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ENERGY DEMAND SUBSTITUTION FROM BIOMASS TO IMPORTED KEROSENE: EVIDENCE FROM TANZANIA

By

Michael Olabisi, David L. Tschirley, David Nyange and Titus Awokuse

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ABSTRACT

We analyze domestic household energy demand and use patterns in Tanzania, using a detailed household survey of purchase transactions, a multivariate probit model, and the QUAIDS modeling framework. The main fuel sources that we study are kerosene, charcoal, and firewood. These three accounted for 96.5% of spending on energy by households. Charcoal and firewood are used for cooking while kerosene is used for both lighting and cooking. Kerosene is almost exclusively imported, while charcoal and firewood are produced domestically. These fuel sources are important, given the impacts of wood harvesting on the environment and kerosene imports on public finances. We find a statistically significant response in kerosene demand to charcoal prices, suggesting a pattern of substitution, but no strong substitution relationships between other fuel-pairs. These results, which we used in a simulation of tariff change, imply that policies centered on price changes may not be effective in changing consumer behavior unless alternative sources of energy are readily accessible.

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1. Introduction

In sub-Saharan Africa, about 600 million people rely primarily on firewood, charcoal and other traditional biomass forms for their energy needs (Brew-Hammond, 2010). These numbers are expected to rise to 700 million by 2030, with potentially serious consequences for natural forests, managed land, and the health of the continent's people. The overriding need, from a policy perspective, is to successfully manage the energy transition from biomass to electricity and other clean energy sources.

We study household energy choices in Tanzania, estimating the own-price and cross-price elasticities of firewood, charcoal and kerosene, using household level purchase transaction data. We focus on Tanzania for several reasons. First, roughly 95% of Tanzanian households are reliant on traditional biomass sources like charcoal and firewood for cooking and heating purposes (Brew-Hammond, 2010). Kerosene is used for both cooking and lighting. The dependency on charcoal, firewood and kerosene is much higher for rural populations where poverty is pervasive and access to alternative energy sources such as grid electricity is limited. In the data, 88% and 30% of the rural population use firewood and charcoal respectively, compared with 30% and 79% of the urban population. 8% of urban households use energy sources outside the three main fuels, compared with 1% of rural households. Underlying the pattern is the fact that 33 % of Tanzanian households in 2016 had access to grid electricity; others largely depended on nature for fuel.

In our sample, 93% of the households use wood and charcoal. The growing population, like most of sub-Saharan Africa, put natural forests and their own health at risk, as households turn standing trees to firewood (Zulu and Richardson, 2013). Total annual charcoal consumption is estimated at 1 million tons. Annual wood need for charcoal production is estimated at 20 million cubic meters. Charcoal production is attributed to contribute up to 125,000 ha of the total 400,000 ha of deforested land annually (UTR, 2016). With the burgeoning population (2.8% per annum) and rapid urbanization, demand for charcoal and fuelwood and hence deforestation are projected to accelerate. New energy sources like kerosene and natural gas must be imported, putting pressure on public finances. Refined petroleum products represented 15% of Tanzania's imports in 2016, $1.3 billion, compared, with $831 million for imports of all agricultural products in the same period (FAO, Dec 2017; UN Comtrade). The country's public finances therefore call for managing the energy transition in a manner that does not create unsustainable trade deficits.

To design policies that address the challenges of population pressure on woodlands, and the costs of new energy sources, it is important to understand how prices affect household fuel choices.

Studying household energy choice is particularly relevant to public policy in Tanzania. Literature review suggests policy objective of the government is to promote households' access to affordable energy. To achieve this objective, the GoT has therefore adopted a number of policies:

i) *Preferential lower tariff (excise duty) for kerosene*: This policy is intended to make kerosene affordable especially to low income households so as to reduce their dependency on charcoal and firewood. This policy was reversed in 1999 as it lead to adulteration of kerosene with diesel and petrol leading to increased emissions from motor vehicles and damage to engines and machines. The GoT decided to reverse the policy as fuel adulteration became a threat to

Tanzania trade as it could have led to the loss of its regional market share in importing fuel to land locked countries. Currently, kerosene is subject to the same level of tariff with petroleum and diesel.

ii) *Rural electrification*: The Got has established a Rural Energy Agency (REA) whose role is to promote public-private partnership in energy generation and distribution in rural areas. REA promote diverse sources of energy on and off-grid including solar, wind, geothermal etc,.A recent report by REA/NBS (2017) indicate the percentage of households with electricity has increased from 18 percent in 2011/12 to 33 percent in 2016. Electricity access for urban households (65.3%) is much higher than in rural households (16.9).

iii) *Rural electrification*: The GoT has embarked on major energy projects for industrial and domestic use including hydropower projects, natural gas and coal projects.

iv) *Energy production*: The Got has adopted a policy to promote a sustainable charcoal sector which among other things calls for formalization and regulation of the charcoal sector, commercial tree plantations, community management of forests, promotion of fuel efficient stoves, etc.

The ability of households to switch into alternative energy sources or adopt energy efficient technologies will depend on the elasticity of demand.

We use detailed household survey data that includes transactions and household level information. The dataset comes from a survey of 10,186 households by the National Bureau of Statistics in Tanzania. Our analysis begins with a multivariate probit (MVP) model to estimate the likelihood of using a given fuel, given household socio-demographic characteristics, and the fuel-using equipment observed in households. Then, we analyze the pattern of product substitution and price elasticities, using a Quadratic Almost Ideal Demand System (QUAIDS) model, first introduced by Banks et al. (1997), and based on Deaton's and Muellbauer's (1980) Almost Ideal Demand System. We use our results to estimate the effectiveness of policy scenarios proposed in this paper.

We aim to contribute novel results to a rich literature that includes studies of energy use in both developing and high-income economies. Ouedraogo (2006) showed that the probability of using firewood as the main cooking fuel source did not diminish with households' quality of life (measured by home-ownership, existence of cooking facilities, and income). Even in the urban region of Ouagadougou, Burkina Faso, the estimates suggest a strong preference for firewood by households. The preference for firewood in Burkina Faso was identified as a threat to savanna woodlands. These findings are consistent with other papers in developing economy contexts (Liu et al., 2013; Andadari et al., 2014; Brouwer and Falcao, 2004). In high-income economies, the energy transition and substitution between energy sources is usually framed around the question of climate change (e.g., Mansur et al., 2008; Braun et al., 2010; Narayan et al., 2007). The same concern exists in Tanzania, one of the countries expected to be seriously harmed by climate change (Bezabih et al., 2011).

Our work is also related to studies of technical and policy options for managing the transition from biomass energy sources in developing economies. The improved cook-stove initiatives, described in Lewis (2012), affect the consumption of firewood and charcoal by increasing the fuel-to-energy efficiency. Solar cook-stoves, which take advantage of the continent's abundant solar

energy resources (Ruiz-Mercado, 2011; Clough, 2012), as well as electricity use, as described in Arthur (2010) are all related to our main research question. The primary mechanism we examine in studying changes to fuel and energy use by household is prices. In effect, we estimate the sensitivity of demand for each energy source to the prices of other energy sources.

We find some evidence of substitution between energy sources in the data. There is a statistically significant, positive relationship between demand for kerosene and charcoal prices when we use the data as-is, and allow households to have zero expenditure in a product group. When we assume that all households would use a positive amount of each energy type if we had enough data, and effectively replaced instances of zero expenditures with predicted budget shares using the multivariate probit model estimates, most cross-price elasticities as statistically significant and positive. This suggests charcoal, firewood, and kerosene may act as substitutes, if all households had access to all types of fuel (and equipment that use the fuels). These estimations imply there is room for policy actions to manage the energy transition in Tanzania, however, price-based policy alone may not be effective.

The rest of the paper is organized as follows: the next section describes the data and methods, the results section contains the results and descriptions of the policy scenarios in Tanzania, and conclusion section concludes.

2. Data and Methods

2.1 Data

We analyze data from the 2011-2012 Tanzania household budget survey (HBS) conducted by the National Bureau of Statistics (NBS). The HBS records contain day-to-day spending of 10,168 households in 692 categories of products and service over twelve months (October 2011 to September 2012). The selected households are part of a stratified, nationally representative random sample that covered 400 geographic clusters in 21 of Tanzania's regions. Each household was followed by a National Bureau of Statistics (NBS) enumerator for about a month, to record all their use and purchase transactions. The data capture quantities and values on about 1.89 million household transactions.

We code spending on energy into 4 categories. The four categories are: Kerosene (corresponding to COICOP code 453101), Charcoal (454101), Firewood (454102), and all other sources[1]. Kerosene, charcoal and firewood accounted for 96.5% of spending on energy by households. Spending in the designated energy categories represent approximately 10% of the total spending observed in the data (and about 11% of the observed transactions). Charcoal is the most purchased fuel source (91,210 purchase transactions), followed by firewood (77,789 purchase transactions). There are 45,670 recorded transactions for kerosene and a negligible number of transactions for other types of energy (solar: 18, electricity: 697, natural gas: 99, other solid fuels: 33).

The data also report the rural-urban status of each sampled household. The majority of households in Tanzania, about 60%, are in rural areas (World Bank,2018; Olabisi et al., 2018). The classification helps to address questions about the well-documented differences in the pattern of

energy sources, by income and urbanization (Heltberg, 2004). The common pattern observed in other research papers is that firewood and charcoal are more common as energy sources in rural areas, and for the poor (Chen and Pitt, 2017; Guta, 2012).

We control for several socioeconomic factors that influence fuel choice. Previous papers show that the gender of the household head is correlated with the adoption of modern fuels -- e.g., female household heads are estimated to have a 3.1% lower probability of using modern fuel (except for kerosene) for lighting (Choumert, 2018). About 25% of households in the HBS have a female head. Age may also play a factor, as habitual fuel use may strongly influence choice over financial considerations. We also consider marital status, as a possible predictor of fuel use, given previous research (Kwakwa et al., 2013). Over 65% of households in the HBS data have a married household head.

Table 1 summarizes the selected socio-demographic characteristics, by rural-urban status, and by income quartile.

The HBS data also includes information on the durable goods observed in a household. Durable goods like kerosene stoves, solar cookers, and electric cookers can clearly predict a household's purchase transactions, we therefore use these in our estimations. Matching our energy use categories for purchase transactions, we use four distinct categories for energy use equipment: kerosene, charcoal, firewood, and other energy equipment. We also included purchases of any of these types of equipment during the survey period. In the data, electric and gas stoves are grouped in the same category. As no special equipment is needed to burn firewood, we assume that if a household does not own any other type of equipment listed above, they use firewood. The most commonly used equipment category is charcoal (over 62%), followed by kerosene (over 53%). Electricity and firewood categories cover 38% and 35% of households, respectively. (Note that the categories are not exclusive and the percentages sum to more than 100%).

We drop transactions marked as purchases for resale, and to avoid omitted transactions or errors by enumerators we drop households that purchased fewer than four different items in the month, or with purchase transactions recorded on fewer than 12 days or greater than 31 days. (Enumerators were instructed to record purchase transaction every day for households with illiterate members, and every other day for literate households.) After these cleaning steps, we are left with 9,833 households.

2.2 Methods

2.2.1 Quadratic Almost Ideal Demand System.[2]

A utility-based structural model of household responses to prices is necessary for this study, given our goal of estimating the potential impacts of policy on how households demand and substitute between energy sources. We adopt the quadratic extension of the Almost Ideal Demand System model (Deaton and Muellbauer, 1980), introduced by Banks et al. (1997), also known as QUAIDS. QUAIDS estimates of the income-expenditure (Engel) curves are more flexible. Formally, for each budget item, with a household budget share , we estimate:

$$w_i = \alpha_i + \sum_{k \epsilon K} \rho_k z_k + \sum_{j \epsilon I} \gamma_{ij} \ln(p_j) + \beta_i \left(\ln\left(\frac{m}{\alpha(p)}\right)\right) + \frac{\lambda_i}{b(p)} \left(\ln\left(\frac{m}{\alpha(p)}\right)\right)^2 + \mu_i \quad (1)$$

With non-linear price aggregators:

$$\ln(\alpha(p)) = \alpha_0 + \sum_{j \epsilon I} \alpha_j \ln(p_j) + \frac{1}{2} \sum_{l \epsilon I} \sum_{j \epsilon I} \gamma_{lj} \ln(p_l) \ln(p_j)$$

$$b(p) = \prod_{j \epsilon I} p_j^{\beta_j}$$

and are the price of the product group , and total spending per household, respectively. is a set of demographic variables introduced as controls, while represents the set of all product-groups in the consumption basket. In line with previous works, (e.g., Deaton and Muellbauer, 1980), we impose constraints of homogeneity of degree zero on prices and income. That is, we assume demand is unaffected if prices and income change in the same ratio. The approach also assumes symmetry in the parameter that determines substitution between product groups and .

To control for potential endogeneity of prices and expenditure we adopt the *aidsills* estimation approach (Lecocq et al., 2015), which like Poi et al. (2012)'s model is based on the almost-ideal demand system (AIDS) of Deaton and Muellbauer (1980) and the quadratic almost-ideal demand system (QUAIDS) of Banks et al. (1997). There may exist unobserved endogeneity that is not accounted for in the Poi et al. (2012) model. The *aidsills* approach considers potential correlation between the error term and log prices, and also between the error term and total budgets.

Aidsills exploits the conditional linearity of the budget share equation presented in the QUAIDS model, and through an iterative process, where parameters are estimated using given values of price aggregators, then used to update the estimated value of the price aggregators. This helps to address potential bias from the endogeneity of prices. Each iteration consists of seemingly unrelated (SUR) or ordinary least squares (OLS) regressions, with the initial values for the price aggregators given by the Stone price index and the unit vector, respectively. Iterations continue until convergence occurs, and consistent and asymptotically normal estimators are achieved. Once convergence occurs, symmetry is imposed on the last estimation. We use price indexes at the ward-level to control for price endogeneity.

2.2.2 Multivariate Probit Model

As shown in previous papers, rural areas generally have limited access to energy sources like kerosene or electricity, especially in sub-Saharan Africa (Brew-Hammond, 2010). Therefore, we expect many households to have no purchases in these energy categories. With a multivariate probit (MVP) model we estimate the relationship between equipment like charcoal cook-stoves and fuel type, expecting a positive relationship between owning equipment and expenditure for fuel used by that equipment. We expect that in addition to access, not being able to afford the necessary equipment also contributes to the large numbers of households with zero expenditures

for some energy sources. These zero observations may introduce bias into our estimates, as discussed in Denton and Mountain (2016). We address this concern with robustness checks that use the Shonkwiler and Yen (1999) two-step estimation. In a first step, a probit model is estimated to predict the cumulative distribution and probability density functions of making purchases in category for each household. The second step uses the estimated distributions to modify Equation (1), creating a predicted budget share , to use in place of the observed budget shares for estimating the price elasticities.

The MVP is a nonlinear model, and so the estimated coefficients may not represent the partial effect of the explanatory variables on the probability of success for the dependent variables (Greene, 2018). In order to estimate the partial effect of our explanatory variables on the probability of using a certain fuel, we look to the first order derivatives of each equation in our MVP model with respect to each explanatory variable. We evaluate these derivatives holding all the explanatory variables at their means to estimate the marginal effects of each explanatory variable.

In sum, our use of the MVP will be two-fold. In addition to using the results to deal with the large number of zero expenditures by predicting expenditure shares, we will also use the estimates to predict how different characteristics affect the probability of adopting a certain type of fuel, as other scholars have done (e.g., Ouedraogo, 2006).

Table 1: Summary Characteristics of Households in HBS

Variable (N=9833)	All	Rural	Urban
Age of HH head	44.01	46.57	42.19
Gender of HH head (Female=1)	0.26	0.25	0.27
Marital status**	0.65	0.72	0.61
Education*	1.54	1.59	1.51
Children under 14	1.87	2.43	1.48
Children under 5	0.84	1.12	0.65
Elderly***	0.17	0.24	0.12
Household size	4.66	5.22	4.26
Adult equivalent size	3.82	4.15	3.59
Energy expenditure	19,942.58	15,716.26	22,941.13
Food expenditure	161,255.40	132,809.00	181,437.90
Total expenditure	358,392.70	229,300.90	449,982.40

Data: Tanzania 2011-12 Household Budget Survey (HBS)

Note: *1=less than secondary, 2= less than university, 3=university or higher

**married=1

***number of elderly people living in household

Age, gender, marital status, education pertain to HH head.

3. Results

3.1 Descriptive Statistics

Table 1 summarizes the socio-demographic variables used as shifters in our estimations, while highlighting rural-urban differences. The data represent 2,845 households from Dar-es-Salaam, 2,907 households from other urban areas and 4,081 households from rural areas. The columns show sample-weighted averages for each of the area groups.

Rural households on average have lower income, more children, and larger household sizes. Urban households tend to have younger household heads. Households headed by females were more common in urban areas outside Dar-es-Salaam, and represent about a quarter of households in rural areas. Household incomes and expenditures, including food expenditures are also noticeably higher in urban areas.

The energy expenditure per household represents about 5.5% of the total household budget for our sample. This varies notably between households, with an average budget share for rural households of 6%, compared with 5% for urban households. Income groups also differ in their pattern of spending on energy, as expected. Energy products represent about 10% of the household budget for the lowest income quartile, while the top quartile spends less than 4% on this category. Households also differ in the energy and fuel products they buy.

Table 2: Share of households that use a given energy type

Fuel	All HHs	Rural	Urban
Kerosene	0.67	0.69	0.63
Charcoal	0.46	0.30	0.79
Firewood	0.69	0.88	0.30
Other	0.04	0.01	0.08

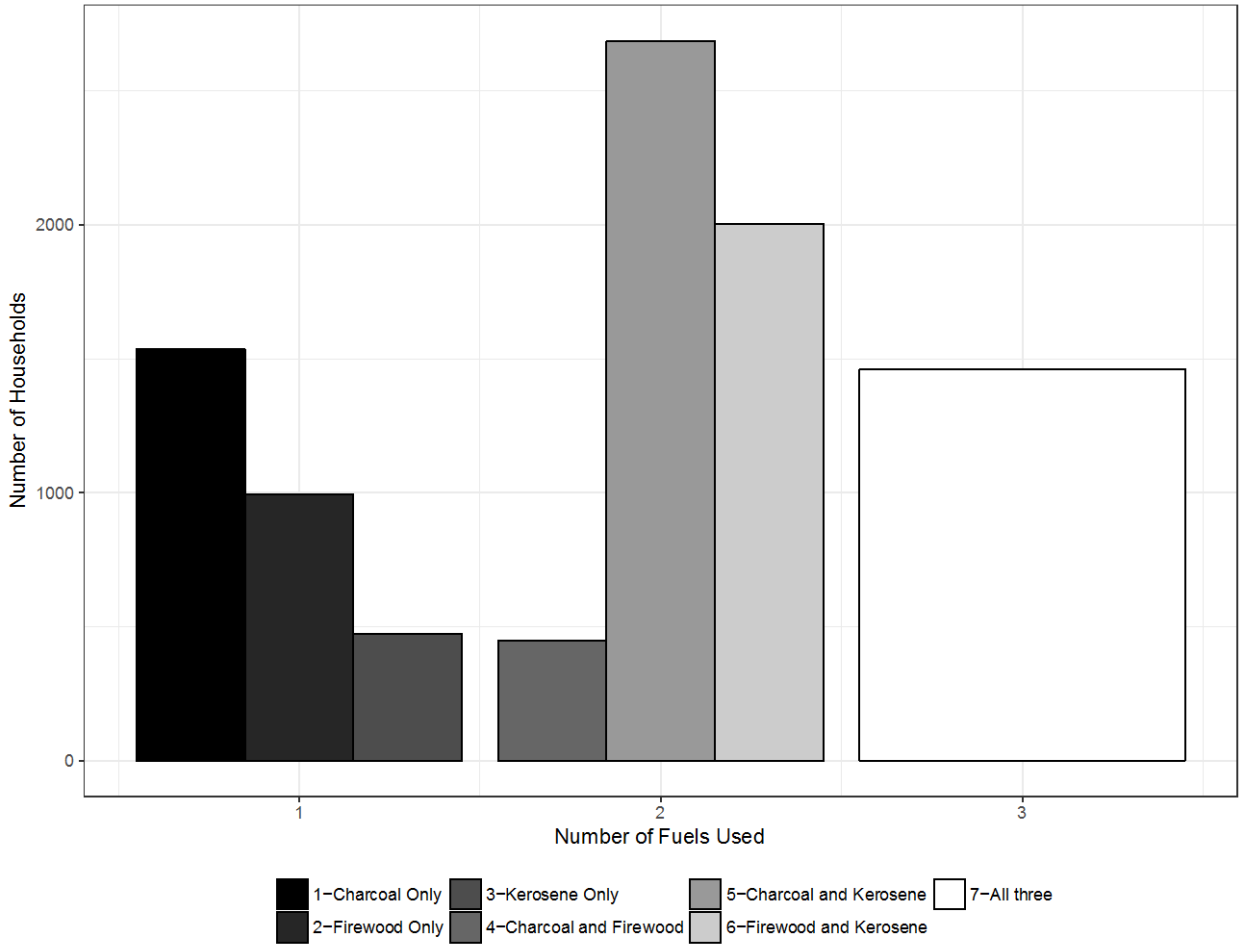
Data: Tanzania 2011-12 Household Budget Survey (HBS)

Table 2 describes energy use by households. The columns show the share of households in each location that use a given fuel type:

Charcoal use is common with urban households, as well as households with relatively higher income. In contrast, most rural households use kerosene and firewood, while a higher percentage of urban households use kerosene and charcoal. (Note that the shares in the table use sample weights, to correctly reflect the share of the general population that use each fuel type) This is consistent with previous studies that show a pattern of households in developing countries using multiple fuel and energy sources (e.g., Ouedraogo, 2006). The other fuels category (mostly electricity) is almost exclusively used in urban households and higher income households. Nevertheless, to understand price-response behavior, we need to understand patterns of buying behavior by households.

Figure 1 shows that the majority of households use a combination of multiple fuel types. For example, more households use kerosene in combination with charcoal or firewood, than use kerosene by itself. Less than 29% of households used only one of the three main fuel types in the survey period.

Figure 1: Patterns of Energy Use by Household



Data: Tanzania 2011-12 Household Budget Survey (HBS)

The data indicate the potential for substitution, as households using multiple types of fuel are more likely to be aware of price changes, before deciding whether to adjust their portfolio of fuel purchases. For clarity, we should indicate that some households produce their own firewood by gathering, while others make their own charcoal using home-made kilns and firewood. These own-produced items are recorded in the transaction diaries, but are also important in describing the price-sensitivity of households. In the data 2,525 (about 25% of) households own-produce charcoal or firewood.

The first column of Table 3 corroborates the evidence in the previous table, and Figure 1. The majority of households record purchases in each of the product categories, because most households use more than one fuel type. That is, the percentages of households using each fuel sum ups to more

than 180% because the use of fuels by households is not exclusive. In effect, the percentages suggest that for the average household using two of the three main fuels is to be expected.

Table 3: Expenditure and Budget Share Summary

	Share of HHs (Spending>0)	Mean Spending	Mean budget share	Median Spending	Median share
Fuels	0.98	19,943	0.116	16,300	0.106
Kerosene	0.66	2,908	0.019	1,500	0.010
Charcoal	0.61	10,119	0.050	3,000	0.020
Firewood	0.50	5,827	0.043	0	0.000
Other fuels	0.06	1,088	0.003	0	0.000
All food	0.97	123,145	0.649	104,800	0.690
Non-food	0.99	53,932	0.235	24,800	0.174

Data: Tanzania 2011-12 Household Budget Survey (HBS)

Table 3 shows most household use fuel (98%), a greater share than households that recorded some purchase of food (97%) within the survey period, and almost as much as nonfood purchases (99%). The median share for fuels is reasonably close to the mean share (11.6% compared to 10.6%). Food accounts for the largest part of the budget (64.9% on average), which is consistent with previous papers, including Olabisi et al. (2018), which used the same dataset. The third column shows the average spending by households in each category, for households that used the category. The mean spending on fuels was 19,943 Tanzanian Shillings (TZS), which is larger than the median of 16,300. We see that food and nonfood have mean household expenditures of TZS 123,145 and TZS 53,932, respectively, both of which are higher than their respective medians of TZS 104,800 and TZS 24,800. Households that do not own-produce fuels have slightly higher fuel expenditures on average (TZS 3,028 on kerosene, TZS 12,386 on charcoal, and TZS 3,416 on firewood).

The data show large differences in household consumption patterns for specific fuel types. The median shares of both firewood and other fuels are zero. The expenditure shares of all fuel types are less than or equal to 5%. "Other fuels" only accounts for 0.3% of household spending. Charcoal and firewood are consumed by households in similar proportions (on average), while the expenditure share for kerosene is less than half of either. The large differences between fuel consumption is seen in the differences between mean and median expenditure shares of kerosene (1.9% and 1%, respectively), charcoal (5% and 2%, respectively), and firewood (4.3% and 0%, respectively). Other fuels are used by a small portion of the sample (6%), which is significantly smaller than the other 3 fuel types. The clear signal in the consumption patterns is that kerosene is used in the largest number of households – both urban and rural, but not as intensively as either charcoal or firewood.

We expect to find some substitution between fuels, (particularly, between kerosene and charcoal, since 39% of all households surveyed purchased both and are therefore aware of both fuel prices). One limitation may be that households in some areas cannot access certain fuel types due to infrastructure or supply constraints. For example, firewood may be less available in some urban areas. There may also be cultural or habitual preferences that increase switching costs and limit the price response of the demand for a given fuel.

3.2 Multivariate Probit Estimation Results

The dependent variable in our model is a dummy for expenditure in one of six expenditure groups: Kerosene, charcoal, firewood, other fuels, food expenditures, and other nonfood expenditures. The results do not include the food and nonfood dummies, as they are not relevant to this step of the analysis. The regressors are listed in Table 4. Equipment for each type of fuel are dummy variables indicating possession of a cooking tool or equipment in the household, as explained in the Data and Methods Section. The other regressors were also explained in that section.

Table 4: Multivariate probit estimates

	Dependent variables			
Explanatory variables	Kerosene	Charcoal	Firewood	Other Fuels
Equipment type in household:				
Kerosene	0.384***	-0.003	0.133***	-0.116*
Charcoal	0.145***	1.237***	-0.314***	-0.017
Firewood	0.052	-0.170***	0.685***	-0.053
Other Fuels	-0.344***	-0.015	-0.223***	0.342***
Rural	0.189***	-0.831***	1.266***	-0.480***
Age	0.005***	-0.002	0.007***	0.001
Houshold Size	-0.017**	-0.011	0.103***	-0.018*
Female	0.168***	0.376***	0.184***	0.089
Married	0.039	0.368***	0.272***	-0.026
Education	-0.100***	-0.039	-0.003	0.110***
Log of total expenditure	0.019	0.171***	-0.304***	0.470***
_cons	-0.131	-2.324***	2.282***	-7.605***
Source: Tanzania 2011-12 Household Budget Survey (HBS)				
	* p<0.05	** p<0.01	*** p<0.001	

The results in Table 4 are consistent with other papers using similar estimation methods in the context of energy use. Owning equipment that uses a given type of fuel increases the probability of using that fuel, as expected. The first coefficient in the left-most column indicates that we observe a higher likelihood for kerosene use in households that have a charcoal stove. This supports the idea that most households with charcoal stoves are also kerosene users. Households with equipment that use electricity (or other fuels) are less likely to use kerosene or firewood, while the relationship between equipment that uses electricity and charcoal is not statistically different from zero. We also see a negative relationship between owning equipment that uses firewood (this includes not owning equipment for the other fuel types), and the likelihood of using charcoal.

The signs on the demographic variables are also in line with expectations. Larger households are more likely to use firewood, while female-headed households are more likely to all three main fuel categories. Married households record a higher likelihood of using charcoal and firewood, while education decreases the likelihood of using kerosene and increases the likelihood of using other sources like electricity. Finally, higher household income (proxied by spending) is associated with increased likelihoods of using charcoal and other energy sources, and lower likelihoods of using firewood.

While the signs of the coefficients describe the direction of the relationship between the explanatory and dependent variables, we cannot interpret the magnitudes of these coefficients in any practical sense. So, in order to provide estimates that will better reflect the marginal effects of the explanatory variables, we will use the first order partial derivatives of each equation with respect to each explanatory variable (displayed in Table 5), holding the other variables at their means.

Table 5: Marginal Effects of Coefficients in Multivariate Probit Model

	Dependent variable, probability of purchasing fuel			
Explanatory variables	Kerosene	Charcoal	Firewood	Other Fuels
Equipment type in household:				
Kerosene	0.139***	-0.001	0.053***	-0.009*
Charcoal	0.052***	0.455***	-0.125***	-0.001
Firewood	0.019	-0.063***	0.273***	-0.004
Other Fuels	-0.125***	-0.006	-0.089***	0.027***
Rural	0.069***	-0.306***	0.504***	-0.039***
Age	0.002***	-0.001	0.003***	0.000
Household Size	-0.006**	0.004	0.041***	-0.001*
Female head of HH	0.061***	0.138***	0.073***	0.007
Married	0.014	0.135***	0.108***	-0.002
Education	-0.036***	-0.014	-0.001	0.009***
Log of total expenditure	0.007	0.063***	-0.121***	0.038***
Source: Tanzania 2011-12 Household Budget Survey (HBS)				
	* p<0.05	** p<0.01	*** p<0.001	

The statistical significance of these results is similar to the results in Table 4. Owning equipment that uses kerosene increases the probability of using firewood by 5.3%. If the household owns equipment that uses charcoal, they have a lower probability of using firewood by 12.5% and a 5.2% increased probability of using kerosene. Owning equipment that uses firewood, on the other hand, reduces the probability of a household using charcoal by 6.3%. This is consistent with our expectations, as more households use either charcoal or firewood with kerosene, but not many households use charcoal and firewood together. There are roughly 1,454 households that use all

three, but this is still smaller than the number of households that use a combination of kerosene with firewood (1,997), or kerosene and charcoal (2,460).

Rural households have a higher estimated probability of using kerosene and firewood by 6.9% and 50.4%, respectively, while they have a decreased probability of using charcoal by 30.6%. This is consistent with current literature, as D'Agostino et al., (2015) found charcoal is more common in urban areas than rural areas. This may be influenced by multiple factors: the equipment that uses charcoal may be limited in rural areas, or many rural households may own-produce the firewood by collecting it themselves.

The estimated coefficients of demographic variables are consistent with other published work (e.g., Oedraogo, 2006; Choumert, 2018). Raising the age of the household head by one increases the probability of using kerosene and firewood by 0.2% and 0.3%, respectively. Household size is estimated to increase the likelihood of using firewood by 4.1%, but reduces the likelihood of using kerosene by 0.6%. Furthermore, female household heads have an increased probability of using all fuel types except for "Other fuels." This paper examines both rural and urban households, unlike others that focus on urban households and that may account for the differences in this paper and Ouedraogo (2006). Higher education is estimated to have a negative effect on kerosene use, and a positive effect on use of all other fuel categories.

We expect that rural/urban status of households and their income levels both of affect the pattern energy use. On average, rural households have lower income than urban households and our results follow this pattern. The estimates in Table 5 show a 0.063% increase in the likelihood of using charcoal, and a 0.12% decrease in the probability of using firewood, for each 1% increase in income. In comparing the rural dummy variable with the income variable, the estimated effect of income is opposite the estimated effect of the rural dummy for charcoal, firewood and "Other fuels."

3.3 QUAIDS Estimation Results

In order to answer our main policy question -- whether subsidies, tariffs or other price-based policies may be used to stimulate demand for specific fuel types, we estimate the cross-price elasticities of the main fuels using the QUAIDS model. In our model, we use 4 energy categories (kerosene, charcoal, firewood, and other fuels) and two categories for all food and other nonfood expenditure. "Other fuels" contains electricity, solar, and other solid fuels. The cross-price (and own-price) elasticities are estimated from a system of equations with the budget shares of each edible oil and food group as the dependent variable. The demand system includes total expenditure as well as instrumental variables for total expenditure - a feature of *aidsills* that corrects for endogeneity in spending. For our instruments, we use the education level of the household head, household size in adult equivalents, and the household's area designation (rural or urban). Each household represents an observation in the demand system. As intercepts, we use a dummy variable indicating the presence of equipment that uses a given fuel, gender and age of the household head, number of children, as given in the data (under 14, as well as under 5), region, and an indicator for marital status. The price indexes for the 6 categories are predictors in the estimation process, which iteratively adjusts the price indexes to correct for endogenous prices.

The shares predicted allow us to estimate cross-price elasticities, which we can use to determine the effectiveness of policy solutions.

Table 6: QUAIDS Model Results: All Households

Change in quantity	Change in price					
	Kerosene	Charcoal	Firewood	Other Fuels	Food	All non food
	b/se	b/se	b/se	b/se	b/se	b/se
Kerosene	-0.968***	0.140**	-0.073	0.004	0.480	-0.007
	(0.059)	(0.053)	(0.090)	(0.007)	(0.491)	(0.146)
Charcoal	-0.056	-0.970***	0.151	0.008	0.958*	0.250***
	(0.029)	(0.035)	(0.127)	(0.005)	(0.384)	(0.038)
Firewood	-0.049	-0.086	-1.094***	0.017	0.269	-0.064
	(0.055)	(0.071)	(0.077)	(0.018)	(0.414)	(0.379)
Other Fuels	-0.281	0.194	0.117	-0.951***	1.520	0.778*
	(0.249)	(0.119)	(0.242)	(0.045)	(1.640)	(0.372)
Food	0.020*	0.066**	0.032	-0.002	-0.412***	0.146***
	(0.010)	(0.022)	(0.033)	(0.003)	(0.027)	(0.018)
All non food	0.048*	0.033	0.085**	0.013***	0.815***	-0.457***
	(0.023)	(0.023)	(0.029)	(0.003)	(0.141)	(0.040)

Source: Tanzania 2011-12 Household Budget Survey (HBS)

* p<0.05 ** p<0.01 *** p<0.001

Predicted Shares, Income, (Un)compensated Elasticities

	shares	income	u_price	c_price
	b/se	b/se	b/se	b/se
Kerosene	0.019***	0.790	-0.983***	-0.968***
	(0.005)	(0.508)	(0.051)	(0.059)
Charcoal	0.052*	1.372***	-1.041***	-0.970***
	(0.021)	(0.360)	(0.026)	(0.035)
Firewood	0.043	0.201	-1.102***	-1.094***
	(0.031)	(0.839)	(0.037)	(0.077)
Other Fuels	0.003	1.776	-0.957***	-0.951***
	(0.003)	(1.476)	(0.046)	(0.045)
Food	0.648***	0.991***	-1.054***	-0.412***
	(0.009)	(0.017)	(0.013)	(0.027)
All non food	0.235***	1.096***	-0.714***	-0.457***
	(0.021)	(0.168)	(0.028)	(0.040)
	* p<0.05	** p<0.01	*** p<0.001	

The table shows compensated elasticities, using *aidsills* with no MVP adjustment. The instrumental variables are: rural-status, adult-equivalent in households, and education. *Source*: Tanzania 2011-12 Household Budget Survey (HBS)

3.3.1 All Households

Table 6 shows the results of our QUAIDS estimation without adjusting for zero expenditures. (That is, we use the data as it is, and take zero expenditures on a particular category as part of the normal behavior of households). All 9,833 households left after data cleaning are used for this table. The first row can be interpreted as follows: The first entry is the own-price elasticity of kerosene adjusted for the wealth effect, which is negative (-0.968, i.e., slightly inelastic), and statistically significant. The second entry is the cross-price elasticity of kerosene with respect to the price of charcoal. For every 1% increase in the price of charcoal, the quantity demanded of kerosene increases by 0.14% which indicates some substitution between the two fuels. However, the cross-price elasticity of charcoal with respect to kerosene prices is not statistically different from zero, (on the first column of the second row), implying that substitution may only go in one direction.

The compensated own price elasticities are negative and slightly inelastic, except for firewood, which is slightly elastic (-1.094), and all are significant at the 1% level. This is consistent with the literature, as others have found the demand for energy may be inelastic due to cultural preferences (types of foods cooked) or socioeconomic factors.

Other cross-price elasticities are not statistically significant. There is a positive coefficient on the relationship between the demand for charcoal and the price of firewood (although not statistically significant). While not significant, it is reasonable to assume firewood and charcoal act as substitutes for one another. However, since charcoal is derived from wood, changes in the price of wood may also increase the price of charcoal, which could reduce the quantity of charcoal demanded.

The coefficients show kerosene as a complement to charcoal, firewood and other fuels, (all not statistically significant). To interpret these coefficients, one may use the pattern of energy use in Figure 1, which suggests that kerosene may be used for different but related purposes within a household. If as anecdotes suggest, kerosene is used for lighting, while charcoal, firewood and other fuels are used for cooking, the estimated relationships would be unsurprising. It may also explain the asymmetric substitution, where price changes for charcoal cause some households to cook with kerosene, but price changes for kerosene have less of an effect on charcoal, as most households still rely on kerosene for lighting. Other coefficients, like the inelastic demand for food, are consistent with expectations.

3.3.2 Rural and Urban Households

To estimate differences in demand between rural and urban households, we ran separate estimations for rural households and urban households (neither adjusted for zero expenditure), and the compensated price elasticities are displayed in Table 7.

Urban household demand for both kerosene and charcoal are more inelastic (-0.807 and -0.884, respectively) than they are in rural households (-1.064 and -0.989, respectively). This is likely due to the fact that charcoal is a more commonly used fuel for urban households than rural households [see Table 2], i.e., it may be easier for rural households to substitute away from charcoal to firewood.

Table 7: QUAIDS Model Results: Rural vs. Urban households

Rural

	Change in price					
Change in quantity	Kerosene b/se	Charcoal b/se	Firewood b/se	Other Fuels b/se	Food b/se	All non food b/se
Kerosene	-1.064***	0.097	-0.004	-0.005	0.565	0.039
	(0.250)	(0.150)	(0.889)	(0.028)	(4.026)	(0.173)
Charcoal	-0.093	-0.989***	0.091	-0.019	0.820	0.073
	(0.510)	(0.054)	(1.608)	(0.029)	(7.886)	(0.342)
Firewood	-0.043	-0.042	-0.986***	0.025	0.651	-0.037
	(0.087)	(0.023)	(0.249)	(0.092)	(0.971)	(0.683)
Other Fuels	-0.252	-0.559	0.851	-0.859	2.225	0.883
	(7.373)	(4.799)	(31.540)	(1.496)	(157.190)	(6.399)
Food	0.026	0.022***	0.066	0.002	-0.479	0.155
	(0.019)	(0.005)	(0.183)	(0.003)	(0.500)	(0.510)
All non food	0.036	-0.009	0.217	-0.017	1.416	-0.591
	(0.091)	(0.033)	(0.520)	(0.058)	(1.498)	(0.602)

Urban

	Change in price					
Change in quantity	Kerosene b/se	Charcoal b/se	Firewood b/se	Other Fuels b/se	Food b/se	All non food b/se
Kerosene	-0.807***	0.193	-0.086	0.005	0.296	-0.179
	(0.218)	(0.265)	(0.142)	(0.024)	(2.018)	(1.516)
Charcoal	-0.102	-0.884***	0.062*	0.007	0.491*	0.194
	(0.101)	(0.024)	(0.030)	(0.021)	(0.246)	(0.290)
Firewood	-0.119	-0.659	-1.201***	-0.004	0.838	0.086
	(0.409)	(0.625)	(0.084)	(0.036)	(1.956)	(1.144)
Other Fuels	-0.272	0.422	-0.035	-0.962***	1.515	0.874
	(0.660)	(1.089)	(0.085)	(0.076)	(3.608)	(1.862)
Food	0.019	0.120**	0.002	-0.005	-0.360**	0.146*
	(0.056)	(0.037)	(0.016)	(0.021)	(0.117)	(0.072)
All non food	0.056	-0.004	0.047***	0.032	0.578	-0.399**
	(0.050)	(0.047)	(0.009)	(0.023)	(0.587)	(0.148)
	* p<0.05	** p<0.01	*** p<0.001			

The table shows compensated elasticities, using aidsills with no MVP adjustment. The instrumental variables are: rural status, adult-equivalent in households, and education. Source: Tanzania 2012 Household Budget Survey (HBS)

Kerosene as an imported good is more accessible to urban households, as are kerosene stoves. Therefore, the use of kerosene may be a stronger element in the pattern of urban household behavior. More urban households use both charcoal and kerosene than they use either alone. Finally, as outlined in Ouedraogo (2006), kerosene may be used more for lighting than cooking.

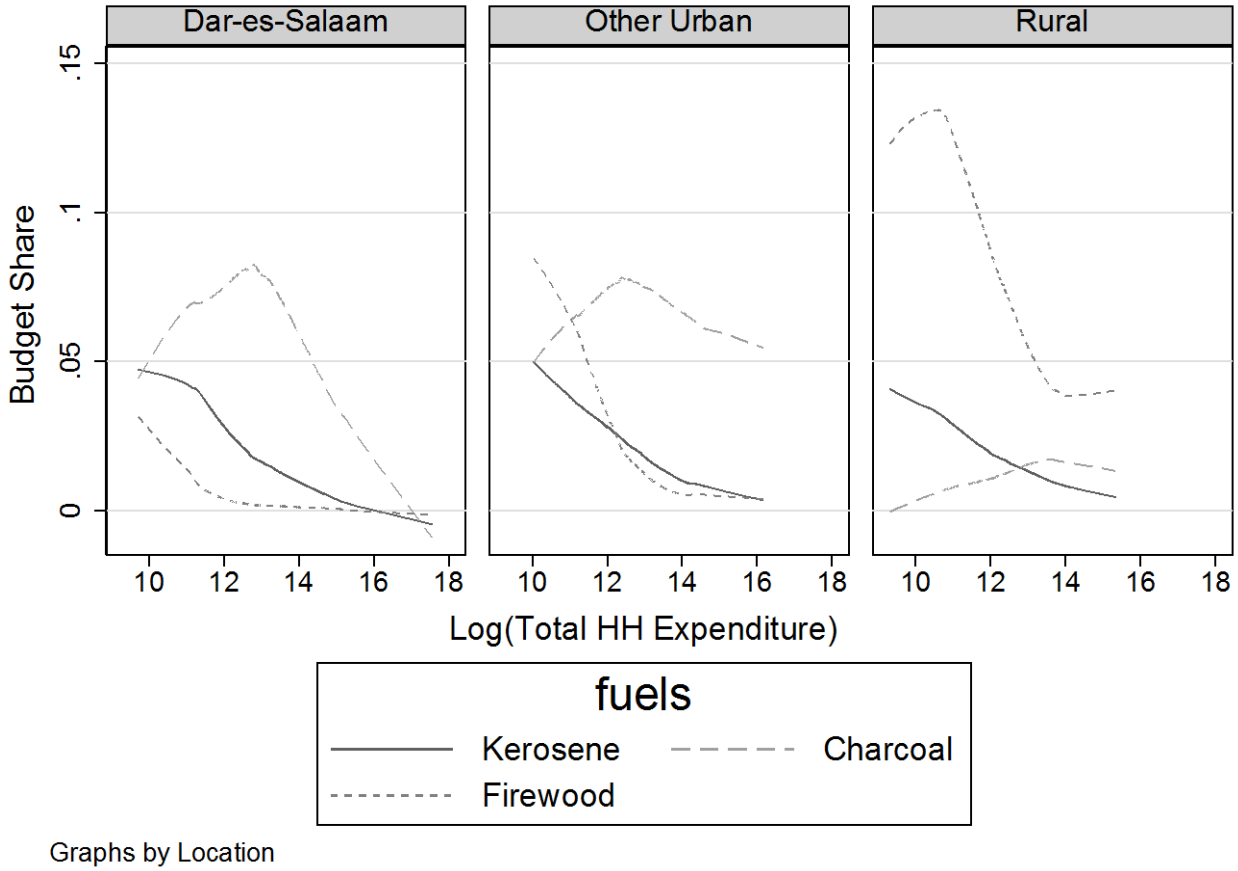
Demand for firewood is estimated to be more elastic in urban households (-1.201), while slightly inelastic for rural households (-0.986). Since firewood and kerosene seem to be used in a larger fraction of rural households than urban households, it makes sense that urban households could more easily substitute away from firewood if wood prices increase. This is also suggested by the positive and statistically significant cross-price elasticity of charcoal demand for firewood prices (0.062), which implies urban households substitute charcoal for firewood as firewood prices increase.

3.4 Rural-Urban Differences

There are clear differences between urban and rural households, as previous sections show. In this section we will address the consumption pattern differences between households in Dar-es-Salaam, other urban areas, and rural households. Figure 2 shows these differences with a loess plot of budget share against income, with separate plots for each of the rural-urban categories. (Note that for convenience, we do not show confidence intervals on the plots).

The differences between rural and urban households show the same pattern as the differences between low and high-income households as seen in Table 2. The poorest in Dar-es-Salaam spend under 5% of their budget on kerosene, charcoal, and firewood. The share spent on all fuel categories generally falls with income, with firewood falling most rapidly, so that near the middle of the income distribution for both Dar-es-Salaam and other urban areas, firewood has the smallest share of the three major fuel types. The poorest households in urban areas outside Dar-es-Salaam dedicate just under 10% of their budget to firewood, and about 5% of their budget on charcoal.

Figure 2: LOWESS Estimates for Share of Household Expenditure on Fuel



Source: Tanzania 2011-12 Household Budget Survey (HBS)

The pattern of charcoal having the highest budget share for urban households is reversed for the rural households in the data. The poorest rural households allocate slightly more than 0% of their budget to charcoal, while they allocate just under 5% to kerosene and over 10% to firewood, on average. The strong reversal in pattern may reflect the higher levels of firewood availability outside urban areas, or the lower costs of gathering and transporting the firewood in rural areas, relative to cities.

Fuels as a share of total spending also generally declines with income for kerosene and firewood in rural areas, while spending on charcoal generally increases. Kerosene is estimated to have the lowest budget share by the middle of the income distribution. Nevertheless, poor rural households on average, allocate a larger share of their budget to kerosene than urban households. This runs contrary to our expectation that kerosene, being imported, would be consumed in higher proportions in urban areas, and the port city of Dar-es-Salaam.

3.5 Robustness Checks

We included results with predicted budget shares from the MVP analysis to reduce bias that may be introduced due to zero recorded expenditures. Using the predicted probabilities of expenditure in one of the 6 categories, we generated predicted shares for each of the 6 spending categories, and use the predicted shares in placed of the observed spending share in the QUAIDS model. The prediction assumes that all households have access to and use all the defined fuels categories, but recorded zero spending in particular categories because the data collection was not for a sufficiently long period. In other words, the results give us the results in the hypothetical scenario where all fuel categories were equally available to all households.

Table 8 shows the compensated elasticities of our estimation after correcting for zero expenditures. The own price elasticities are negative with an absolute value less than 1, indicating demand for energy is inelastic. The cross-price elasticities between all fuel types are positive, which suggests they each act as substitutes for one another once we correct for zero expenditures.

Table 8: Compensated Elasticities with Zero-Expenditure Adjustment

	Change in price					
	Kerosene	Charcoal	Firewood	Other Fuels	Food	All non food
Change in quantity	b/se	b/se	b/se	b/se	b/se	b/se
Kerosene	-0.806***	0.145***	0.139***	0.053	0.349***	0.118***
	(0.022)	(0.028)	(0.015)	(0.045)	(0.090)	(0.003)
Charcoal	0.176***	-0.843***	0.136***	0.031	0.387***	0.125**
	(0.024)	(0.022)	(0.011)	(0.039)	(0.093)	(0.043)
Firewood	0.188***	0.140***	-0.902***	0.050	0.376**	0.082***
	(0.040)	(0.037)	(0.023)	(0.046)	(0.124)	(0.016)
Other Fuels	0.294	0.228	0.235	-0.887***	0.529	0.236**
	(0.170)	(0.162)	(0.153)	(0.036)	(0.355)	(0.080)
Food	0.167***	0.138***	0.119***	0.046	-0.731***	0.049*
	(0.010)	(0.014)	(0.004)	(0.038)	(0.061)	(0.021)
All non food	0.209	0.113	0.166	0.066	0.438	-0.617***
	(0.164)	(0.090)	(0.095)	(0.034)	(0.261)	(0.052)
	* p<0.05	** p<0.01	*** p<0.001			

The table shows compensated elasticities, using aidsills with MVP adjustment for instances of zero expenditure. The instrumental variables are: rural-status, adult-equivalent in households, and education.
Source: Tanzania 2012 Household Budget Survey (HBS)

With this empirical model, we observe statistically significant substitution effects between all energy groups. This implies there may be room for policy to induce different fuel choices. In the hypothetical scenario of equal access, these estimates can be used to represent the price response to policy actions that change the prices of one or more of the fuel categories. We can also interpret these results as evidence that it may be necessary to encourage suppliers to provide energy services

to more regions, through subsidies or waivers, so that more households have access to more energy source options (including electricity, which is not analyzed in this paper).[3]

We use a subset of the data to address the concern that access to different fuel categories shapes household behavior significantly, so that the observed pattern of fuel purchases determines the pattern of substitution, and the pattern of substitution is not consistent across the main fuel use patterns. Table 9 estimates our main results, using only households that purchased both kerosene and charcoal. This is one of the largest groups, in the patterns of use documented in Figure 1.

Table 9: Compensated Elasticities for kerosene/charcoal households (No MVP)

	Change in price					
	Kerosene	Charcoal	Firewood	Other Fuels	Food	All non food
Change in quantity	b/se	b/se	b/se	b/se	b/se	b/se
Kerosene	-0.974***	0.109**	-0.055	0.011	0.203	-0.055
	(0.078)	(0.038)	(0.073)	(0.018)	(0.847)	(0.263)
Charcoal	-0.110	-0.927***	0.080*	0.012	0.548	0.173***
	(0.064)	(0.023)	(0.038)	(0.008)	(0.295)	(0.047)
Firewood	-0.027	-0.004	-1.234***	-0.023	-0.138	-0.201
	(0.182)	(0.117)	(0.309)	(0.021)	(1.821)	(0.615)
Other Fuels	-0.197	0.326	0.059	-0.953***	1.726	0.800
	(0.398)	(0.448)	(0.248)	(0.062)	(3.378)	(0.560)
Food	-0.001	0.104***	0.019	-0.002	-0.407***	0.114*
	(0.026)	(0.007)	(0.025)	(0.005)	(0.046)	(0.050)
All non food	0.163***	-0.000	0.038	0.014***	0.936***	-0.369***
	(0.038)	(0.033)	(0.024)	(0.004)	(0.253)	(0.022)
	* p<0.05	** p<0.01	*** p<0.001			

The table shows compensated elasticities, using aidsills with MVP adjustment for instances of zero expenditure. The instrumental variables are: rural-status, adult-equivalent in households, and education.
Source: Tanzania 2012 Household Budget Survey (HBS)

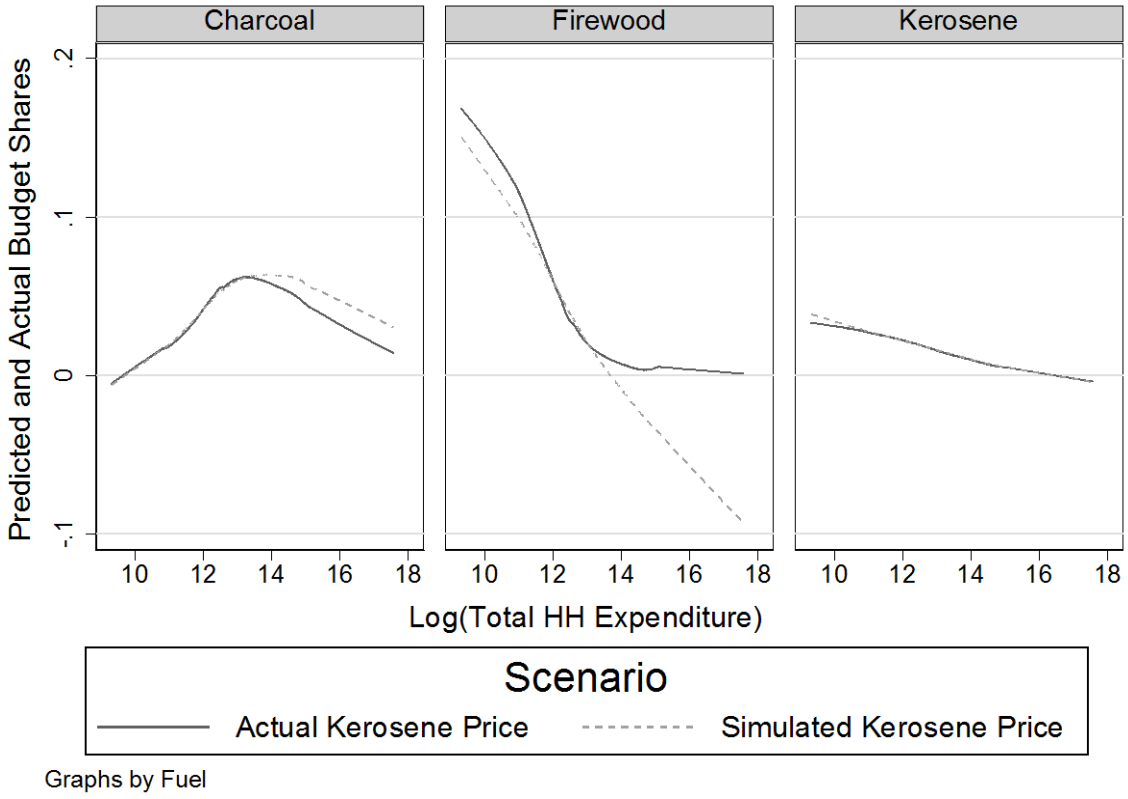
The results are remarkably similar to Table 6. The estimates show a statistically significant (1%) and positive cross-price elasticity between kerosene demand and the price of charcoal. Charcoal demand responds positively to price increases in firewood, implying there is some substitution from firewood to charcoal in this subset of the sample. The own-price elasticities of charcoal (-0.974) and firewood (-0.927) are slightly inelastic. Other cross-price elasticities broadly follow the pattern in the previous tables, with no significant substitution across categories. The results in Table 10 suggest that for the largest pattern of fuel use, the main findings remain valid.

3.6 Policy Simulations

To better understand the demand response to policy actions, we plot the predicted and actual spending shares from the QUAIDS estimation for simulated price changes. We use a hypothetical

scenario of a 10% price hike for kerosene, which could happen as the result of tariffs on imported kerosene by 10 percentage points, (where the tariff was passed through to customers.)

Figure 3: Predicted Budget Shares for Simulated Scenarios



Source: Tanzania 2011-12 Household Budget Survey (HBS)

Figure 3 shows the current demand profile, and the expected change in the profile of kerosene, charcoal, and firewood over the range of income levels in the data.

The policy scenario does not significantly affect the estimated budget share for kerosene except for the lowest income households. The budget share for firewood is also reduced across the lower half of the income distribution, from where the budget share is relatively unchanged. Charcoal budget shares are unchanged for middle and lower income households in this scenario, while they are estimated to increase for the top half of the income distribution.

The policy scenario simulation suggests that price-based policy will not have large effects on household demand. Increasing fuel options through expanding access to energy may have a larger effect, by giving households the option to substitute between fuel types. This simply reflects our QUAIDS regression estimates, as most cross-price elasticities in the tables are not statistically significant (without adjusting for zero expenditures). The claim of potential benefits from expanding options was informed by the statistically significant substitution estimated, when we adjust for zero expenditures.

4. Conclusion

We analyze demand for energy in Tanzania, using a detailed household survey of purchase transactions, a multivariate probit model, and the QUAIDS model. This paper is largely motivated by the increasing numbers of people that depend on traditional biomass for heating, cooking, and to a lesser extent, lighting. Our analysis seeks to inform policy decisions that could mitigate the effects of the biomass use for fuel on the environment, as well as the concern that increasing kerosene use may not be economically sustainable. We examine energy use patterns of different income categories, as well as urban and rural groups of the population. The main fuel sources that we study are kerosene, charcoal, and firewood. (These three accounted for 96.5% of spending on energy by households). Kerosene is almost exclusively imported, while charcoal and firewood are produced domestically.

Interestingly, the estimates suggest low levels of substitution between fuels, except for a positive response in kerosene demand to increases in charcoal prices. While demand for charcoal and kerosene are relatively inelastic, demand for firewood is slightly elastic, with own-price elasticities close to unity. Our estimates of own- and cross-price elasticities are consistent with the energy use patterns we see in these data. In a context where most households use a portfolio of energy sources that contain kerosene, and either firewood or charcoal, with many using kerosene for lighting and the other fuels for cooking, the results would be expected. Therefore, policy centered around price changes may be *ineffective*. A simulation of higher kerosene prices, based on the QUAIDS estimates, supports our conclusion that price-based policy interventions are unlikely to result in large changes in the budget shares of the main fuel options.

Our QUAIDS estimates suggest energy use patterns change with rising incomes. We estimate positive income effects (statistically significant for only charcoal in our main specification), which implies the fuels in question generally behave like normal goods. This holds true for rural and urban households. Nevertheless, the share of spending on kerosene, charcoal, and firewood generally decreases with rising income, consistent with expectations, given a similar pattern of spending changes for food.

Finally, these data suggest noticeable differences between urban and rural energy use. These differences are consistent with our expectations that firewood is more commonly used in rural areas, and charcoal is more commonly used in urban areas. We also see little variation in kerosene usage, which runs contrary to our expectation that kerosene use would be higher in a port city like Dar-es-Salaam. The data suggest that the implementation of policy should reflect the large differences in rural-urban consumption patterns for fuels.

Extensions and areas for future research include understanding differences in access to fuel types, and how changes in access can affect household energy demand.

Notes

[1]The last category of energy sources includes electricity (451100, 451101), Solar power (451102, 531403), and Natural gas (452101).

[2]The method and method descriptions in this paper closely follow Olabisi et al. (2018).

[3]As expected, the budget shares predicted by the QUAIDS model, after adjusting for zero expenditures through the MVP, are not consistent with the data and other sources. The predicted budget share for food is much lower than literature would suggest.

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