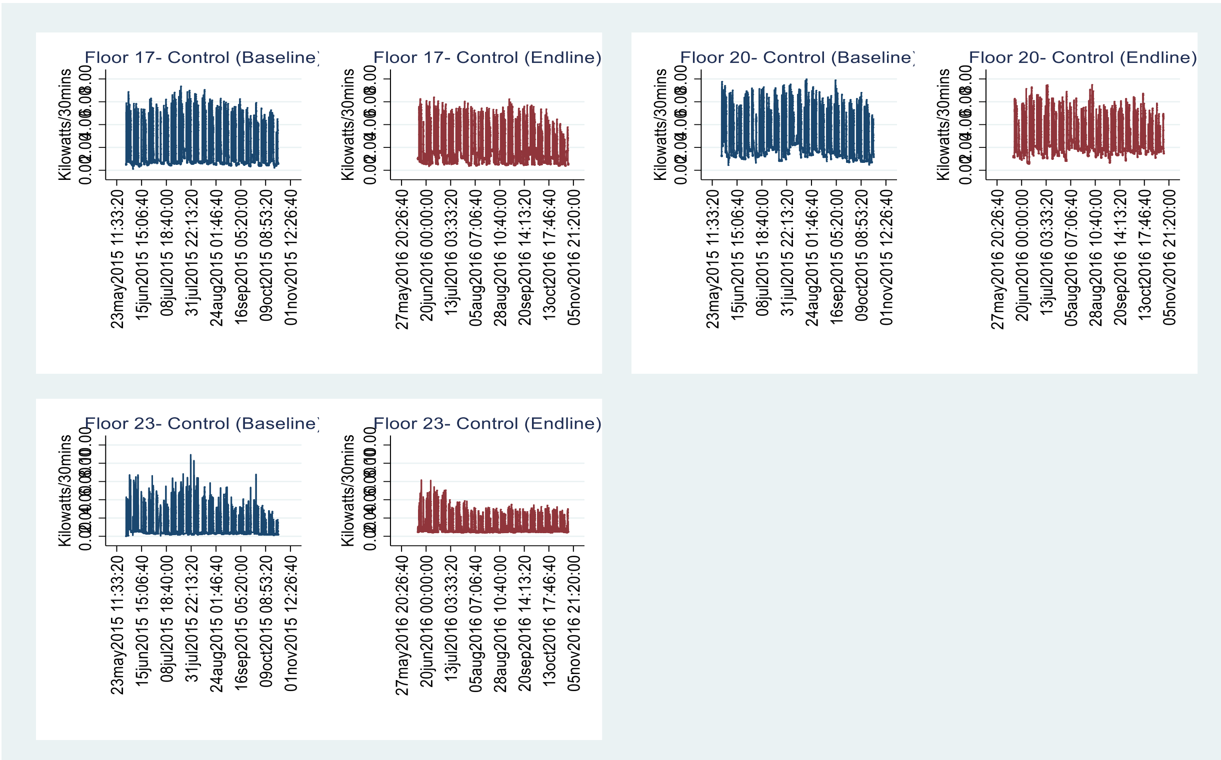
Table B.1.Treatment Effects of Interventions on Energy Consumption.

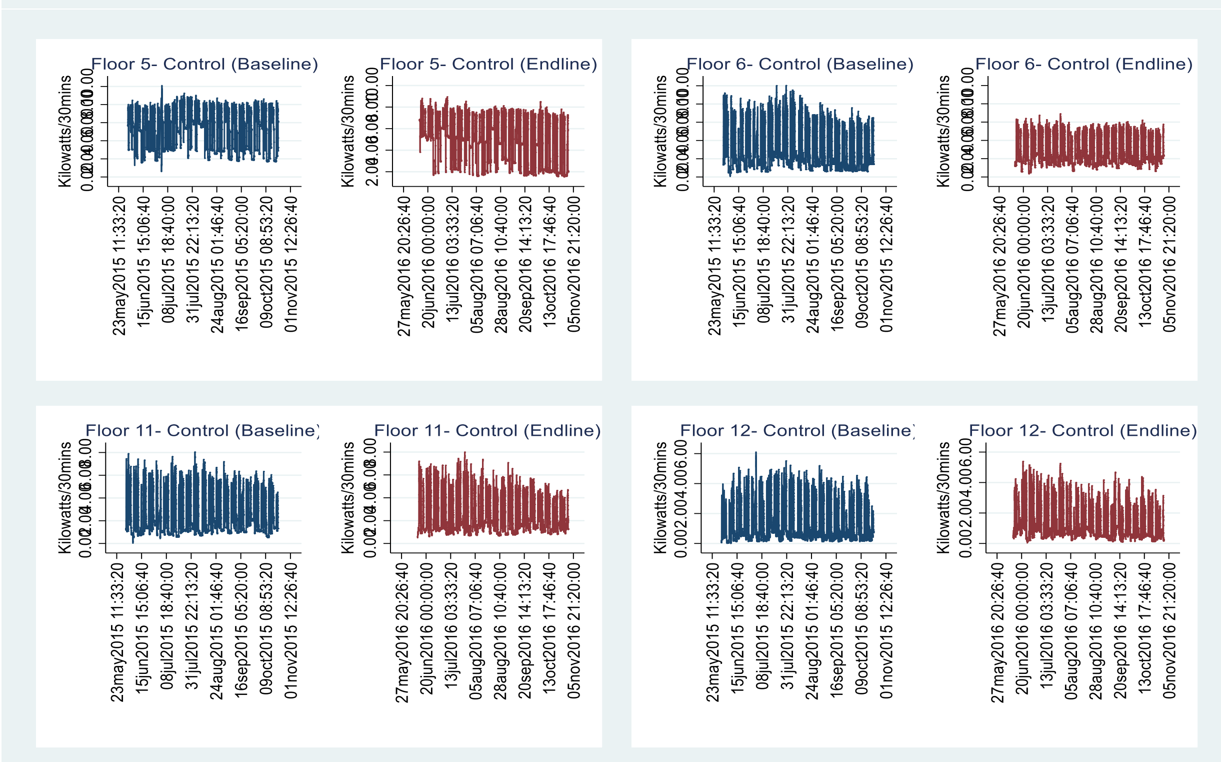
VARIABLES	(1)	(2)	(3)
Treatment 1	2.788***	2.746***	1.535
	(0.729)	(0.729)	(1.136)
Treatment 2	2.344***	2.384***	2.387***
	(0.626)	(0.626)	(0.627)
Post	-0.124**	-0.312***	-0.341***
	(0.0576)	(0.0843)	(0.0842)
Treatment 1 X Post	-0.116	-0.119	-0.215*
	(0.168)	(0.169)	(0.123)
Treatment 2 X Post	-0.324*	-0.349*	-0.351**
	(0.180)	(0.179)	(0.179)
headcount	0.0148***	0.0171***	0.0173***
	(0.00458)	(0.00470)	(0.00472)
Constant	0.371	0.270	0.269
	(0.458)	(0.454)	(0.455)
Observations	528,928	528,928	502,030
R2	0.166	0.169	0.155
Wald P-Value	0.00	0.00	0.00
Control	185,521	185,521	185,521
Treatment1	182,840	182,840	155,942
Treatment 2	160,567	160,567	160,567
Number of floors	20	20	19
Number of meters	40	40	38

Robust standard errors in parentheses clustered at meter level *** p<0.01, ** p<0.05, * p<0. Pre-intervention period: June – October 2015

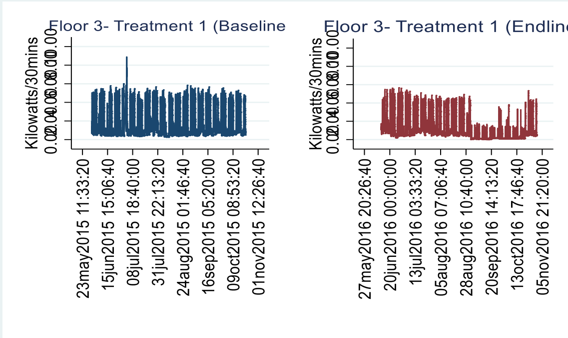
Appendix C: Energy consumption patterns for baseline and intervention period by floors

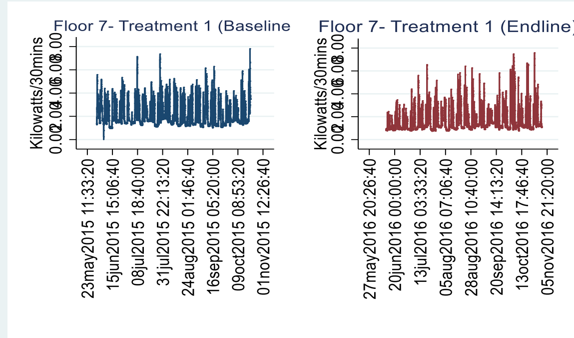
C1: Control Floors

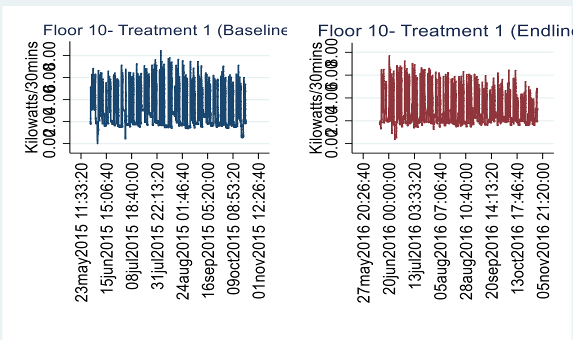


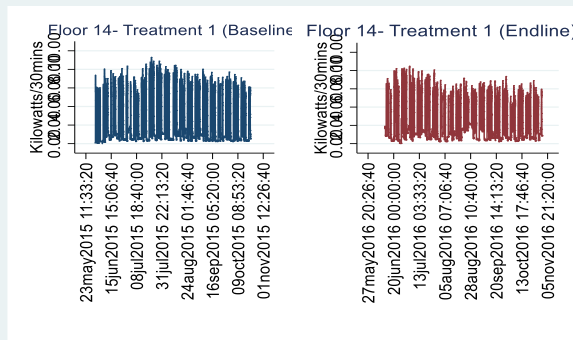


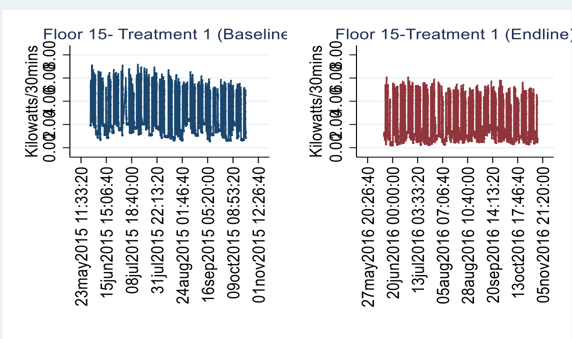
C2: Treatment 1 floors

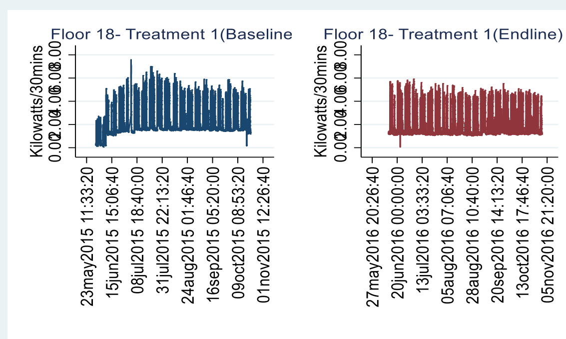


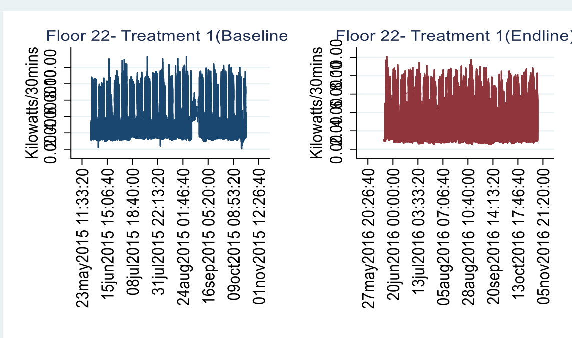




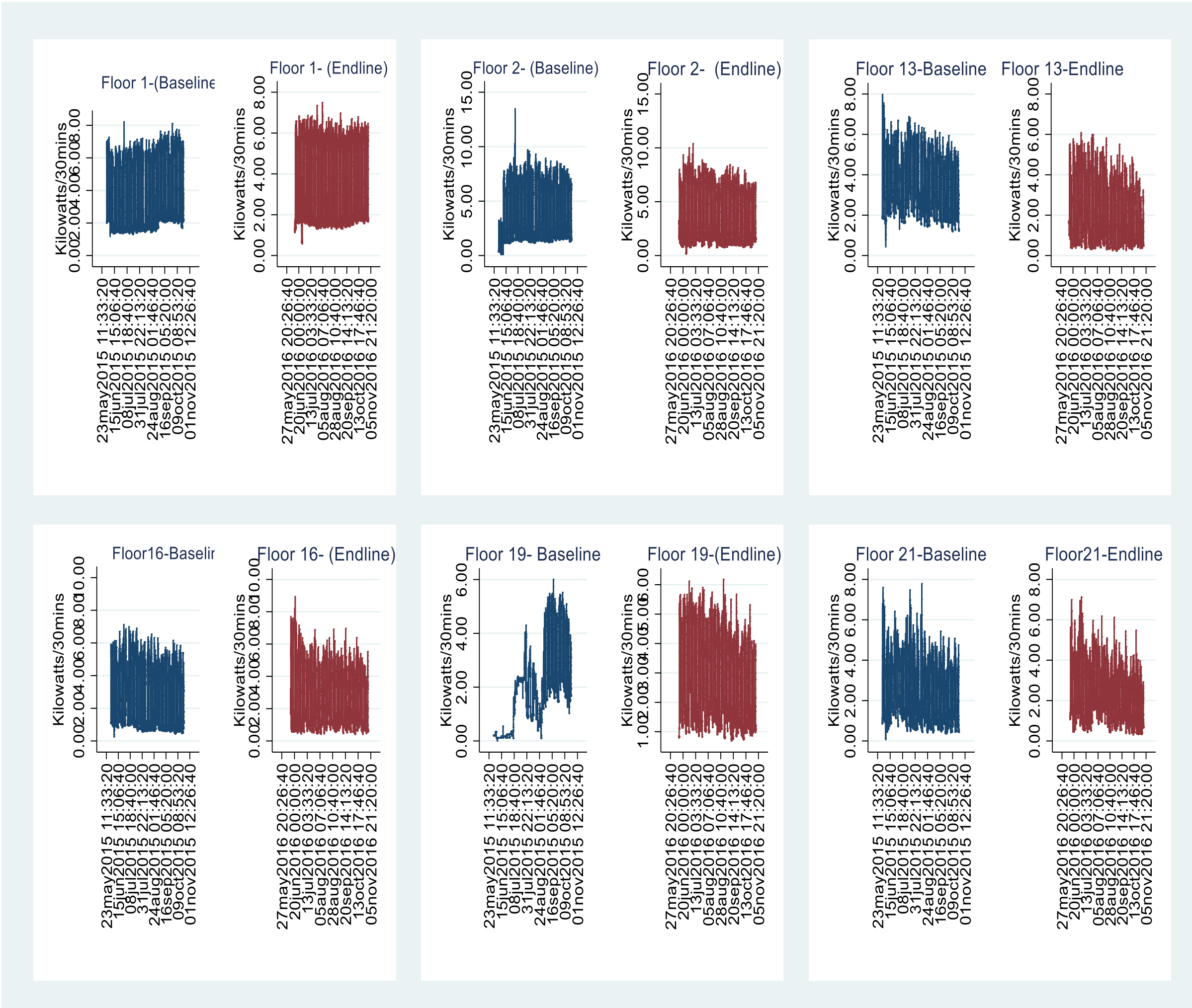








C3: Treatment Two floors



Chapter 6: Conclusion

In the context of addressing some of the complexities and challenges in the energy sector, this thesis leverage on empirical and experimental methods to investigate (i) households energy use patterns ; (ii) the role of competitiveness and risk-taking and its effects on the successfulness of energy businesses from the perspective of including more women in the energy sector and (iii) the effectiveness of behavioural nudges in promoting energy conservation in a non-residential sector. In this section, the results in reference to these thematic areas are outlined.

(i) Households energy use patterns

The first paper **'Energy Choices and Tenancy in Rwanda'** set the tone for two subsequent papers of the thesis by examining the energy use patterns of Rwanda. The paper contributes to the energy literature by investigating the role of tenancy and dwelling types in determining household cooking and lighting energy choices. To achieve this objective, the most recent household national survey conducted by the Rwandan National Institute of Statistics is used. Additionally, a bivariate probit model to attenuate potential endogeneity biases is adopted. The paper further analyses the heterogeneity in household energy choices using income, gender of household heads and the geographical location of households by tenure status and dwelling type.

Results show that renters compared to owner-occupants use charcoal and "other" fuels but less of fuelwood for cooking. We find no effect for compound house residents compared to private house residents. Results for lighting energy show that renters in comparison to homeowners use more electricity and "other" fuels but fewer oil lamps and torches. Household residing in compound houses tend to use more electricity but fewer torches and "other" lighting energy sources. In contrast with previous findings, our findings weakly supports the energy ladder hypothesis.

The findings reinforce the role of higher socio-economic status on energy choices. Low -income group homeowners in Rwanda who are usually based in the rural areas of the country are likely to move from dirty lighting and cooking fuels with improvement in income levels. Programs and policies targeted at eradicating poverty will, therefore, enhance cleaner household energy choices.

(ii) The role of competitiveness and risk-taking and its effects on the successfulness of energy businesses from the perspective of including more women in the energy sector

In addition to understanding the energy use patterns in Rwanda, women participation in the energy sector through entrepreneurship is of importance in promoting welfare opportunities and economic freedom. However, competitiveness and risk-taking abilities are discussed in the literature as important characteristics of entrepreneurship (Shane, Locke & Collins, 2003) that can influence their participation and success rates.

The renewable sector of Rwanda is also booming as the government of Rwanda is determined to promote private sector involvement, in its quest to accelerate rural electrification to off-grid communities in order to provide 100% energy access to its citizenry, women's participation in the private energy sector of Rwanda is low, as there are no gender policies governing the private energy sector (Parshotam & van der Westhuizen, 2018).

Against this background, the second and third papers of the thesis contribute to the energy literature by examining women's competitiveness and risk-taking abilities to provide key insights into including more women as entrepreneurs in the private energy sector of Rwanda.

Specifically, the second paper **'Competition and Gender in the Lab vs Field: Experiments with Off-Grid Renewable Energy Entrepreneurs in Rural Rwanda'** examines the gender differences in competitiveness and how this affects the business success of entrepreneurs operating renewable energy enterprises. This paper relies on a lab-in-the-field experiment using the standard experimental design of Niederle and Vesterlund (2007). The sample pool for the experiments are entrepreneurs operating off-grid solar recharging centres in Rwanda as part of an extensive RCT study to understand the role of gender quota business models.

Contrary to most previous studies, female entrepreneurs are not less likely to compete and are not outperformed by male entrepreneurs. This stands in contrast to several studies, mostly conducted on university students of developed countries. Furthermore, we leverage administrative and self-reported business data to show that the female entrepreneurs who chose to compete in the lab perform as well as their male counterparts, providing some external validity to our lab results

The third paper '**Risk attitudes, Gender and Business Performance Among off-grid Renewable Energy Entrepreneurs in Rural Rwanda'** examines risk attitudes among entrepreneurs and the effect of risk aversion on business performance using the same subjects as in paper two. The paper makes use of both subjective and experimental risk measures. A multiple price list experimental design was used to elicit risk attitudes.

Findings show a strong risk aversion among entrepreneurs. Results also reveal a negative relationship between risk aversion and business performance. Thus, entrepreneurs with high risk-taking abilities tend to record better sales. Contrary to experimental results, we find no significant relationship between risk attitudes and business performance for subjective risk measures. Women reveal higher risk aversion levels than men for both experimental and survey risk measures. Surprisingly, despite the gender differences in risk aversion, women tend to perform as well as men. The findings raise important insights for the inclusion of more women in the private energy sector of Rwanda.

While addressing this thematic area unleashes the applicability of experimental results by adding to the competition and risk literature, the two papers also provide insights for the private energy sector. Currently, women's participation in the private energy sector of Rwanda is low, as some companies potentially see the inclusion of women as a limitation for revenue maximization (Parshotam & van der Westhuizen, 2018). By showing that women are equally competitive and are also likely to perform as well as men when given the opportunity, our study provides an impetus for private energy companies in Rwanda to reconsider the involvement of more women in this sector. It further provides support for the notion of gender quotas within this sector to even out disparities in access to labour markets for women, especially in recent times, where pro-gender national policies are gradually permeating the perceptions and sense of agency among the people of Rwanda.

Also, given the many benefits associated with the inclusion of more women in the energy sector, policies geared towards hedging against risk aversion in entrepreneurial programs can be vital in reducing gender gaps in business success.

Future studies testing differences in the impact of competitiveness and risk attitudes on business success for solo and team business models will also be a useful extension to these findings.

(iii) The effectiveness of behavioural nudges in promoting energy conservation in a non-residential sector

The fourth paper addresses a key challenge in the energy sector: energy conservation. The paper, **'The power of nudging: Using feedback, competition and responsibility assignment to save electricity in a non-residential setting'** contributes to the application of nudges literature by focusing on commercial buildings. This stems from the fact that a greater part of the energy conservation literature has been centred on the residential sector despite evidence showing large wastage in office buildings (Masoso & Grobler, 2009).

The paper directly answers the question 'Can behavioural interventions achieve energy savings in non-residential settings where users do not face the financial consequences of their behaviour?' A randomised control trial was adopted to address this question leveraging on two behavioural interventions: social comparison and responsibility assignment aimed at reducing electricity consumption in a large provincial government office building with 24 floors.

Floors were divided into two treatments arms. Treatment one floors received regular emails encouraging recipients to turn off appliances and lights before leaving the office, as well as weekly ranked energy consumption results by floors. Treatment two floors were additionally assigned to weekly "energy advocates".

Results show that behavioural interventions are valuable and effective tools for conserving energy in the workplace. Floors that participated only in the inter-floor competitions reduced energy consumption by 9%, while those additionally assigned floor-wise "energy advocates" reduced energy consumption by 14%. A follow-up interview with employees revealed that most major behaviour changes occurred at the close of the day as part of a conscious initiative by occupants to switch of appliances after work.

Although an attempt was made to show the sustainability of results by examining the attenuation effect month by month during the intervention period, the study was unable to study the long-run effect of the interventions. Future research focused on the durability of these effects will be a critical input into efforts towards the sustainable and effective use of nudges in the commercial sector.

Further, given the duration and focus of the study, the paper did not experiment with the effect of incentivization, but it is an avenue for future research. Overall, this paper presents additional evidence which suggests there may be a large scope for implementing behavioural nudges in the non-residential sector.

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