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Stacking up the Ladder: A Panel Data Analysis of Tanzanian Household Energy Choices

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Abstract

Energy-use statistics in Tanzania reflect the country's low level of industrialization and development. In 2016, only 16.9% of rural and 65.3% of urban inhabitants in mainland Tanzania were connected to some form of electricity. We use a nationally representative three-wave panel dataset (2008-2013) to contribute to the literature on household energy use decisions in Tanzania in the context of the stacking and energy ladder hypotheses. We firstly adopt a panel multinomial-logit approach to model the determinants of household cooking- and lighting-fuel choices. Secondly, we focus explicitly on energy stacking behaviour, proposing various ways of measuring what is inferred when stacking behaviour is thought of in the context of the energy transition and presenting household level correlates of energy stacking behaviour. Thirdly, since fuel uses have gender-differentiated impacts, we investigate women's bargaining power in the decision-making process of household fuel choices. We find that whilst higher household incomes are strongly associated with a transition towards the adoption of more modern fuels, especially lighting fuels, this transition takes place in a context of significant fuel stacking. In Tanzania, government policy has been aimed mostly at connecting households to the electric grid. However, the public health, environmental and social benefits of access to modern energy sources are likely to be diminished in a context of significant fuel stacking. Lastly, we present evidence that the educational attainment of women in the household is an important aspect of household fuel choices.

JEL codes

O13; Q41; N5

Keywords

Fuel choices; Intra-household bargaining; Sub-Saharan Africa

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1. Introduction

Tanzanian energy-use statistics reflect the country's low level of industrialization and development. According to The United Republic of Tanzania (2017), in 2016, only 16.9% of rural and 65.3% of urban inhabitants of mainland Tanzania were connected to some form of electricity. According to other sources, nationally only 2% of rural and 39% of urban inhabitants have access to electricity and only 10% of households have direct access to the national grid (UNDP, 2016).

The recent 2015 Tanzania National Energy Policy⁴ sets the framework to implement the new energy policy, accounting for the United Nations' global initiative of providing sustainable energy for all⁵, the need for energy conservation and efficiency and the recent gas discoveries in the south-east coast of the country. The policy's long-term objective is to improve reliable energy production and to promote productive use of energy in line with policies aimed at shaping the economic transformation of the country, where almost 30% of the population cannot meet their basic consumption needs (World Bank, 2015).

The types of fuels used by households for everyday activities, such as cooking, lighting and heating, have an important bearing on various factors influencing well-being (See Bruce et al., 2000; Dherani et al., 2008; Khandker et al., 2013; Kishore et al., 2014; Peters and Sievert, 2016; Po et al., 2011; van de Walle et al., 2017). These factors range from health outcomes and exposure to safety and financial risks, to aspects of individual and collective time use. In addition, the societal relations which dictate who is exposed to the adverse effects associated with the use of traditional, 'dirty' fuels, such as firewood and charcoal, intimately link fuel use to the risks faced and the work carried out by women and children. Time spent collecting wood or other energy sources also represents an opportunity cost of time not spent on education or income generating activities. These immediate linkages between fuel use and well-being are also not divorced from the broader effects of a reliance on traditional fuels such as forest degradation and pollution which endanger environmental systems (Baland et al., 2010; Heltberg et al., 2000; Hofstad, 1997). For these reasons, both the short-term determinants of demand and the mechanisms of a longer-term energy transition are important to understand in order to work effectively against these adverse effects.

Considering the importance of the types of fuels households use, and in recognition of the various benefits associated with the adoption of modern, 'clean' fuels such as electricity and gas, there

⁴ https://mem.go.tz/wp-content/uploads/2014/02/National-Energy-Policy_December-2015.pdf

⁵ Although energy was not a key component of the Millennium Development Goals, the United Nations "Sustainable Energy for All" initiative renewed interest in initiatives to reduce energy poverty. The Sustainable Development goals (Goal 7: "Ensure access to affordable, reliable, sustainable and modern energy for all") make room for energy in development policy objectives.

has been much engagement in the literature on theories of the energy transition from traditional to modern fuels.

A key early concept in the literature of the household energy transition is the energy ladder hypothesis, which views the process by which households substitute traditional fuels for modern fuels as one driven mostly by increases in income and socio-economic status (Bruce et al., 2000; Hosier and Dowd, 1987; Leach, 1992; van der Kroon et al., 2013). An important aspect of this view is that it sees the energy transition as a series of largely disjointed steps in which households switch from traditional fuels, to transition fuels, and finally to clean fuels. Empirical investigations have repeatedly confirmed the importance of income in energy choices. Early studies on this topic, such as that of Hosier and Dowd (1987), also recognised that household fuel choice decisions are the result of an array of factors in addition to income levels. According to the authors, factors which influence households in 'stepping up the ladder' away from traditional fuels, include location, price, and infrastructure, amongst others.

In recent decades, this conception of the energy transition as one defined by fuel switching as households move up the energy ladder has been challenged by a growing body of empirical evidence that shows that households simultaneously use multiple different fuels, a characteristic described as fuel stacking (Heltberg, 2004; Masera et al., 2000; Ruiz-Mercado and Masera, 2015). The implication is that a clean-break with the use of traditional fuels is unlikely to be occurring in many developing regions today. The energy stacking hypothesis holds that as household incomes rise, the transition towards the use of modern fuels takes place in a context of the simultaneous use of various types of fuels. In this view, poorer households usually use a small variety of traditional fuels, such as firewood, animal residue and charcoal. As incomes increase, households adopt the use of modern fuels, but also continue using traditional fuels for some activities, thus 'mixing' various energy sources.

The household energy landscape in Tanzania is characterised by a very high prevalence of traditional fuel use, especially charcoal and firewood (The United Republic of Tanzania, 2017). Until now, to the best of our knowledge no large scale quantitative studies have been conducted in Tanzania to empirically model the correlates of household fuel decisions using household surveys. Recent studies focus on electricity use only (Rahut et al., 2017) and charcoal expenditures only (D'Agostino et al., 2015). Considering Tanzania's current national policy issues and priorities, the main goal of this paper is to develop an understanding of the nature of household energy use in Tanzania in the context of the energy ladder and stacking hypotheses. More precisely, our contribution is threefold.

Firstly, we adopt a panel multinomial logit approach to model the determinants of household cooking and lighting fuel choices. To the best of our knowledge this is the first-time household fuel choices have been explicitly modelled in this manner in Tanzania using a nationally representative panel survey. Whilst some authors, such as Mekonnen and Köhlin (2009) and Alem et al. (2016) in Ethiopia and Zhang and Hassen (2017) in urban China, have recently made use of panel data in approaching the modelling of household fuel choices, the majority of past empirical studies on this subject have been reliant on cross-sectional data. One short-coming of multinomial logit models is that they assume a series of discrete choices between the use of various fuels, thus not explicitly being able to account for stacking or fuel-mixing behaviour if mixing is not one of the categories of the dependent variables. Thus, secondly, we focus on energy stacking behaviour, proposing four ways of measuring it and deriving household correlates with these measures. Finally, since fuel uses have gender-differentiated impacts, we investigate women's bargaining power in the decision-making process of fuel choices. Our contribution allows us to present evidence that the situation in Tanzania is more accurately described by the energy stacking hypothesis, that various factors other than income or access influence fuel choices, and we discuss the relevance of these findings in light of Tanzania's energy policy.

The remainder of the paper is organized as follows. Section 2 provides an overview of the energy situation in Tanzania and the data sets used for the empirical analysis. Section 3 details the empirical strategy. Thereafter, Section 4 presents the econometric results. Section 5 presents the discussion of the results.

2. Overview of the data

In this section, we firstly provide an overview of the Tanzanian National Panel Survey, which provides a wide range of information on households and their energy use from 2008 to 2013. Secondly, we describe how we measure intra-household bargaining. Thirdly, we detail how we proxy electricity supply and provide an overview of household energy use and fuel purchases.

2.1. Presentation of Tanzanian National Panel Survey

The compilation of the Tanzanian National Panel Survey (TZNPS) over the five-year period from October 2008 until October 2013⁶, resulted in the production of a nationally representative panel survey which provided information on a range of socio-economic indicators at the household, individual and community levels (NBS, 2014a).⁷

Throughout the course of the survey, the same households were tracked over three data collection rounds. Total household attrition at 4.84% (NBS, 2014b) over the entire period of the survey is sufficiently low to dispel worries of attrition-induced bias. The panel nature of the dataset and the low level of attrition are invaluable in helping to account for time-based variability, which goes unobserved in the hitherto mostly cross-sectional studies of energy use which have characterised the majority of studies on energy use in Tanzania.

The sampling design⁸ of the first round of the TZNPS allows for the production of representative statistics at the national, rural/urban and major agro-ecological zone levels. The sampling design of the two subsequent rounds was based on re-contacting all households interviewed in the initial round as well as any new households which formed as a result of the splitting of original households, for example, as a result of marriage or migration. For this reason, the sample size grew from an initial sample of 3,265 households in the 2008/2009 wave, to 3,924 and 5,010 households in the 2010/2011 and 2012/2013 waves, respectively (NBS, 2014b).

We chose to restrict this analysis to only those households that participated in all three waves of the survey. The reason for this is grounded in the desire to observe the factors affecting household energy choices over time, and the sample size is large enough to allow for a balanced panel dataset of 3,088 households interviewed in each of the three rounds.

⁶ The National Panel Survey 2014-2015, Wave 4, was published in 2017. However, the sample is composed of fresh new households and is therefore not included in this study.

⁷ The dataset is publicly available and published by the World Bank as part of its Living Standards Measurement Study (LSMS) programme.

⁸ The unit of observation of the survey is the household and primary sampling units (PSUs) are Enumeration Areas (EAs) from the 2002 Census. A clustered two-stage sampling design was chosen with eight households sampled randomly per PSU, and clusters were stratified along the eight administrative zones and rural areas (65%), Dar es Salaam (17.5%) and other urban areas (17.5%). The end target sample was 3,280 households in 410 EAs. The sample design is detailed in Sandefur (2009).

For both the energy ladder and stacking model approaches, we identify in the TZNPS numerous variables, shown in Table 1 (summary statistics are provided in Table 4), which are likely to have relevance to household fuel choices. Among these are variables capturing household characteristics (what van der Kroon et al. (2013) term the “household opportunity set”), such as characteristics of the household head and the education levels and age and gender compositions of the household, and other factors relevant at the intra-household level. Secondly, household socio-economic status has been recognized in both models as a key variable influencing the energy transition from traditional to modern fuels. In order to determine that the results are robust to different proxies of socio-economic status, we use both real per-adult-equivalent household expenditure, derived from the TZNPS expenditure questions, and a wealth index.⁹ Thirdly, locational aspects, such as the district and time dummy variables, are also included.

⁹ It was constructed using household assets and living conditions. Steps taken in the derivation of the wealth index available from the authors upon request.

Table 1. Description of control variables

		Variable	Description
Household characteristics ¹⁰	Education level of the household head	Less than primary	= 1 if household head's highest level of education is below primary school, including no schooling.
		Primary	= 1 if household head completed primary but not junior secondary school.
		Junior secondary	= 1 if household head completed junior secondary but not secondary school.
		Secondary	= 1 if household head completed secondary school but not a tertiary qualification.
		Tertiary	= 1 if household head completed a tertiary qualification.
	HH size	Number of persons who normally live and eat their meals together in the household.	
	Head age	Age of household head.	
	Ratio of women to men	Ratio of female residents to male residents.	
	Dependency ratio	Ratio of number of members under 15 and over 65 years of age to number of members between 15 and 64 years of age.	
	Female-headed household	= 1 if household head is a woman.	
Measures of women's bargaining power	Indicator no 1	Heducouple	= 1 if the husband has attained at least junior secondary education and the wife has attained less than junior secondary education (Head-powered couple)
		Seducouple	= 1 if wife has attained at least junior secondary education and husband has attained less than junior secondary education (Spouse-powered couple)
		Educouple	= 1 if both husband and wife have attained at least junior secondary education (Educated couple)
		Neducouple	= 1 if neither husband nor wife has attained junior secondary education (Undereducated couple)
	Indicator no 2	Spouse Education	Years of education of the wife.
	Indicator no 3	Education Difference	Years of education of the husband minus years of education of the wife.
	Indicator no 4	Age difference	Husband's age in years minus wife's age in years.
Socio-economic	Log real per-adult-equivalent expenditure		Real yearly household expenditure divided number by of adult equivalent members. ¹¹ Real yearly household expenditure is already constructed in the data and comprised of the sum of food and non-food expenditures for the household. Spatial price heterogeneity is accounted for by using Fischer food price indices. To account for inflation, we weight this by a yearly consumer price index ¹² based on 2010 prices.
	Wealth index score		Score for asset-based wealth index.

¹⁰ "The word 'household' refers to people who live together and share income and basic needs. In other words, residents of a household share the same centre of production and consume from that centre." (NPS, Household Questionnaire)

¹¹ Information on adult equivalent weights used can be found in the Survey Basic Information Document (NBS, 2014b).

¹² The World Bank World Development Indicators CPI is used (World Bank, 2017).

	Elec/Gas stove ownership	= 1 if household owns at least one electric and/or gas stove.
	Other stove ownership ¹³	= 1 if household owns another type of stove.
Locational characteri	Luminosity	Average level of luminosity (measured as a percentage) for the ward in which the household is located (Source: National Oceanic and Atmospheric Administration, 2008-2013)
	Rural household	= 1 if household is classified by the TZNPS as being situated in a rural area.
	Administrative District Dummy variables	Sample is divided into 7 mainland administrative districts and Zanzibar.
Fuel prices	Log Kerosene price	Based on mean reported per-litre price in the EA the household is situated in.
	Log Firewood price	Based on mean reported per-kilogramme price in the EA the household is situated in.
	Log electricity price	Based on national energy tariffs for domestic consumption of between 50-283kWh/month.
	Log Charcoal price	Based on mean reported per-kilogramme price in the EA the household is situated in.

¹³ In the questionnaire, there is no distinction between regular stoves and improved stoves.

2.2. Intra-household bargaining variables

Since fuel uses have gender-differentiated impacts (see Pachauri and Rao, 2013 for a review), we also investigate women's bargaining power in the decision-making process of household fuel choices. As stressed by Pachauri and Rao (2013) most studies on fuel choices fail to address the gender dimension. In the context of Tanzania, recent evidence shows the importance of intra-household bargaining on household decisions related to farming (Anderson et al., 2017), and more generally theoretical research highlights the relationship between intra-household distribution of power and household behaviour (Chiappori and Meghir, 2014). Moreover, there is an established literature showing that women carry out most of the house-related work in Tanzania (Budlender, 2010). In addition, in the TZNPS women report more time spent collecting firewood or other fuels than men.

While measures of household welfare or locality are likely to be correlated with household cooking and lighting fuel decisions, these household-level variables do not capture intra-household dynamics which may also influence these decisions. Thus, in recognition of these societal aspects, we also include various measures of the intra-household decision making power of women. To measure women's bargaining power, we use several proxies. They are presented in Table 1 (and their summary statistics in Table 5) and include (i) a measure of the wife's relative education level, (ii) the number of years of education of the wife, (iii) the number of years of education of the husband minus the number of years of education of the wife, and (iv) the age in years of the husband minus the age the wife. Since we are interested in women's relative bargaining power to their husband, we only include households with a husband and a wife, and where the husband is the household head. This restricted sample has a size of 1,901 households present in each wave of the survey.

2.3. Energy variables

Below, we present the outcome variables used to test the energy ladder and energy stacking hypotheses. The TZNPS contains a range of information of relevance to household fuel use and spending decisions. This includes information on the major cooking and lighting fuels used by the household, the type and amount of four different fuels (kerosene, charcoal, electricity and gas) purchased, and information on fuel prices in the enumeration area in which the household is located.

In our approach to the energy ladder model, we adopt the classical typology of cooking fuels: (i) Modern fuels: petroleum products (e.g. kerosene and LPG) and electricity; (ii) Transition fuels: charcoal and (iii) Traditional fuels: wood fuels and agricultural waste. We classify lighting fuels similarly.

2.3.1. Variables for the energy ladder model

We identify variables in the TNZPS household questionnaires which relate to the major cooking and lighting fuels used by households based on the typology outlined above. Whilst this provides some information on the fuel-choice profile of households, it is limited by the nature of the data. Only information on the *major* fuels used is available in the TNZPS, whilst in its original conception, the energy ladder model concerns the exclusive use of different fuels (See Table 2).

Table 2. Constructed variables for major household cooking and lighting fuels

	Name	Description
Household's main cooking fuel	Firewood, animal residue	= 1 if the household's major cooking fuel is either firewood or animal residue.
	Charcoal	= 2 if the household's main cooking fuel is charcoal.
	Electricity, gas or kerosene	= 3 if the household's main cooking fuel is electricity, gas or kerosene.
Household's main lighting fuel	Candles, firewood	= 1 if the household's major lighting fuel is either candles or firewood.
	Paraffin lamps	=2 if the household's major lighting fuel is paraffin lamps.
	Electricity, solar or gas	= 3 if the household's major lighting fuel is either electricity, solar lamps, or gas.

2.3.2. Variables for the energy stacking model

In order to create a sound basis for explicitly testing the energy stacking model, a key step involves creating a well-defined outcome variable which captures the qualitative and quantitative aspects of stacking behaviour. In order to do this, some theoretical decisions need to be taken.

On the one hand, an indiscriminate outcome variable in which the level of fuel stacking is determined solely by the number of different fuels a household purchased can be created. Using this, the level of fuel stacking is deemed equivalent to the number of fuels purchased. On the other hand, various continuous outcome variables can be derived, taking into account the extent to which households engage in stacking behaviour. In order not to limit the results to the type of stacking measure chosen, we present four different indicators of stacking behaviour. The four measures are outlined in Table 3, below.

Table 3. Various approaches to measuring fuel stacking behaviour

Name	Specification	Explanation
1.Simple Stacking	Number of different fuels purchased: $W_{it} = (0,1,2,3,4)$	Where W_{it} refers to the number of different fuels purchased by household i in wave t .
2.Directionality Stacking	Ratio of electricity and gas in number of fuels purchased: $D_{it} = EG_{it}/W_{it}$	W_{it} as above. $EG_{it} = \sum(E_{it} + G_{it})$, where E_{it} and G_{it} are dummy variables taking a value of 1 if electricity and gas respectively are purchased.

3.Share Stacking	Ratio of electricity and gas expenditure in energy expenditure: $S_{it} = \frac{\text{Spending on Electricity \& Gas}_{it}}{\text{Total Energy Spending}_{it}}$	S_{it} is the share of electricity and gas expenditure in total energy expenditure by household i in wave t .
4.Stacking Index	Extent of stacking given by: $I_i = S_{it} \sum_{k=1}^4 \frac{1}{4} F_{ktn}$	Stacking index, following Andadari et al. (2014), augmented to take into account the share of energy expenditure on clean fuels. S_{it} as above. F_{ktn} is a dummy variable taking on a value of 1 if household i bought fuel k in period t .

Each of the four stacking measures outlined above relies on a particular conception of stacking behaviour and, whilst linked, effectively measures different types of household decisions. The simple stacking variable captures the most basic conception of fuel stacking by only taking into account the number of types of fuel bought, but has clear shortcomings: it does not take into account the direction of stacking, i.e. which fuels are being bought, and it does not differentiate between the extent of stacking behaviour in terms of expenditure shares. There is a clear difference between a household which buys charcoal and firewood, and one which buys electricity and gas, but both households would have the same stacking score. The second, directional stacking variable takes into account the nature of fuel stacking by favouring stacking “up the ladder” in terms of purchases of clean fuels. The third stacking share variable captures the fact that households may change energy use by changing relative expenditures on various fuels. In this regard, households which dedicate more of their energy budget to modern fuels score higher on this measure. The final stacking index weights the number of fuels bought by the share of expenditure dedicated to clean fuels. This index has the advantage of taking into account both the number of fuels bought and the share of the energy expenditure allotted to modern fuels. Arguably it would most accurately reflect stacking behaviour by having the highest score for households which purchase numerous fuels, whilst dedicating the largest share of energy expenditures towards electricity and gas.

2.3.3. Energy prices

Among the aspects of the external decision context of the household, prices households face could play an important role in the decision-making process. The community level questionnaire in the TZNPS contains price data on kerosene, charcoal and firewood. From this data, per litre prices for kerosene and per kilogramme prices for firewood and charcoal are derived.¹⁴ Next, average prices faced by each

¹⁴ Potential outliers are identified using Stata’s Bacon algorithm using the 15th percentile as a threshold. However, they were only excluded from the analysis in the case that they were clearly the result of coding or capturing errors.

household are calculated by taking the mean of all prices in the EA in which the household is located. It is thus assumed that households face the average fuel prices of the community they reside in.

The TZNPS does not provide information on electricity prices. For this reason, we use national electricity tariffs. In this regard, there is no spatial variation in electricity prices, but substantial time-variation due to tariff hikes. The price information is sourced from Peng and Poudineh (2016). The State electricity provider, TANESCO, allocates five different tariff bands, dependent on the type of electricity use of the consumer. The categorisation of the consumer is based on the average voltage and consumption level of the consumer. We use the domestic use tariffs as indicators of electricity prices. Within this domestic category, there is a lifeline price which applies to usage lower than 50kWh per month, as well as a general tariff which applies to domestic use between 50-283 kWh per month. Given that a two-plate electric stove used for 3 hours a day equates to around 135kWh per month, we use the 50-283kWh tariff as an indicator of electricity prices faced by households. This tariff was subject to three adjustments throughout the panel: from 2008 until 2011 the price was 156 TZS/kWh, from 2011 to 2012 it was 195 TZH/kWh and from 2012 to 2013 it was 274 TZH/kWh.

2.4. Luminosity data as a proxy for electricity availability

In modelling household energy decisions in developing regions which are often characterised by low levels of connection to the electricity grid, access to electricity is a factor which should be taken into account. In the absence of a market for electricity (i.e. without direct household access to the electricity grid), the assumption that households face the choice whether or not to use electricity in an indirect utility maximising context is flawed. Prices are one way of getting around this factor, by assuming that prices would reflect relative levels of supply, but in the case of electricity where prices are centrally set, this would also be inadequate.

In the absence of data on whether or not households are directly connected to the electricity grid,¹⁵ we control for electricity access using luminosity data. We make use of the DMSP-OLS Nighttime Lights data published by the U.S. National Oceanic and Atmospheric Administration (NOAA, 2008-2013).

Although there is substantial debate on whether nighttime lights data are a good proxy for economic activity in developing countries, there are several convincing arguments in favour of using this measure as a proxy for electricity consumption (Amaral et al., 2005; Chand et al., 2009; Mellander et al., 2015). Indeed, the light captured by the satellites is mainly the result of electricity-powered illumination. For instance, in a study conducted in Australia, Townsend and Bruce (2010) find a 0.93 correlation between electricity consumption and nighttime lights between 1997 and 2002. Doll and Pachauri (2010) use nighttime lights data in developing countries from 1992 to 2000 in order to investigate the capability of

¹⁵ In the questionnaire, there is no specific question asking respondents whether they are connected to the grid network or not.

nighttime lights data to estimate populations without electricity access. They stress that the data tends to overestimate the population without access to electricity, as the satellite sensors may not capture low density energy usage or indoor lighting. Moreover, such data would fail to reflect situations in which households do have access to the electricity grid in an infrastructural sense, but do not use electricity. Nevertheless, this data remains extremely valuable. Hence, in the absence of publicly available information on the electricity grid in Tanzania, nighttime lights data appears to be a good and relevant proxy for electricity access.

Thus, relying on the assumption that at least some of the households in the surrounding area would have been connected to electricity grid (which would be reflected in the luminosity data), we use mean rates of luminosity at the ward¹⁶ level as a proxy for electricity access.

Table 4. Pooled¹⁷ summary statistics of explanatory and explained variables (2008-2013)

Variable	Mean	SD	Min	Max
<i>Household Characteristics</i>				
Less than primary	0.41	0.49	0	1
Primary	0.47	0.50	0	1
Junior Secondary	0.08	0.27	0	1
Secondary	0.02	0.13	0	1
Tertiary	0.01	0.10	0	1
HH Size	5.33	3.00	1	55
Head Age	47.86	15.30	16	107
Ratio of women to men	1.28	1.08	0	8
Dependency ratio	102.10	89.15	0	800
Female Headed Household	0.24	0.43	0	1
<i>Household main cooking fuel</i>				
Firewood/Animal Residue	0.71	0.43	0	1
Charcoal	0.25	0.45	0	1
Electricity/Gas/Kerosene	0.04	0.43	0	1
<i>Household main lighting fuel</i>				
Candles/Firewood	0.02	0.14	0	1
Paraffin Lamps	0.65	0.48	0	1
Electricity/Gas/Solar	0.24	0.42	0	1
<i>Measures of stacking behaviour</i>				

¹⁶ A ward is an administrative unit of the Tanzanian local governance structure that contains sub-divisions of urban and rural areas. Rural wards encompass several villages. In deriving the luminosity measure, the luminosity score of a household is given by the average level of luminosity emanating from the area covered by the ward in which it is located. Ward shape files come from the Tanzanian National Bureau of Statistics, available here: <https://goo.gl/nnoiqo>. The resolution of the nighttime lights data is 30 arc seconds, which equates to roughly 1 km squared (Henderson et al., 2012).

¹⁷ A yearly breakdown of these statistics is provided in the Appendix, Annex 1.

Simple stacking	1.37	0.85	0	4
Directional stacking	0.11	0.21	0	1
Share stacking	0.12	0.25	0	1
Stacking index	0.07	0.15	0	0.97
<i>Socio-economic status indicators</i>				
Log per-adult-equivalent expenditure	13.51	0.78	10.57	16.72
Wealth index score	0.00	1.97	-2.82	15.41
Elec/Gas stove ownership	0.09	0.29	0	1
Other stove ownership	0.55	0.50	0	1
<i>Stacking Measures</i>				
Simple Stacking	1.37	0.85	0	4
Directional Stacking	0.11	0.21	0	1
Share Stacking	0.12	0.25	0	1
Stacking Index	0.07	0.15	0	0.97
<i>Fuel Prices & Electricity Access</i>				
Log Kerosene price	7.49	0.44	5.19	8.51
Log Firewood price	4.92	0.82	3.24	8.40
Log Electricity price	5.40	0.41	4.88	5.95
Log Charcoal price	5.77	0.67	3.74	9.52
<i>Locational characteristics</i>				
Rural household	0.67	0.47	0	1
Luminosity	9.44	19.14	0	63
<i>Administrative zone</i>				
Lake	0.10	0.29	0	1
Western	0.11	0.31	0	1
Northern	0.12	0.33	0	1
Central	0.05	0.21	0	1
Southern Highlands	0.11	0.32	0	1
Eastern	0.21	0.41	0	1
Southern	0.15	0.36	0	1
Zanzibar	0.15	0.35	0	1
N ¹⁸ =9264				

Source: Authors' calculations from TZNPS (2008-2013) pooled data

¹⁸ These statistics relate to the pooled data across all three waves. Estimates for means of particular variables may be lower due to missing data.

Table 5. Pooled summary statistics of proxies for women’s intra-household bargaining power¹⁹

Variable	Mean	SD	Min	Max
Educouple	0.03	0.18	0	1
Seducouple	0.02	0.15	0	1
Heducouple	0.07	0.26	0	1
Neducouple	0.85	0.36	0	1
Age difference	7.80	6.85	-20	53
Education difference	0.44	2.41	-9	10
Spouse Education	7.05	2.09	0	18

N=5703²⁰

Source: Authors’ calculations from TZNPS (2008-2013) pooled data

2.5. Descriptive overview on energy use in Tanzania

On a descriptive level, many of the stylized facts concerning energy use in Tanzania are reflected in the TZNPS (2008-2013) data. High levels of traditional fuel dependency, especially for cooking, and a particularly low level of reported reliance on electricity characterise the energy situation of most households. Using the pooled data, the average reported time spent collecting firewood per household in the previous day was 40 minutes and the average time spent collecting firewood by women/female household members was four times higher than that spent by men. At the same time, there is also a significant level of spatial heterogeneity²¹ in dependence on both traditional lighting and cooking fuels, with the lowest rates found near Dar es Salaam. We also find that across the country’s 26 regions there is a much higher level of variation in rates of reliance on traditional fuels for lighting purposes than for cooking. When the main cooking and lighting fuel choices of households are averaged for different segments of the per-adult-equivalent expenditure distribution in Table 6, the predominance of firewood and charcoal as the major cooking fuel types across the distribution is made clear. We see that in terms of per-adult-equivalent expenditures, of the households in the bottom 33% of the expenditure distribution, close to 96% in 2012/2013 rely on firewood as their main cooking fuel. This number consistently declines as incomes increase, as can be seen in the figures. However, it is very stable over the five-year period of the panel despite an increase in the state electricity company TANESCO’s residential users from 722 031 in 2008 to 1 014 096 in 2012 (Knoema, 2014). Of the households in the top third of the expenditure distribution in 2012/2013, 37% rely on firewood as their main cooking fuel, whilst the majority (54%) rely on charcoal. Similar results are shown for lighting fuels. The proportion

¹⁹ A yearly breakdown of these statistics is provided in the Appendix, Annex 2.

²⁰ These statistics relate to the pooled data of all three waves of the restricted sample of households which have a patriarchal family structure i.e. a male head and a female spouse.

²¹ This is demonstrated in the maps of rates of traditional cooking and lighting fuel dependency in Annex 3.

of households which cite electricity, gas and solar as their main lighting fuels consistently increases as incomes increase. At the same time, the proportion of households using kerosene lamps for lighting decreases as one moves up the expenditure distribution. There is also much more time-variation in lighting fuels than in cooking fuels. In 2008-2009 45.66% of the top 33% of the expenditure distribution used electricity, gas or solar power, whilst the same figure for the 2012-2013 round is 58.17%.

Table 6. Main cooking and lighting fuels, by segment of per-adult-equivalent expenditure distribution

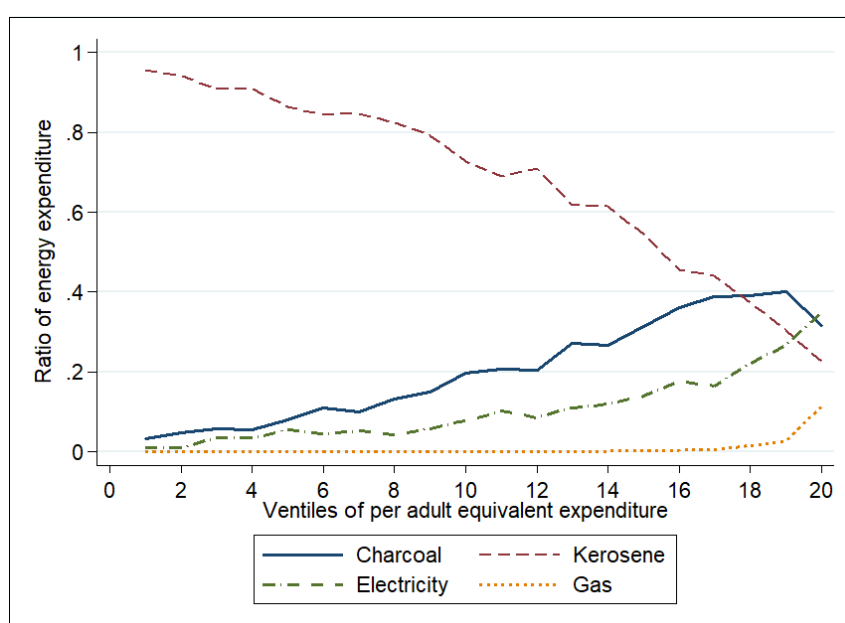
Main Cooking Fuel	Type of Fuel	2008/2009	2010/2011	2012/2013
Poorest 33%	Firewood	94.6	95.3	95.8
	Charcoal	4.2	4.3	4.1
	Elec/Gas/Kerosene	1.3	0.4	0.1
	Total	100.0	100.0	100.0
Middle 33%	Firewood	82.2	79.5	77.4
	Charcoal	16.8	19.6	21.5
	Elec/Gas/Kerosene	1.1	0.9	1.1
	Total	100.0	100.0	100.0
Richest 33%	Firewood	41.1	36.9	36.7
	Charcoal	47.9	52.2	54.0
	Elec/Gas/Kerosene	10.9	10.9	9.3
	Total	100.0	100.0	100.0
	N =	3,073	3,064	3,058
Main Lighting Fuel	Type of Fuel	2008/2009	2010/2011	2012/2013
Poorest 33%	Candles/Firewood	4.35	3.61	4.76
	Kerosene Lamps	91.3	91.58	85.33
	Electricity/Gas/Solar	4.35	4.81	9.92
	Total	100.0	100.0	100.0
Middle 33%	Candles/Firewood	1.57	1.57	1.82
	Kerosene Lamps	84.07	81.17	74.64
	Electricity/Gas/Solar	14.36	17.26	23.54
	Total	100.0	100.0	100.0
Richest 33%	Candles/Firewood	0.79	1.21	2.26
	Kerosene Lamps	53.55	47.38	39.57
	Electricity/Gas/Solar	45.66	51.41	58.17
	Total	100.0	100.0	100.0
	N ²² =	3,042	2,863	2,490

Source: Authors' calculations using TZNPS (2008-2013).

²² Statistics are calculated on non-missing data, which is why the number of observations varies by year and variable.

From this overview, there is a clear indication that, although richer households are more likely to use modern fuels, the largest part of any transition in cooking fuels as one moves up the expenditure distribution is characterised by the tendency of richer households being more likely to use charcoal than firewood for cooking, rather than a transition towards modern fuels. This could also be explained by the fact that better-off households are likely to be urban households where firewood would not be available. On the other hand, there is much more expenditure-based variability, as well as a more substantial portion of households using modern fuels for lighting. This suggests that the rates at which households change their fuel use decisions over time and as incomes rise are different for cooking and lighting fuels.

Figure 1. Spending on various fuels as a ratio of total energy expenditure, by ventile of the per-adult-equivalent expenditure



N²³ = 9264, Source: Authors' own calculations from TZNPS (2008-2013) pooled data.

Using expenditure data, the information presented in Figure 1 speaks directly to the notion of fuel mixing and the energy stacking model. Households were asked whether they purchased electricity, charcoal, gas or kerosene in the preceding 30 days.²⁴ In addition, if the answer to the question was yes, they were asked how much they spent. In Figure 1, household energy expenditures are broken down and the average share of expenditure accruing to each of the four fuels is calculated per ventile of the distribution. We see that on average, the poorest households spend nearly all of their energy expenditure on kerosene, whilst richer households have a much more mixed portfolio of fuels. As one moves up the expenditure distribution, increasing shares of the household energy budget are allocated to electricity and gas.

²³ This is the combined number of observations of households across all three waves. Expenditure information was only collected for households which purchased the given fuels. In this regard, 82% of households purchased kerosene, 31% purchased charcoal, 2% purchased gas, 21% purchased electricity.

²⁴ Sampling rounds were structured such that the households were interviewed at the same time-period of the year in each wave.

However, the results echo those presented in Table 6, by demonstrating the low levels of adoption of modern fuels for most of the population. The share of energy expenditure on gas and electricity only rises above 20% for the top 10% of the income distribution scale and is under 10% for the bottom half of the income distribution scale. To put these figures into context, the data shows that the poorest households use nearly exclusively firewood and animal residue as main cooking fuels and their energy expenditure goes mostly to kerosene, which is used as the main source of lighting. Around the median of the expenditure distribution scale, households still cook mainly with firewood and animal residue, whilst more exclusively relying on kerosene as a main lighting fuel, seconded by electricity, solar or gas. The best-off households (close to the top 5% of the distribution scale) cook mainly with charcoal and use mostly modern lighting sources. The ratios of energy expenditure to total household expenditures show that most households spend between 10-20% of their total monthly expenditures on energy sources. Richer households are largely located in urban areas where due to transport costs and higher demand they are likely to have to purchase fuels such as charcoal at higher costs than in rural areas. In addition, in an urban context the possibilities for household members collecting firewood are also likely to be more limited. For this reason, richer households are seen to spend slightly larger shares of their household budget on fuels.

Figure 2. Mean number of fuels purchased, by ventile of per-adult-equivalent expenditure

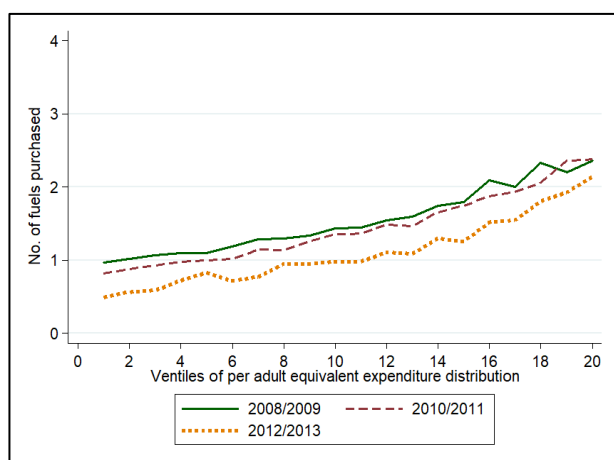
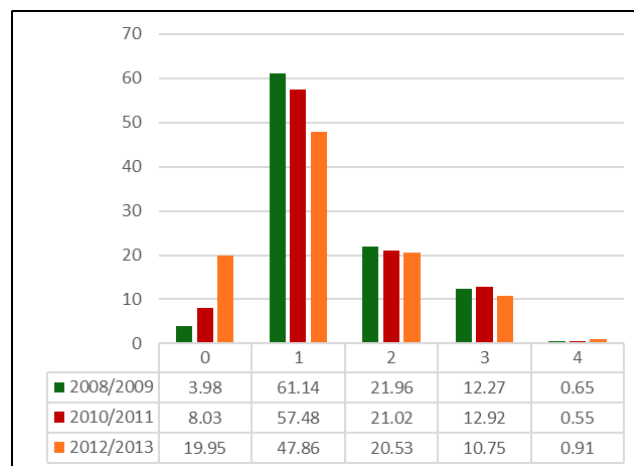


Figure 3. Proportion of households citing purchasing x fuels²⁵ for x = (0, 1, 2, 3, 4)



N = 9264. Source: Authors' own calculations from TZNPS (2008-2013) pooled data.

When the average number of fuels purchased per ventile of the per-adult-equivalent expenditure distribution is plotted in Figure 2 we see that on average richer households tend to purchase a larger number of fuels, in line with the fuel stacking hypothesis. Figure 3 shows that a large proportion (close to 30%) of households purchase²⁶ more than one of the fuels surveyed. In 2012-2013 around 10% of

²⁵ Including: kerosene, charcoal, electricity and gas.

²⁶ Note these statistics relate to fuels purchased and not to fuels used. This is the extent of the information in the TZNPS data. The total number of fuels used may be higher.

households reported purchasing three of the four fuels (charcoal, kerosene, electricity and gas) that were surveyed in the questionnaire, whilst 20% reported purchasing two of them.

3. Empirical strategy and econometric model

Our empirical strategy revolves around two main goals. The first is to contribute to the existing literature on the determinants of cooking and lighting fuel choices in Tanzania by adopting a multinomial logit approach. As a second goal, in recognition of the increasing relevance of the notion of fuel stacking in the literature, as well as relatively few explicit attempts to model fuel stacking using nationally representative data, we propose various ways of measuring the concept of fuel stacking and provide an analysis of the correlates of these measures.

3.1. Multinomial logit model of household fuel choices to test the energy ladder hypothesis

When individuals are presented with the same choice successively in different time-periods, especially when that choice involves a monetary or habitual investment, they tend to make similar choices over time. There is a strong basis for this to be true, especially of cooking fuel choices. Cooking fuel choices are often associated with some investment in technology, such as stoves or hearths, as well as household-specific habits and preferences which are often persistent. These household-specific factors lead to household-specific heterogeneity, which is never fully observed.

In the fuel-choice literature numerous authors have adopted a pooled multinomial logit approach to model fuel choices (Heltberg, 2005; Ouedraogo, 2006; Pundo and Fraser, 2006). However, this approach does not account for unobserved household heterogeneity. For these reasons, we adopt a model which takes these unobserved household effects into account.

In order to account for unobserved household heterogeneity, the two commonly used approaches are via fixed or random effects.²⁷ Neither of these specifications imposes the assumption that repeated household fuel choices in different time periods are independent of one another, that is, both approaches assume there is a household-specific effect but differ in the assumptions made about the nature of these effects.

We categorize both cooking and lighting fuels, respectively, into three groups according to their position in the energy spectrum, from traditional to modern fuels. In the case of cooking fuels, these categories are 1=firewood and animal residue, 2=charcoal and 3=electricity, gas or kerosene. In the case of lighting fuels, the categories are 1=candles and firewood, 2=paraffin lamps and 3=electricity, solar or gas. In

²⁷ A general outline of random effects multinomial logit models can be found in Frees (2004, Ch.11.2) and Chen and Kuo (2001), whilst that of a fixed effects approach to multinomial logit models can be found in Pferr (2014).

addition, each household in the panel is observed in 3 time periods ($T = 3$). Thus, the t^{th} observation of household i can take on a value of $j = (1, 2, 3)$ where j refers to the category of the fuel choice.

Implicit in the model is the assumption that at any point in time, households choose those cooking or lighting fuels which maximise indirect household utility, subject to household constraints. Thus, in a general specification taking into account unobserved household-specific effect, household i 's indirect utility associated with the choice of fuel j in time t is given by:

$$V_{itj} = \mathbf{x}_{it} \boldsymbol{\beta}_j + \mathbf{u}_i + \epsilon_{it} \quad t = 1,2,3 ; j = 1,2,3 \quad (1)$$

Where \mathbf{x}_{it} is a vector of observed explanatory variables particular to the household, and $\boldsymbol{\beta}_j$ is a vector of parameters specific to fuel choice j . In addition, \mathbf{u}_i is the unobserved household-specific effect and ϵ_{it} is an independent and identically distributed error term. In a pooled multinomial logit model, the \mathbf{u}_i household-specific effect is not taken into account, whilst both fixed and random effects models rely on the assumption that the explanatory variables are exogenous conditional on the household-specific term, i.e. $E(u_i | x_{it}, \epsilon_{it}) = 0$.

A key additional assumption specific to random effects models is that $E(u_i | x_{it}) = E(u_i) = 0$ i.e. that the unobserved household effect u_i is independent of the explanatory variables. Under this condition and in the case where there are no omitted variables, random effects coefficient estimates are deemed to be consistent, as well as more efficient than fixed effects estimates. On the other hand, a fixed effects estimation relaxes this additional assumption and allows the household-specific effect \mathbf{u}_i to be correlated with the explanatory variables. Thus, a fixed effects approach allows for the derivation of consistent estimates in a case where there exist time-invariant unobserved factors which may be related to the observed explanatory variables.

The inclusion of household-specific effects implies that the probability of a household making a particular choice in one time period is subject to the same unobserved characteristics as in the other periods. This accounts for likely correlations in the error terms across repeated choices. In a multinomial logit model with unobserved household heterogeneity, the conditional probability that household i chooses fuel j in time t is thus given by:

$$Pr(f_{it} = j | \mathbf{x}_{it}, \mathbf{u}_i) = \frac{\exp(\mathbf{x}_{it} \boldsymbol{\beta}_j + \mathbf{u}_i)}{1 + \sum_{k=0}^j \exp(\mathbf{x}_{it} \boldsymbol{\beta}_k + \mathbf{u}_i)}, u_B = \boldsymbol{\beta}_B = 0 \quad (2)$$

where \mathbf{B} refers to the base outcome category. The probability is conditional on the set of household level effects and on the observable household characteristics and is estimated by way of a maximum likelihood estimator.

3.2. Stacking model

Whilst multinomial logit approaches are suited to the modelling of the energy ladder model if fuels are classed into various groups, specific studies focussed on fuel stacking need an explanatory measure capturing stacking behaviour. Some studies have attempted to explicitly model stacking behaviour using data which is not uniquely collected for that purpose. In a study in Guatemala Heltberg (2005) creates outcome variables, capturing the stacking behaviour of households by looking at the correlates with households that use either: only wood, only LPG or LPG and charcoal for cooking. The shortcoming of this approach is that it does not take into account the extent of the stacking behaviour, nor the use of more than two fuels. In a study carried out in India, Cheng and Urpelainen (2014), use expenditure shares and information on the specific uses of different fuels, distinguishing between lighting and cooking fuels, where households use electricity and kerosene for lighting and LPG and biomass fuels in cooking. They find that whilst higher household incomes lead to decreased fuel stacking for lighting, the same is not true for cooking. In an impact evaluation study of a government LPG promotion programme, Andadari et al. (2014) create an index of fuel stacking by weighting the number of fuels used by the total number possible in the dataset. This is useful in a descriptive sense, but does not capture the direction of fuel stacking, i.e. households which perform higher on the index do not necessarily stack 'up the ladder' by increasing modern fuel use.

4. Results

4.1. Multinomial logit regression results

Both household cooking and lighting decisions are modelled using a multinomial logit approach. The full regression output using pooled, fixed effects and random effects specifications, as well as the constructed wealth index as an alternative measure of socio-economic status, are displayed in Annex 4 and 5. Below, in Table 7 and Table 8, the average marginal effects of the random effects regressions are displayed due to the omission of time-invariant household variables, such as location and educational attainment, in a fixed effects estimation. The marginal effects we display allow us to illustrate how these factors correlate with fuel choices. A Small-Hsiao test rejects the null hypothesis of a violation of the independence of irrelevant alternatives assumption across all eliminated categories in the case of lighting fuels, and consistently for two of the eliminated categories for cooking fuels, and inconsistently for the third. However, there has been extensive engagement on the reliability of these types of tests which cast doubt on their usefulness for empirical work (Cheng and Long, 2007; Fry and Harris, 1998; Fry and Harris, 1996).

Table 7. Average marginal effects: cooking fuels

	Firewood/Animal Res.		Charcoal		Electricity/ Kerosene/Gas	
	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Log per. ad. eq. expenditure	-0.095***	0.009	0.082***	0.010	0.013***	0.005
Luminosity	-0.003***	0.000	0.002***	0.000	0.000**	0.000
Rural Household	0.175***	0.017	-0.162***	0.018	-0.013**	0.006
Primary	-0.040***	0.011	0.023*	0.013	0.017**	0.008
Junior Secondary	-0.121***	0.024	0.087***	0.027	0.034**	0.016
Secondary	-0.122**	0.048	0.099**	0.050	0.023	0.021
Tertiary	-0.130	0.087	0.036	0.082	0.095**	0.043
Female Headed HH	-0.028**	0.012	0.035***	0.013	-0.008	0.005
HH Size	0.002	0.002	0.001	0.002	-0.003**	0.001
Ratio of Women to Men	-0.001	0.004	0.005	0.004	-0.004	0.002
HH Head age	0.001***	0.000	-0.001**	0.000	0.000	0.000
Elec/Gas stove	-0.066***	0.022	0.025	0.022	0.041***	0.011
Other Stove	-0.131***	0.013	0.147***	0.014	-0.016**	0.008
Log Kerosene Price	-0.012	0.026	0.000	0.028	0.013	0.012
Log Firewood Price	0.005	0.008	-0.005	0.009	-0.001	0.003
Log Charcoal Price	-0.003	0.012	0.002	0.012	0.001	0.005
Log Electricity Price	-0.009	0.046	0.044	0.048	-0.034*	0.019
Admin. District Dummy Variables	YES		YES		YES	
Wave Dummy Variables	YES		YES		YES	

N= 3575

* p<0.10, ** p<0.05, *** p<0.010. Marginal effects calculated from random effects estimates presented in Annex 6.

Annex 6

The average marginal effects estimates for the random effects cooking fuel regression show that per-adult-equivalent expenditure is significantly correlated with household fuel choices and that households with higher levels of per-adult-equivalent expenditures on average are less likely to use biomass fuels as their main cooking fuel, but more likely to use charcoal than electricity. This result is not so puzzling, given the high level of charcoal use and low levels of electricity use for cooking in the country.

In addition, we see that the relationship between luminosity rates and major cooking fuel choices is very weak and the marginal effects coefficient close to zero. This alludes to the likelihood that *ceteris paribus*, access to electricity does not necessarily lead to the exclusive adoption of modern fuels. This could be explained by the positive externalities of having neighbours or businesses with access to electricity or living in a town with street lights. Following van de Walle et al. (2017), there is a distinction between the internal effects of a household's electrification and the external effects of village electrification which can lead to different types of spillovers, hence of behaviour in terms of energy choices.

Rural households are substantially less likely to use clean fuels as their major cooking fuel than urban households. We see that rural households are 17% more likely to use firewood/animal residue, 16% less likely to use charcoal and 1% less likely than urban households to use clean fuels as their main cooking fuel. Similarly, households in areas where luminosity scores are higher are less likely to use firewood and animal residue. We also see that households which have access to electric or gas stoves are significantly more likely than those which do not to use clean fuels and less likely to use biofuels. Female-headed households are more likely than non-female-headed households to rely on charcoal and less likely to rely on biofuels as a main cooking fuel source.

The level of education of the household head is positively associated with a transition towards the use of modern fuels. In particular, we see that households in which the head has obtained tertiary are 9% more likely to use clean fuels as their main cooking fuels than households without primary education (the base case). When looking at the price effects, it is surprising to see that only the electricity price is weakly significant (at the 10% level). The marginal effects illustrate that a 10% increase in the electricity price is associated with a 0.3% decrease in the likelihood of using modern fuels.

Table 8. Average marginal effects: Lighting fuels

	Candles/ Firewood		Lamp Oil (Kerosene/ Paraffin)		Electricity/ Gas/ Solar	
	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Log per.ad.eq. Expenditure	-0.006**	0.003	-0.088***	0.009	0.094***	0.009
Luminosity	0.000**	0.000	-0.003***	0.000	0.003***	0.000
Rural Household	0.000	0.002	0.122***	0.014	-0.121***	0.014
Primary	-0.002	0.002	-0.061***	0.011	0.064***	0.011
Junior Secondary	-0.001	0.003	-0.262***	0.033	0.264***	0.035
Secondary	-0.004**	0.002	-0.384***	0.090	0.388***	0.090
Tertiary	-0.004**	0.002	-0.331***	0.124	0.334***	0.124
Female Headed HH	-0.002	0.001	0.032***	0.012	-0.031**	0.012
HH Size	-0.001	0.000	-0.004**	0.002	0.005***	0.002
Ratio of Women to Men	0.000	0.000	-0.011*	0.004	0.011**	0.004
HH Head Age	0.000	0.000	-0.001***	0.000	0.001***	0.000
Log Kerosene Price	0.001	0.004	-0.089***	0.024	0.087***	0.024
Log Firewood Price	-0.003*	0.002	-0.006	0.007	0.009	0.007
Log Electricity Price	0.017*	0.010	-0.015	0.046	-0.002	0.045
Admin. District Dummy Variables	YES		YES		YES	
Wave Dummy Variables	YES		YES		YES	

N = 5007

* p<0.10, ** p<0.05, *** p<0.010. Marginal effects calculated from random effects estimates presented in Annex 5.

The marginal effects estimates for the categorical lighting fuel variable in Table 8 also show that per-adult-equivalent expenditure is positively and significantly correlated with the use of modern fuels. In the case of lighting fuels, the effect of increases in per-adult-equivalent expenditure is largest for modern fuels. All else equal, rural households are also less likely than urban households to use more modern lighting sources. In addition, as expected, households in areas with higher rates of luminosity have a higher probability of mainly using modern lighting fuels.

Female-headed households are less likely to use modern fuels than households headed by men; however, households with a higher ratio of women to men are more likely to use mainly modern lighting fuels. In addition, larger households are more likely to use modern fuels, perhaps alluding to the relative cost of modern fuels, which can be more easily incurred by larger households. The results in Table 6 also show that a 10% increase in the kerosene price results in a 0.9% decrease in the likelihood of using lamp oil as a fuel source for lighting and an almost equivalent 0.9% increase in the likelihood of using modern fuels, suggesting that households easily switch between paraffin lamps and modern lights, such as solar or electric lamps.

We also see that marginal changes in expenditure have larger effects on the probabilities of households' main cooking fuel choices as one moves up the expenditure distribution²⁸. We observe that at the mean of the per-adult-equivalent expenditure, a 10% increase in per-adult-equivalent expenditure results in a roughly 11% decrease in the probability of using mainly firewood and animal residue, a 10% increase in the probability of using charcoal and a 1% increase in the probability of using modern fuels. Across the expenditure distribution, the probability of using charcoal associated with an increase in expenditure is always higher than the probability of using modern fuels. For lighting fuels, we see that at the mean of the per-adult-equivalent expenditure distribution, a 10% increase in per-adult-equivalent expenditure results in a 1% decrease in the probability of using firewood and candles as a main lighting fuel, a 10% decrease in the probability of using lamp oil and a 9% increase in the probability of using modern lighting fuels. Thus, when focussing on the relative sizes of the marginal effects, increases in income are always associated with an increase in the probability of using modern fuels and a decrease in the probability of using lamp oil, firewood, and candles.

4.2. Household fuel stacking results

Table 9 displays the results of panel regressions of the correlates of fuel stacking using the stacking index presented in Table 3 as the dependent variable and using three different estimators. We display results of the random effects generalised least squares (GLS) and maximum likelihood (ML) estimators as well as fixed effects results. As a robustness test, GLS regressions using each of the other stacking measures are presented in the Appendix, Annex 7, showing that the results are not generally dependent on the choice of the stacking measures proposed here.

Table 9. Fuel stacking panel regressions: Stacking Index as dependent variable²⁹

	(1) Random Effects GLS	(2) Random Effects ML	(3) Fixed Effects
Log per.ad.eq.expenditure	0.0343*** (0.00)	0.0346*** (0.00)	0.00897*** (0.00)
Luminosity	0.00217*** (0.00)	0.00216*** (0.00)	0.00143*** (0.00)
Rural Households	-0.0269*** (0.00)	-0.0271*** (0.00)	
Primary	0.00803** (0.00)	0.00796** (0.00)	
Junior Secondary	0.0748*** (0.01)	0.0751*** (0.01)	
Secondary	0.117*** (0.01)	0.117*** (0.01)	
Tertiary	0.192*** (0.02)	0.193*** (0.02)	
Female Head HH	-0.00674 (0.00)	-0.00675 (0.00)	-0.00555 (0.01)
Household size	0.00192*** (0.00)	0.00195*** (0.00)	-0.000509 (0.00)
Ratio of women to men	0.000724 (0.00)	0.000755 (0.00)	-0.00217 (0.00)

²⁸ This relates to marginal affects estimates presented in Annex 6.

²⁹ Here three estimates using different estimators are displayed as a robustness test. Regression results of other stacking measures presented in Annex 7.

Log Kerosene Price	0.0234** (0.01)	0.0236** (0.01)	
Log Electricity Price	0.00318 (0.02)	0.00299 (0.02)	
Log Firewood Price	-0.00680** (0.00)	-0.00681** (0.00)	
Log Charcoal Price	0.00707* (0.00)	0.00709* (0.00)	
Constant	-0.617*** (0.11)	-0.621*** (0.11)	-0.0600 (0.04)
Admin District Dummy Variables	YES	YES	NO
Wave Dummy Variables	YES	YES	YES
sigma_u constant		0.0830*** (0.00)	
sigma_e constant		0.0704*** (0.00)	
Overall R-Squared	0.41		0.23
Observations	4936	4936	7288

* p<0.10, ** p<0.05, *** p<0.010. Standard errors in parentheses.

Across all three specifications in Table 9, we find significant correlations of fuel stacking behaviour as measured by the stacking index and by increases in per-adult-equivalent expenditure. Using the other measures of fuel stacking presented in Annex 7, we find the same result, supporting the fuel stacking hypothesis. We find that a 10% increase in per-adult-equivalent expenditure on average is associated with an increase of between 0.001 and 0.0035 on the stacking index score. Similar positive and significant effects for the luminosity coefficients suggest that household access to electricity is not necessarily a determinant of a full transition to the exclusive use of modern fuels. The results also show significant urban-rural disparities in levels of fuel stacking, with rural households scoring on average around 0.03 less on the stacking index than urban households, *ceteris paribus*.

Higher education levels are also correlated with higher levels of fuel stacking. The size of the coefficients on the education dummy variables increase as the level of education increases. Thus, the largest coefficient of all the education dummy variables is on tertiary education, signifying that households in which the household head is more educated are more likely to score higher on the stacking index. Of the price measures, we see that wood and kerosene price effects are significant at the 5% level.

Aside from the nature of the household energy transition, there has been debate on why households choose to use a mixture of different fuels. It has been highlighted that fuel choice decisions are explained by numerous, often interlinked factors. In particular, the influence of cultural preferences has emerged in the literature. Ruiz-Mercado and Masera (2015) argue that in most cases, modern fuels are not perfect substitutes for traditional fuels, given that particular fuels are tightly bound to cultural and traditional aspects of daily life which inform fuel choices. For example, in a study done in Zanzibar, men emphasized the superior taste of food cooked on firewood (Winther, 2007). In another study in Haryana, India, respondents preferred chapatti cooked on traditional biomass 'chulah' stoves (Joon et al., 2009). In addition to these cultural aspects, Van der Kroon et al. (2013) identify factors such as the irregularity of income flows, unreliability of fuel supply, fluctuations of energy prices and the role of traditional cooking

methods as reasons why households may use various fuels. A recent South African study by Harris et al. (2017) shows that despite an increase in household electricity access over the long run, this increase does not happen monotonically, and factors such as disconnections from the electricity grid, migration and new-household formation mean that households transition between having and not having electricity access over time. Another reason households may use a mixture of energy sources, suggested by Louw et al. (2008), is as a method to decrease vulnerability to unforeseen fluctuations in energy supply. Diversification, in this light, can also function as a method of coping with risk.

4.3. Women's intra-household bargaining power

In focussing on households with a patriarchal family structure, we ask whether the relative or absolute power of the woman spouse in the household influences household fuel-use decisions. This involves a subsample of the 1,901 households which have a present male head and a woman as spouse, which are present in all three waves of the survey. Using the measures to approximate the decision-making power of the wife in the household outlined in Table 1, we display the multinomial logit regression results for main cooking and lighting fuel choices below. We also display panel generalised least squares estimates with the stacking index as dependent variable.

The results in Table 11 suggest that those households where the wife has a higher level of formal education are more likely to adopt mainly modern lighting fuels while controlling for the level of education of the husband. In addition, the results in Table 10 show that those households where either the husband or the wife, or both, are relatively well educated are more likely to adopt charcoal and modern cooking fuels. The stacking results, in Table 12, also show that on average, households where the spouse has a higher level of education are likely to score higher on the stacking index, controlling for the level of education of the husband. We see that, controlling for the level of education of the husband, the difference in education between husband and wife, as well as their age difference are found not to be significantly correlated with cooking, lighting or stacking decisions.

These results suggest that while the absolute level of the combined educational attainment of the husband and wife is likely to be important in determining fuel-use choices, intra-household inequality in educational attainment or age seem to be less important.

Table 10. Pooled Multinomial logit regression results for measures of women's bargaining power: cooking fuels

	(1) Main Cooking Fuel (Base: Firewood/Animal Res)		(2) Main Cooking Fuel (Base: Firewood/Animal Res)		(3) Main Cooking Fuel (Base: Firewood/Animal Res)		(4) Main Cooking Fuel (Base: Firewood/Animal Res)	
	Charcoal	Elec/Gas/Ker	Charcoal	Elec/Gas/Ker	Charcoal	Elec/Gas/Ker	Charcoal	Elec/Gas/Ker
Educouple³⁰	1.293** (0.51)	1.553** (0.62)						
Heducouple	0.489* (0.26)	0.929** (0.40)						
Seducouple	1.224*** (0.42)	1.559** (0.62)						
Spouse_educ			0.0752 (0.07)	0.0419 (0.13)				
Educ_diff					-0.101 (0.07)	-0.0130 (0.13)		
Age_diff							0.0232 (0.01)	0.0374 (0.04)
Log Per.Ad.Eq. Expenditure	1.555*** (0.15)	2.298*** (0.31)	1.718*** (0.24)	2.559*** (0.50)	1.649*** (0.24)	2.573*** (0.52)	1.774*** (0.18)	2.617*** (0.44)
Luminosity Score	0.0381*** (0.00)	0.0528*** (0.01)	0.0462*** (0.01)	0.0703*** (0.02)	0.0456*** (0.01)	0.0679*** (0.02)	0.0408*** (0.01)	0.0609*** (0.01)
Rural	-2.047*** (0.17)	-2.452*** (0.42)	-2.546*** (0.26)	-2.982*** (0.70)	-2.622*** (0.28)	-3.033*** (0.74)	-2.261*** (0.21)	-2.302*** (0.57)
Household size	-0.0131 (0.03)	-0.176** (0.08)	-0.0714* (0.04)	-0.148 (0.10)	-0.0736* (0.04)	-0.136 (0.10)	-0.0257 (0.03)	-0.131 (0.09)
Electric/Gas stove	1.018*** (0.30)	2.885*** (0.40)	1.044** (0.44)	3.685*** (0.73)	0.971** (0.45)	3.662*** (0.72)	1.111*** (0.39)	3.504*** (0.55)
Other stove	2.238*** (0.15)	0.902** (0.39)	2.082*** (0.22)	0.836 (0.66)	2.032*** (0.23)	0.700 (0.65)	2.238*** (0.19)	0.981** (0.48)
Womentomen	0.0131 (0.08)	-0.281 (0.18)	-0.0271 (0.11)	-0.0606 (0.22)	-0.0642 (0.12)	-0.0785 (0.22)	-0.00473 (0.10)	-0.164 (0.21)
Head Age	-0.0270*** (0.01)	-0.0475*** (0.01)	-0.0104 (0.01)	-0.0414 (0.03)	-0.0123 (0.01)	-0.0481 (0.03)	-0.0236*** (0.01)	-0.0481** (0.02)
Log Kerosene Price	0.535 (0.45)	0.883 (0.84)	0.327 (0.59)	1.024 (1.20)	0.235 (0.58)	0.881 (1.21)	0.456 (0.52)	0.473 (1.02)

³⁰ The reference group here is neducouple (neither head nor spouse have junior secondary education).

Log Wood Price	-0.0953 (0.14)	-0.178 (0.25)	-0.110 (0.18)	-0.153 (0.32)	-0.122 (0.18)	-0.152 (0.31)	0.00660 (0.16)	-0.0833 (0.29)
Log Charcoal Price	-0.00408 (0.20)	0.0345 (0.33)	-0.0172 (0.28)	0.305 (0.53)	-0.147 (0.29)	0.181 (0.53)	-0.0617 (0.23)	-0.218 (0.43)
Log Electricity Price	0.200 (0.66)	-1.597 (1.22)	0.448 (0.94)	-2.263 (1.85)	0.623 (0.96)	-1.928 (1.85)	0.830 (0.79)	-1.584 (1.66)
Primary			0.432 (0.29)	2.593* (1.36)	1.074** (0.47)	1.744 (1.41)	0.595** (0.23)	2.557*** (0.90)
Junior Secondary			0.616 (0.39)	1.271 (1.76)	1.596** (0.65)	2.166 (1.50)	1.093*** (0.32)	3.156*** (0.91)
Secondary			0.462 (0.72)	2.901** (1.34)	1.653* (0.98)	0.583 (1.81)	0.828 (0.61)	1.818 (1.12)
Tertiary			0.910 (1.53)	4.215** (2.01)	2.479 (1.79)	3.628 (2.29)	1.263 (1.29)	4.363*** (1.48)
Constant	-27.49*** (5.15)	-31.22*** (9.53)	-30.31*** (7.29)	-38.10*** (13.63)	-29.10*** (7.52)	-37.06*** (13.71)	-33.76*** (6.01)	-35.65*** (12.49)
District dummies	YES		YES		YES		YES	
Wave Dummies	YES		YES		YES		YES	
Observations	3575		1658		1711		2675	

Standard errors in parentheses * p<0.10, ** p<0.05, *** p<0.010.

Table 11. Pooled multinomial logit regression results for measures of women's bargaining power: lighting fuels

	(1) Main Lighting Fuel (Base: Paraffin Lamps)		(2) Main Lighting Fuel (Base: Paraffin Lamps)		(3) Main Lighting Fuel (Base: Paraffin Lamps)		(4) Main Lighting Fuel (Base: Paraffin Lamps)	
	Candles/Firewood	Elec/Gas/Solar	Candles/Firewood	Elec/Gas/Solar	Candles/Firewood	Elec/Gas/Solar	Candles/Firewood	Elec/Gas/Solar
Educouple	-11.62*** (0.47)	2.616*** (0.50)						
Heducouple	-0.442 (1.05)	1.434*** (0.20)						
Seducouple	-12.76*** (0.36)	0.958*** (0.35)						
Spouse_educ			0.00391 (0.11)	0.139*** (0.05)				
Educ_diff					0.0194 (0.15)	-0.0614 (0.05)		
Age_diff							-0.0134 (0.02)	-0.00907 (0.01)
Log Per.Ad.Eq Expenditure	-1.321*** (0.20)	1.706*** (0.11)	-1.416*** (0.40)	1.551*** (0.17)	-0.937** (0.45)	1.506*** (0.18)	-1.650*** (0.25)	1.553*** (0.13)
Luminosity	0.0380*** (0.01)	0.0274*** (0.00)	0.0283 (0.02)	0.0273*** (0.01)	0.00254 (0.02)	0.0269*** (0.01)	0.0240** (0.01)	0.0273*** (0.00)
Rural	0.0914 (0.32)	-1.437*** (0.13)	-1.108* (0.57)	-1.525*** (0.18)	-0.864 (0.80)	-1.624*** (0.19)	-0.557 (0.37)	-1.542*** (0.15)
Household size	-0.213*** (0.06)	0.0856*** (0.02)	0.0589 (0.04)	0.0470 (0.03)	0.162* (0.08)	0.0410 (0.04)	-0.190** (0.08)	0.0654*** (0.02)
Women to men	-0.0141 (0.10)	0.123** (0.05)	-0.261 (0.25)	0.114 (0.08)	-0.0314 (0.25)	0.129* (0.08)	-0.0612 (0.13)	0.150** (0.06)
Head Age	-0.000427 (0.01)	0.0101** (0.00)	-0.0111 (0.02)	0.0264*** (0.01)	-0.0200 (0.02)	0.0310*** (0.01)	-0.00370 (0.01)	0.0180*** (0.01)
Log Kerosene Price	0.234 (0.83)	1.339*** (0.32)	-0.280 (2.20)	1.377*** (0.43)	-0.479 (2.18)	1.229*** (0.44)	0.384 (1.14)	1.261*** (0.36)
Log Wood Price	-0.546** (0.26)	0.0200 (0.09)	-0.433 (0.45)	-0.00403 (0.13)	0.156 (0.44)	-0.0295 (0.13)	-0.451 (0.32)	-0.0277 (0.11)
Log Electricity	4.187** (1.90)	0.0933 (0.61)	-1.122 (2.64)	0.0517 (0.83)	-2.204 (3.44)	0.0808 (0.86)	2.188 (1.81)	0.314 (0.73)
Primary			-0.727 (0.48)	0.502** (0.22)	0.466 (0.71)	0.878*** (0.30)	-0.230 (0.31)	0.680*** (0.17)
Junior Sec.			-14.15*** (0.52)	1.501*** (0.28)	-13.37*** (0.82)	2.139*** (0.42)	-0.517 (1.08)	1.983*** (0.24)
Secondary			-13.85*** (0.73)	1.723*** (0.49)	-13.00*** (1.14)	2.427*** (0.66)	-11.67*** (0.53)	2.294*** (0.48)

Tertiary			-12.69***	1.898**	-11.81***	3.154***	-10.11***	3.812**
			(1.47)	(0.95)	(1.79)	(1.02)	(0.93)	(1.48)
Constant	-5.619	-35.35***	25.66	-34.62***	21.65	-32.51***	8.212	-34.23***
	(10.83)	(3.84)	(20.63)	(5.53)	(21.64)	(5.68)	(11.90)	(4.59)
District Dummies	YES		YES		YES		YES	
Wave Dummies	YES		YES		YES		YES	
Observations	5007		2328		2102		3740	

Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.010.

Table 12. Panel GLS estimates of women's intra-household bargaining power: stacking behaviour

	(1) Stacking Index	(2) Stacking Index	(3) Stacking Index	(4) Stacking Index
Educouple	0.112*** (0.01)			
Heducouple	0.0496*** (0.01)			
Seducouple	0.0505*** (0.01)			
Spouse_educ		0.00678*** (0.00)		
Educ_diff			-0.00230 (0.00)	
Age_diff				0.000148 (0.00)
Log Per.Ad.Eq.Expenditure	0.0372*** (0.00)	0.0357*** (0.00)	0.0399*** (0.01)	0.0310*** (0.00)
Luminosity	0.00228*** (0.00)	0.00262*** (0.00)	0.00263*** (0.00)	0.00245*** (0.00)
Rural	-0.0280*** (0.00)	-0.0277*** (0.01)	-0.0309*** (0.01)	-0.0282*** (0.00)
Household size	0.00185*** (0.00)	0.00197* (0.00)	0.00221* (0.00)	0.00181** (0.00)
Women to men	-0.000489 (0.00)	-0.00150 (0.00)	-0.00138 (0.00)	-0.000619 (0.00)
Log Kerosene Price	0.0218** (0.01)	0.0135 (0.01)	0.0126 (0.02)	0.0176 (0.01)
Log Electricity Price	0.00225 (0.02)	0.0177 (0.03)	0.0245 (0.03)	0.0113 (0.02)
Log Wood Price	-0.00754*** (0.00)	-0.00967** (0.00)	-0.0123** (0.00)	-0.00943*** (0.00)
Log Charcoal Price	0.00659 (0.00)	0.00664 (0.01)	0.0102 (0.01)	0.00585 (0.00)
primary		-0.000511 (0.01)	0.0128 (0.01)	0.00956** (0.00)
junsec		0.0517*** (0.01)	0.0758*** (0.01)	0.0674*** (0.01)
sec		0.0528*** (0.02)	0.0797*** (0.02)	0.0927*** (0.02)
tertiary		0.105*** (0.02)	0.153*** (0.03)	0.160*** (0.02)
Constant	-0.626*** (0.11)	-0.665*** (0.18)	-0.722*** (0.20)	-0.560*** (0.13)
District Dummies	YES	YES	YES	YES
Wave Dummies	YES	YES	YES	YES
Observations	4936	2311	2085	3695

Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.010.

5. Discussion and Conclusion

5.1. Stacking up the ladder

Our results suggest that the energy use decisions of Tanzanian households conform to the energy stacking hypothesis. By all four measures we derive, we find that increases in household income are associated with an increase in measured fuel stacking. In addition, our results suggest that Tanzanian households stack up the ladder. The energy transition as incomes increase is complicated by evidence that even relatively well-off households with access to electricity may still prefer to use charcoal as a main cooking fuel over modern fuels.

Our results also highlight the differences in the rates with which households are willing and/or able to change their main lighting fuels, as opposed to their cooking fuels, as incomes increase. Whilst more well-off households do transition away from the use of firewood and animal residue as main cooking fuels, this is largely a transition towards the use of charcoal, rather than to modern fuels. A much larger proportion of households uses mainly modern lighting fuels. As household incomes rise, a transition “up the ladder” does take place. However, in the case of cooking fuels, this transition is a partial one and is mostly characterised by the transition away from firewood and animal residue towards charcoal.

Lighting fuels show much more variability across income strata, suggesting that households find it easier and/or more preferable to substitute traditional lighting fuels for modern fuels than for cooking fuels. There are a range of possible reasons for this result. The first relates to the cost of infrastructure associated with changing cooking fuels. Stoves and gas bottles are expensive in relation to solar lamps or fittings for electric lighting. This also speaks to the large expansion of low cost, micro-solar technology in much of Tanzania (Ondraczek, 2013). In addition, Ruiz-Mercado and Masera (2015) raise the issue that modern fuels are not perfect substitutes for traditional fuels, especially in the case of cooking. In this regard, the preferences such as taste, which may inhibit households from changing to modern cooking fuels, are likely not to be present in the case of lighting fuels. The substitutability of lighting fuels is higher than that of cooking fuels. Thirdly, the opportunity costs of undependable electricity or gas supplies is likely to be higher for cooking activities than for lighting activities, and factors such as the reliability of supply may be an additional important reason why households continue relying mainly on traditional fuels for cooking.

5.2. Do prices matter?

Households' behaviour discussed above also explain the results which highlight that in the case of charcoal use for cooking, the own-price elasticity of demand is likely to be relatively inelastic. Our regression estimates show no significant own-price effects on the choice of charcoal as a main cooking fuel. The general Le Chatelier-Samuelson principle which attests to the increased elasticity of long-run demand can also help explain this (Milgrom and Roberts, 1996). In this regard, households that face

constrained supplies of a particular good (in this case, modern fuels), have lower price elasticities of the compensated demand for alternative fuels (in this case, charcoal). Our results also suggest that kerosene prices are significantly correlated with the probability of adopting modern lighting fuels. However, cooking fuel choices are not found to be responsive to prices, suggesting that fuel levies encouraging the uptake of modern cooking fuels may be regressive. Policy makers may find it easier to encourage a household transition towards the use of modern lighting fuels, which households are more willing to substitute than cooking fuels. Pricing could thus be a more effective demand-management tool in countries where access and supply of modern fuels is secured.

In any case, adoption of electricity in Tanzania will likely be slow as evidenced in a recent impact evaluation of a large energy project in the country funded by the Millennium Challenge Corporation (MCC) specifically investigating the impact of building new lines to the electricity grid and providing availability of low-cost connections to some households (Chaplin et al., 2017). The slow adoption of modern technologies is not new and has been nicely described by David (1990) in his analysis of the “productivity paradox” and the slow uptake of electricity in the USA. The author also warns of the “pitfall of unrealistic impatience into which current discussions of the productivity paradox seem to plunge all too frequently”.

5.3. Does technology matter?

In our dataset, we cannot make a precise distinction between different types of cook stoves. This would deserve further attention in the context of Tanzania. In their systematic review on who adopts improved fuels and cookstoves, Lewis and Pattanayak (2012) find that cookstoves programmes have low rates of adoption in developing economies, and this despite the triple dividends (household health, local environmental quality, and regional climate benefits) that could result from the use of improved cook stoves and clean fuels. Yet some studies find encouraging results. For example, Brooks et al. (2016) investigate the impact of using clean cook stoves, mostly LPG stoves, in North India and find that it reduces the quantity of biomass fuel used cooking with traditional stoves and time spent collecting biomass fuels. They also find that socio-economic status (better-off and better educated households) is a key factor in explaining the adoption of clean cook stoves. Unfortunately, most household surveys do not provide such detailed information.

From a policy perspective, the adoption of clean cook stoves raises two interesting questions. Firstly, how to promote the use of cleaner technologies, especially by the poorer segments of the population. Secondly, how to manage the fact that households cook on multiple stoves attenuating the benefits of using clean cook stoves? In order for the adverse effects of the use of biomass and solid fuels to be addressed, more creative policy would be necessary to minimise these effects in a context of fuel stacking. In this regard, policies which aid households in funding or accessing credit to purchase electric and gas stoves may be

useful in encouraging the use of clean fuels for cooking. Ultimately what matters is the technology used, especially for cooking, and whether cooking in a separate room or not.

5.4. Does women's bargaining power matter?

Our results show that the level of education of the spouse in the household is positively correlated with the uptake of modern lighting fuels, controlling for the level of education of the husband. At the same time the results suggest that it is the combined educational attainment of the husband and wife which drives of fuel choices. Inequality in educational attainment or age seem to be less important in fuel choice decisions. However, this warrants further investigation.

Our analysis shows that understanding intra-household dynamics is an important dimension of targeting interventions and policies in the energy sector. Women are often seen as “agents of change” (Pachauri and Rao, 2013) and further research should expand to account for all family members including in-laws and siblings to better understand both fuel choices decisions, and the decision to invest or not in improved cook stoves, in line with Miller and Mobarak (2013).

5.5. Is fuel stacking desirable from a policy perspective?

A key question raised by the evidence of fuel stacking behaviour concerns whether fuel stacking is desirable from a policy perspective. On the one hand, at the household level, there are clear reasons why households engage in fuel stacking, including to mitigate against the risks associated with dependence on only one fuel in a context where supply and prices may be variable. However, from a broader public-health perspective, Ruiz-Mercado and Masera (2015), for example, attest to the negative effects fuel stacking has on policy goals such as decreasing indoor air pollution. They find firstly that in a context where households mix traditional and modern fuels, savings in firewood and resultant levels of deforestation are likely to be very modest. Secondly, energy savings are likely to be much less than if modern fuels were fully adopted. In one study, for example, it was found that mixed fuel users consume more energy than households which rely on firewood (Masera et al., 2000). Thirdly, Ruiz-Mercado and Masera (2015) point out that reductions of air pollution, within households, are likely to be modest in a fuel mixing context. The same arguments are likely to extend to other factors such as gendered roles which cast women as the main collectors of firewood. Given these consequences of energy stacking, a government energy policy aimed mostly at the rollout of electrical infrastructure would come up short in its attempt to address the various policy goals with which this rollout is associated.

As a result, should we give more weight to health arguments to implement energy policies? Indeed, the questions addressed in this paper do not relate only to Tanzania's energy policy and economic development, but also to health policies, thus understanding the barriers to adoption in the context on Tanzania will be crucial. Acute respiratory infections are a major cause of death in children under five and is more likely to occur in those suffering from existing respiratory conditions due to indoor air

pollution from the use of biomass fuels (Bruce et al., 2000; Collings et al., 1990). Moreover, although there remain significant gaps in the literature on household air pollution despite significant progress in research (Jeuland et al., 2015; Lewis et al., 2017), Rosenthal et al. (2017) rightly argue that “the challenge is to accelerate the widespread, sustained adoption of demonstrably clean cooking to promote public health”. The answer to these questions is not straightforward since, from a sustainability analysis, the impacts of different fuels vary. In terms of health impacts, the most detrimental fuel is firewood, followed by charcoal, and then LPG. However, the health impact of these fuels depends on the use of appropriate equipment.³¹

³¹ In terms of environmental impacts, the most polluting fuel is charcoal, followed by firewood. Finally, in terms of job creation, the fuel that provides the fewest opportunities is kerosene, followed by LPG, and then by fuelwood and charcoal (Sepp, 2014).

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Appendix

Annex 1. Yearly summary statistics of explanatory variables

Variable	2008/2009				2010/2011				2012/2013			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
<i>Household Characteristics</i>												
Less than primary	0.41	0.49	0	1	0.41	0.49	0	1	0.40	0.49	0	1
Primary School	0.47	0.50	0	1	0.48	0.50	0	1	0.47	0.50	0	1
Junior Secondary	0.08	0.27	0	1	0.08	0.26	0	1	0.08	0.27	0	1
Secondary	0.02	0.13	0	1	0.02	0.12	0	1	0.02	0.13	0	1
Tertiary	0.01	0.09	0	1	0.01	0.09	0	1	0.01	0.10	0	1
HH Size	5.08	2.84	1	46	5.47	3.06	1	55	5.45	3.07	1	54
Head Age	46.15	15.41	18	102	47.91	15.20	16	105	49.53	15.09	18	107
Ratio of women to men	1.27	1.02	0	8	1.29	1.11	0	8	1.27	1.10	0	8
Dependency ratio	104.80	93.93	0	800	102.33	88.00	0	700	99.16	85.23	0	700
Female Headed Household	0.24	0.43	0	1	0.24	0.43	0	1	0.25	0.43	0	1
<i>Household main cooking fuel</i>												
Firewood/Animal Residue	0.72	0.45	0	1	0.70	0.46	0	1	0.70	0.46	0	1
Charcoal	0.23	0.42	0	1	0.25	0.43	0	1	0.26	0.44	0	1
Electricity/Gas/Kerosene	0.04	0.20	0	1	0.04	0.20	0	1	0.03	0.18	0	1
<i>Household main lighting fuel</i>												
Candles/Firewood	0.02	0.15	0	1	0.02	0.14	0	1	0.02	0.15	0	1
Paraffin Lamps	0.75	0.43	0	1	0.68	0.47	0	1	0.52	0.50	0	1
Electricity/Solar/Gas	0.21	0.41	0	1	0.23	0.42	0	1	0.26	0.44	0	1
<i>Socio-economic status indicators</i>												
Log per-adult-equivalent expenditure	13.15	0.71	10.57	16.36	13.45	0.69	11.24	16.03	13.94	0.71	10.95	16.72
Wealthindex score	-0.12	1.94	-2.61	15.41	0.01	1.97	-2.82	13.78	0.11	2.00	-2.82	12.78
Elec/Gas stove ownership	1.00	0.00	0	1	0.07	0.25	0	1	0.06	0.24	0	1
Other stove ownership	1.00	0.00	0	1	0.50	0.50	0	1	0.40	0.49	0	1

<i>Fuel Prices</i>													
Log Kerosene price	7.08	0.18	5.18	7.54	7.37	0.18	6.46	8.00	8.05	0.14	7.46	8.51	
Log Wood Price	4.17	0.46	3.23	6.44	5.10	0.61	4.02	8.40	5.70	0.35	4.26	6.36	
Log Electricity Price	4.96	0.05	4.88	4.99	5.30	0.15	5.05	5.39	5.92	0.04	5.87	5.95	
Log Charcoal price	5.10	0.43	3.73	9.52	6.04	0.46	4.23	7.82	6.27	0.39	4.95	8.33	
<i>Stacking Measures</i>													
Simple Stacking	1.44	0.78	0	4	0.40	0.83	0	4	1.25	0.92	0	4	
Directional Stacking	0.09	0.19	0	1	0.10	0.21	0	1	0.14	0.25	0	1	
Share Stacking	0.10	0.22	0	1	0.11	0.25	0	1	0.15	0.28	0	1	
Stacking Index	0.06	0.14	0	0.94	0.07	0.15	0	0.94	0.09	0.16	0	0.97	
<i>Locational characteristics</i>													
Rural household	0.65	0.48	0	1	0.69	0.46	0	1	0.66	0.47	0	1	
Luminosity Score	7.45	16.95	0	63	10.84	10.84	0	63	9.74	19.31	0	63	
<i>Administrative zone dummy variables</i>													
Lake	0.10	0.29	0	1	0.09	0.29	0	1	0.10	0.30	0	1	
Western	0.11	0.31	0	1	0.11	0.31	0	1	0.11	0.31	0	1	
Northern	0.13	0.33	0	1	0.12	0.33	0	1	0.12	0.33	0	1	
Central	0.05	0.21	0	1	0.05	0.22	0	1	0.05	0.21	0	1	
Southern Highlands	0.11	0.32	0	1	0.11	0.32	0	1	0.11	0.32	0	1	
Eastern	0.21	0.41	0	1	0.21	0.41	0	1	0.21	0.41	0	1	
Southern	0.15	0.36	0	1	0.15	0.36	0	1	0.15	0.36	0	1	
Zanzibar	0.15	0.35	0	1	0.14	0.35	0	1	0.14	0.35	0	1	

Source: Authors' own calculations using TZNPS (2008-2013) data.

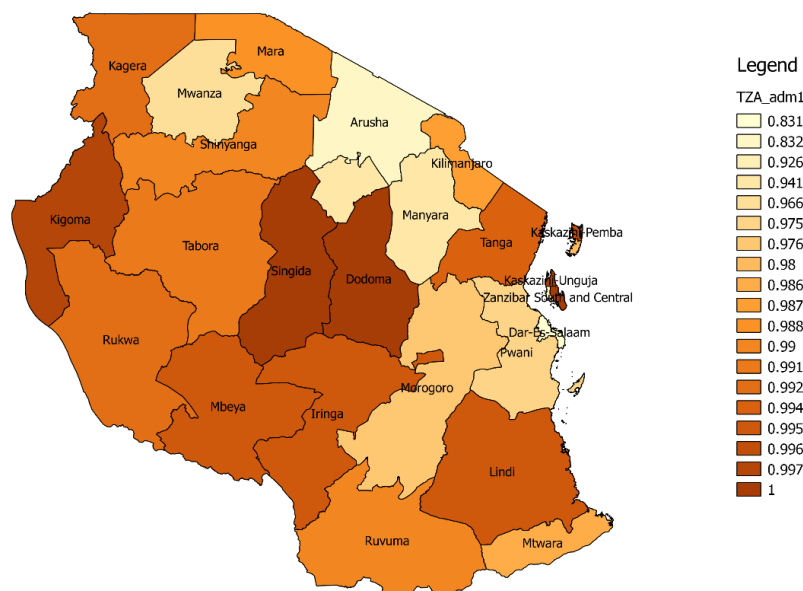
Annex 2. Yearly summary statistics of intra-household bargaining power proxy variables

Variable	2008/2009				2010/2011				2012/2013			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Educouple	0.03	0.17	0	1	0.03	0.17	0	1	0.04	0.19	0	1
Seducouple	0.02	0.14	0	1	0.02	0.14	0	1	0.02	0.15	0	1
Heducouple	0.08	0.27	0	1	0.07	0.26	0	1	0.07	0.26	0	1
Neducouple	0.84	0.37	0	1	0.85	0.35	0	1	0.85	0.36	0	1
Age difference	7.64	6.79	-20	53	7.79	6.79	-13	53	7.97	6.94	-13	53
Education difference	0.50	2.44	-7	10	0.42	2.38	-9	10	0.42	2.42	-7	9
Spouse Education	7.02	2.12	0	18	7.03	2.06	0	18	7.10	2.09	1	18

Source: Authors' own calculations using TZNPS (2008-2013) data. N=1,901 in each wave.

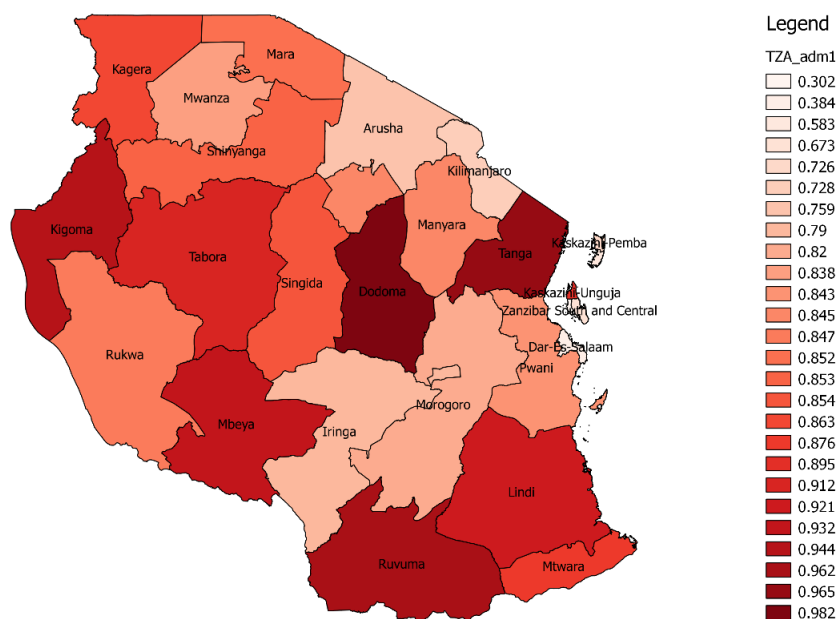
Annex 3. Spatial heterogeneity in traditional cooking and lighting fuel dependency in Tanzania

Proportion of households using mainly firewood, animal residue or charcoal for cooking fuel



Source: Authors' own calculations from TZNPS (2008-2013) pooled data. Note: The sampling strategy of the TZNPS is such that these statistics are not representative at the regional level.

Proportion of households using mainly candles, firewood or paraffin lamps for lighting fuel



Source: Authors' own calculations from TZNPS (2008-2013) pooled data. Note: The sampling strategy of the TZNPS is such that these statistics are not representative at the regional level.

Annex 4. Multinomial logit regression results – Cooking fuels

	(1) POMLOGIT	(2) REMLOGIT	(3) FEMLOGIT	(4) REMLOGIT
Charcoal				
Log per ad. eq. expenditure	1.531*** (0.15)	2.385*** (0.27)	1.025*** (0.32)	
Wealth Index Score				0.751*** (0.09)
Luminosity	0.0369*** (0.00)	0.0689*** (0.01)	0.0464* (0.02)	0.0767*** (0.01)
Rural Households	-2.030*** (0.15)	-3.216*** (0.33)		-2.978*** (0.33)
Primary	0.568*** (0.17)	1.001*** (0.30)		0.748** (0.31)
Junior Secondary	1.280*** (0.24)	2.403*** (0.45)		2.112*** (0.46)
Secondary	1.265*** (0.42)	2.548*** (0.87)		2.116** (0.88)
Tertiary	1.887 (1.28)	2.485 (1.52)		2.472 (1.56)
Female Headed HH	0.498*** (0.18)	0.712** (0.30)	-1.200 (0.77)	0.839*** (0.31)
Household size	-0.01000 (0.02)	-0.0373 (0.05)	-0.325*** (0.12)	-0.360*** (0.06)
Elec/Gas stove	1.023*** (0.30)	1.369*** (0.44)	0.314 (0.46)	1.331*** (0.46)
Other stove	2.168*** (0.16)	2.934*** (0.28)	1.265*** (0.29)	2.766*** (0.29)
Ratio of women to men	0.00823 (0.07)	0.0399 (0.10)		0.0269 (0.11)
HH Head age	-0.0228*** (0.01)	-0.0308*** (0.01)		-0.0527*** (0.01)
Log Kerosene price	0.461 (0.45)	0.273 (0.67)		-0.0178 (0.69)
Log Firewood price	-0.0778 (0.14)	-0.137 (0.21)		-0.188 (0.22)
Log Charcoal price	0.0402 (0.19)	0.0747 (0.30)		-0.00301 (0.31)
Log Electricity price	0.210 (0.63)	0.332 (1.16)		0.909 (1.23)
Constant	-27.59*** (5.14)	-39.99*** (8.11)		-6.046 (7.49)
Electricity/Gas/Kerosene				
Log per ad. eq. expenditure	2.143*** (0.29)	3.236*** (0.46)	1.099** (0.48)	
Wealth Index Score				0.768*** (0.15)
Luminosity	0.0511*** (0.01)	0.0851*** (0.01)	0.0410 (0.03)	0.105*** (0.02)
Rural Households	-2.428*** (0.39)	-3.843*** (0.59)		-3.764*** (0.63)
Primary	1.565*** (0.51)	2.310*** (0.74)		1.845** (0.78)
Junior Secondary	2.355*** (0.55)	4.094*** (0.87)		3.982*** (0.93)
Secondary	1.946** (0.78)	3.655*** (1.28)		3.507*** (1.35)
Tertiary	4.367*** (1.34)	5.656*** (1.74)		5.865*** (1.84)
Female Headed HH	-0.464 (0.52)	-0.0904 (0.61)	-0.485 (1.44)	-0.206 (0.68)
Household size	-0.187** (0.08)	-0.250*** (0.10)	-0.666*** (0.18)	-0.658*** (0.12)
Elec/Gas stove	2.750*** (0.40)	3.673*** (0.67)	1.254** (0.63)	4.240*** (0.76)
Other stove	0.843** (0.35)	1.424*** (0.55)	1.007* (0.58)	1.280** (0.60)
Ratio of women to men	-0.247 (0.16)	-0.280 (0.22)		-0.402 (0.25)
HH Head age	-0.0435*** (0.01)	-0.0523*** (0.02)		-0.0778*** (0.02)

Log Kerosene price	1.267 (0.85)	1.293 (1.17)		0.902 (1.30)
Log Firewood price	-0.140 (0.25)	-0.197 (0.33)		-0.504 (0.38)
Log Charcoal price	0.134 (0.32)	0.151 (0.50)		0.172 (0.56)
Log Electricity price	-1.871 (1.23)	-2.594 (1.94)		-1.206 (2.18)
Constant	-32.21*** (9.37)	-46.17*** (13.63)		-3.499 (13.36)
Admin. District. Dummy Variables	YES	YES	No	YES
Wave Dummy Variables	YES	YES	YES	YES
var(RI2[hhid]) constant		5.506*** (1.27)		6.379*** (1.46)
var(RI3[hhid]) constant		9.082*** (2.78)		13.52*** (3.84)
cov(RI3[hhid],RI2[hhid]) constant		6.010*** (1.64)		8.230*** (2.05)
Log likelihood	-1007.09	-958.58	-192.93	-949.01
Pseudo R2	0.57		0.21	
Observations	3575	3575	691	3528

* p<0.10, ** p<0.05, *** p<0.010. Standard errors in parentheses. "Firewood and animal residue" is used as base outcome. Equation (4) is presented using the constructed wealth index as an alternative measure of socio-economic status to per-adult-equivalent expenditure which is used in the first three equations.

POMLOGIT: Pooled multinomial logit (mlogit)

REMLOGIT: Random Effects multinomial logit (gsem)

FEMLOGIT: Fixed Effects multinomial logit (femlogit)

Annex 5. Multinomial logit regression results - lighting fuels

	(1)	(2)	(3)	(4)
	POMLOGIT	REMLOGIT	FEMLOGIT	REMLOGIT
Elec/Solar/Gas				
Log per.ed.eq.expenditure	1.594*** (0.11)	2.548*** (0.24)	0.450** (0.21)	
Wealth Index Score				1.251*** (0.09)
Luminosity	0.0269*** (0.00)	0.0878*** (0.01)	0.0512*** (0.01)	0.0750*** (0.01)
Rural Households	-1.422*** (0.11)	-2.823*** (0.30)		-1.971*** (0.28)
Primary	0.712*** (0.12)	1.753*** (0.31)		0.719** (0.29)
Junior Secondary	2.186*** (0.17)	4.858*** (0.52)		3.107*** (0.45)
Secondary	2.873*** (0.38)	6.547*** (1.11)		4.577*** (1.01)
Tertiary	3.078*** (1.02)	5.926*** (1.56)		5.701*** (2.01)
Female Headed HH	-0.392*** (0.13)	-0.861** (0.35)	-0.855 (0.55)	-0.563* (0.33)
Household size	0.0812*** (0.02)	0.122*** (0.04)	0.0695 (0.07)	-0.272*** (0.05)
Ratio of women to men	0.173*** (0.04)	0.287** (0.11)		0.225** (0.11)
HH Head age	0.0201*** (0.00)	0.0360*** (0.01)		0.00608 (0.01)
Log Kerosene price	1.405*** (0.31)	2.375*** (0.66)		1.935*** (0.64)
Log Firewood price	0.0368 (0.09)	0.230 (0.20)		-0.0206 (0.19)
Log Electricity price	0.276 (0.56)	-0.0383 (1.23)		0.811 (1.24)
Constant	-36.30*** (3.65)	-59.77*** (8.42)		-21.68*** (7.52)
Candles/Firewood				
Log per.ed.eq.expenditure	-1.319*** (0.20)	-1.530*** (0.29)	-0.491* (0.29)	
Wealth Index Score				-0.585*** (0.17)
Luminosity	0.0406*** (0.01)	0.0500*** (0.01)	0.0455 (0.04)	0.0623*** (0.01)
Rural Households	0.0229 (0.31)	-0.231 (0.46)		-0.775 (0.48)
Primary	-0.536** (0.24)	-0.558 (0.34)		-0.348 (0.35)
Junior Secondary	-0.212 (0.75)	-0.192 (0.99)		0.553 (0.94)
Secondary	-11.17*** (0.43)	-30.26 (5420030.56)		-25.15 (936161.96)
Tertiary	-10.20*** (0.68)	-29.03 (10711063.07)		-22.13 (1608551.91)
Female Headed HH	-0.380 (0.25)	-0.564 (0.38)	-1.666* (0.85)	-0.692* (0.39)
Household size	-0.212*** (0.06)	-0.257*** (0.07)	-0.249** (0.11)	-0.0949 (0.07)
Ratio of women to men	0.0196 (0.10)	0.0274 (0.13)		0.00551 (0.13)
HH Head age	-0.00567 (0.01)	-0.00530 (0.01)		0.00231 (0.01)
Log Kerosene price	0.235 (0.84)	0.450 (1.13)		0.772 (1.11)
Log Firewood price	-0.562** (0.25)	-0.730** (0.34)		-0.691** (0.34)
Log Electricity price	4.382** (1.82)	4.755** (2.10)		3.699* (2.00)
Constant	-5.973 (10.83)	-7.489 (13.83)		-25.66** (12.98)
Wave Dummy Variables	YES	YES	YES	YES

Admin. District Dummy Variables	YES	YES	NO	YES
var(RI2[hhid]) Constant		5.136*** (1.67)		5.801*** (1.90)
var(RI3[hhid]) Constant		16.47*** (3.11)		11.31*** (1.79)
cov(RI3[hhid],RI2[hhid]) Constant		0.635 (0.84)		5.747*** (1.95)
Log likelihood	-1899.0197	-1666.0519	-340.75755	-1551.422
Pseudo R2	0.39		0.22	
Observations	5007	5007	1202	4947

* p<0.10, ** p<0.05, *** p<0.010. Standard errors in parentheses. Lamp oil (paraffin/kerosene) as base outcome. Source: Authors' own calculations using TZNPS (2008-2013) data.

POMLOGIT: Pooled multinomial logit (mlogit)

REMLOGIT: Random Effects multinomial logit (gsem)

FEMLOGIT: Fixed Effects multinomial logit (femlogit)

Annex 6. Marginal effects of changes in log per-adult-equivalent expenditure at various points of the expenditure distribution.

At:	p25	p50	p75	p90	p95	p99	Mean	
Main Cooking Fuel	Firewood& Animal Residue	-0.093***	-0.105***	-0.125***	-0.152***	-0.170***	-0.211***	-0.106***
	(S.E)	0.009	0.011	0.016	0.021	0.025	0.037	0.012
	Charcoal	0.086***	0.095***	0.112***	0.135***	0.150***	0.182***	0.097***
	(S.E)	0.009	0.011	0.016	0.022	0.026	0.038	0.012
	Electricity, Gas, Kerosene	0.007***	0.009***	0.013***	0.017**	0.020**	0.029	0.010***
	(S.E)	0.001	0.002	0.004	0.007	0.010	0.018	0.002
Main Lighting Fuel	Firewood, Candles	-0.019**	-0.010**	-0.004**	-0.001**	-0.001*	0.000	-0.009**
	(S.E)	0.009	0.004	0.002	0.001	0.000	0.000	0.004
	Lamp Oil	-0.064***	-0.089***	-0.115***	-0.140***	-0.158***	-0.204***	-0.092***
	(S.E)	0.009	0.009	0.013	0.018	0.022	0.035	0.010
	Electricity, Gas, Solar	0.083***	0.098***	0.119***	0.142***	0.159***	0.205***	0.100***
	(S.E)	0.006	0.009	0.013	0.018	0.022	0.035	0.009

* p<0.10, ** p<0.05, *** p<0.010. Source: Authors' own calculations using TZNPS (2008-2013) data. Marginal effects calculated from random effects estimates presented in Annexes 5 and 6.

Annex 7. Stacking results: robustness to different measures of stacking behaviour

	(1)	(2)	(3)	(4)
	Simple Stacking	Directional Stacking	Share Stacking	Stacking Index
Log per.ad.eq.expenditure	0.244*** (0.01)	0.0468*** (0.00)	0.0514*** (0.01)	0.0343*** (0.00)
Luminosity	0.0104*** (0.00)	0.00305*** (0.00)	0.00327*** (0.00)	0.00217*** (0.00)
Rural Households	-0.448*** (0.02)	-0.0462*** (0.01)	-0.0403*** (0.01)	-0.0269*** (0.00)
Primary	0.131*** (0.02)	0.0149*** (0.01)	0.0163** (0.01)	0.00803** (0.00)
Junior Secondary	0.407*** (0.04)	0.112*** (0.01)	0.122*** (0.01)	0.0748*** (0.01)
Secondary	0.671*** (0.07)	0.120*** (0.02)	0.148*** (0.02)	0.117*** (0.01)
Tertiary	0.504*** (0.10)	0.286*** (0.03)	0.324*** (0.03)	0.192*** (0.02)
Female Headed HH	0.0703*** (0.02)	-0.0123* (0.01)	-0.0145* (0.01)	-0.00674 (0.00)
Household Size	0.0143*** (0.00)	0.0000625 (0.00)	0.00136 (0.00)	0.00192*** (0.00)
Ratio of Women to Men	0.0217*** (0.01)	0.00316 (0.00)	0.000816 (0.00)	0.000724 (0.00)
Log Kerosene Price	0.200*** (0.05)	0.0568*** (0.01)	0.0486*** (0.02)	0.0234** (0.01)
Log Electricity Price	-0.118 (0.09)	-0.0183 (0.03)	-0.0116 (0.03)	0.00318 (0.02)
Log Firewood Price	-0.0185 (0.02)	-0.0159*** (0.00)	-0.0158*** (0.01)	-0.00680** (0.00)
Log Charcoal Price	0.0411* (0.02)	0.00668 (0.01)	0.00981 (0.01)	0.00707* (0.00)
Constant	-2.754*** (0.63)	-0.830*** (0.17)	-0.896*** (0.20)	-0.617*** (0.11)
Administrative district dummy variables	YES	YES	YES	YES
Wave dummy variables	YES	YES	YES	YES
Observations	5562	4936	4936	4936
R Squared	0.49	0.37	0.36	0.41

* p<0.10, ** p<0.05, *** p<0.010. Source: Authors' own calculations using TZNPS (2008-2013) data. Note: The dependent variables in each of the equations above refer to the stacking measures outlined in Table 1.

Available from the authors upon request

Creation of a wealth index as an alternative measure of socio-economic status

In order to provide an alternative indication of household socio-economic status to expenditure, a wealth index is created from the questions in the TZNPS related to assets and living conditions.

Firstly, assets and housing variables are identified in the questionnaires. The TZNPS contains asset counts for each asset variable. This has a clear advantage over the largely dummy-variable nature of many other surveys of capturing much more variation in responses. In addition to asset counts, information on the household's source of water in the dry season, as well as the material from which the household floor is constructed and included in the wealth index. In order to create a wealth index that is not itself a proxy for electricity access, we opt to include only variables which do not require direct household access to electricity. Wittenberg and Leibbrandt (2015)³² note that given rural-urban disparities in electricity access, asset indices which rely heavily on assets that require access to electricity can lead to distortions. Mobile phones are still included as it is common to charge mobile phones in shops or in neighbours' homes in Tanzania. In addition, radios are included on the pretext that they are likely to be battery powered. Stoves, both electric/gas and other types are not included in order to be included separately in the regression as a variable of interest.

Secondly, households with missing values for these variables are dropped from the analysis. Though this could result in a biasing of the results if the number of households with missing variables was large, only 1.3% of households had missing responses to any of the questions on asset variables. Moreover, missing values are evenly distributed over the three waves. There is, thus, little chance of this decision affecting the validity of the index, whilst allowing for a more complete asset index.

Thirdly, in order to account for the panel structure of the data, wealth scores are predicted for each household in each wave, using Principal Component Analysis (PCA). In order to do this, a mean asset count for each of the variables entered into the wealth index is created for each household, based on the pooled data. PCA is carried out on these mean values to create a base wealth index score for each household. Thereafter, yearly wealth scores are predicted relative to this base-wealth score. As a robustness check, this method was also carried out, using a pooled sample of all three waves to derive the index. Both methods yielded very similar results in regressions.

PCA was used to derive the asset index, resulting in a measure with a mean of zero and standard deviation of 1. Given that the majority of the variables included are count data, as well as the ordinal nature of the

³² Wittenberg, M., Leibbrandt, M., 2015. "Measuring inequality by asset indices: A general approach with application to South Africa (working paper)".

two infrastructure variables, PCA is an acceptable approach. The values of the wealth index were then projected onto the three waves in the panel to create a household level wealth index score for each wave.

The table below provides an outline of the various assets which constitute the index. In the case of the two categorical variables: “Floor type” and “Main water source in the dry season”?, the percentage attributable to each category is displayed. In addition, the weight of each variable in the final index is displayed.

Summary of variables used in the derivation of the wealth index

Component	Type/Categories	Mean Count /Percentage	Weight Multipliers in Index
Sofa	count	1.1	0.4075
Mobile Phone	count	1.1	0.4582
Radio	count	0.8	0.3117
Motorcycle	count	0.1	0.2367
Car	count	0.05	0.2581
Bicycle	count	0.5	0.1563
Bed	count	2.4	0.3421
Floor type	(Ordinal) 0=Earth	56.91%	0.4027
	1=Concrete/Cement/Tiles/Timber	43.09%	
Main water source in dry season	(Ordinal) 1=Open water sources	13.6%	0.3173
	2=Water from a well	35.4%	
	3=Water vendor/Truck	7.7%	
	4=Public tap	15.1%	
	5=Neighbour’s tap	11.1%	
	6=Private tapped water	17.2%	