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Household Energy Expenditure in Ghana: A Double-Hurdle Model Approach.

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Abstract

This study examines the factors affecting household energy expenditures in Ghana. We employ the double-hurdle model to investigate whether the factors affecting fuel choice differ from those affecting fuel expenditures. The following results are obtained using a nationwide representative household dataset. First, we show that the factors influencing the household's decision to participate in either the LPG or charcoal market differ from those influencing how much is spent. Second, households that already use and, therefore spend money to acquire LPG or charcoal are indifferent to prices of other fuels. At the same time, households using and spending positive amounts on multiple cooking fuels (charcoal and LPG) are insensitive to the prices of other fuels. Third, although income plays a role in rural and urban residents' expenditures on LPG, it is insignificant in terms of urban residents' spending on charcoal. These findings suggest that different programs and policies may be necessary for (1) households that already use modern cooking fuels and those that do not and (2) households in urban and rural areas.

Keywords: energy expenditure, double-hurdle, cooking fuels, LPG, charcoal, Ghana.

1. Introduction

In most developing countries, the primary household cooking energy source is fuelwood. According to the International Energy Agency (IEA; 2015), more than 2.7 billion people in developing countries rely on traditional biomass (i.e., wood, agricultural residues, and animal dung) for cooking. In sub-Saharan Africa (SSA) alone, more than 753 million people use traditional biomass for cooking. Such overdependence on traditional biomass combined with the use of inefficient cooking stoves cause indoor air pollution, which is harmful to human health particularly for the elderly, women, and children. The World Health Organization (WHO; 2009) estimates that 1.3 million people die prematurely every year as a result of indoor air pollution from the use of solid fuels. In fact, 85% of these deaths can be attributed to biomass usage, with the remaining 15% caused by the use of coal.

Many governments and development agencies have proposed various measures to reduce such overdependence on traditional biomass use. One measure is encouraging households to adopt a modern cooking fuel, such as liquefied petroleum gas (LPG) and electricity. However, in most developing countries, lower purchasing power prevents the adoption of modern cooking fuels. Modern fuels are generally expensive, and therefore, households in developing countries that choose to adopt them would have to expend a significant portion of their income on energy. Although some measures have led to an increased adoption rate of modern cooking fuels,[1] considerable efforts are still needed to achieve Goal 7 of the Sustainable Development Goals (SDGs): ensure universal access to affordable, reliable, sustainable, and modern energy by 2030.

Empirical studies on developing countries tend to focus on households' access to modern cooking fuels and factors influencing their choice of fuel (Heltberg 2004; Chambwera and Folmer, 2007; Akpalu et al. 2011; Ouedraogo, 2006; Barnes et al. 2005). While decision making regarding fuel choice is undoubtedly important, it is also key for policy makers to consider how much households spend on these fuels after the decision to adopt them. For example, households that spend a large proportion of their income on a modern cooking fuel will be forced to forgo other consumption opportunities and thus, policies should focus on ways to improve fuel affordability. As modern fuels become increasingly available, households must decide whether to adopt them

[1] The national LPG penetration share for Ghana increased from 6% in 2000 to 18% in 2010. However, Ghana's Energy Commission failed to achieve the national LPG penetration target of 50% for 2016.

and the amount they are willing to spend. Understanding household energy expenditure is critical for a smooth transition from traditional cooking fuels to cleaner and modern ones.

Using household survey data for Ghana, this study examines the role of demographic and economic characteristics in explaining household energy expenditure in a developing country. More concretely, we can state our research question as follows: Do the factors determining a household's decision to participate in a fuel market differ from those influencing how much it will spend? Several empirical studies have explored factors influencing fuel choice in Ghana (Heltberg, 2004; Akpalu et al., 2011; Karimu, 2015; Karimu et al., 2016; Kwakwa et al., 2013; and Mensah and Adu, 2015). However, the factors identified in these studies may vary from those that determine how much a household will spend on these fuels. A unique feature of this study is that it examines these two decisions separately by using the double-hurdle model, which is uncommon in the extant literature. Understanding the effect of household demographic and economic characteristics on energy spending in Ghana will reveal the implications of policies that not only address household decisions to adopt a cooking fuel, but also work toward making such fuels affordable for most households.

This study classifies LPG as a modern fuel and charcoal as a transition fuel, in line with the energy ladder hypothesis (van der Kroon et al., 2013). This hypothesis characterizes the development of fuel use evolution into three stages. First, there is universal dependence on traditional biomass fuels, such as firewood, crop residue, and animal dung. Second, fuel switching occurs from traditional biomass to transition fuels, such as kerosene, charcoal, and coal as a result of higher incomes. Third, the switch from transition to modern fuels, such as LPG and electricity occurs. The hypothesis identifies household income as the main and sole determinant of household fuel choice and fuel switching, respectively (Heltberg, 2004). We focus on LPG and charcoal, because in addition to firewood, they are the most frequently used cooking fuels in Ghana. Therefore, sufficient data are available on cooking fuel expenditure to enable our analysis. As an extension, we examine the behavior of households who spend a positive amount on LPG and charcoal based on the fuel stacking model (Masera et al., 2000). In contrast to the energy ladder hypothesis, the fuel stacking model assumes that households use multiple fuels at the same time.

The remainder of this paper is organized as follows. Section 2 briefly reviews the relevant literature. Sections 3 and 4 describe the data and methodology adopted in this study. Section 5 presents the results. Section 6 concludes the paper and provides policy implications.

2. Literature Review

Given the lack of sufficient data on energy prices and expenditures, few studies on household energy spending in developing countries have been carried out. Consequently, most of the studies have tended to focus on the determinants of household cooking fuel choice. These studies can be grouped mainly into research investigating (1) the determinants of household energy demand and energy choices (Heltberg et al. 2000; Chambwera and Folmer, 2007; Akpalu et al. 2011; Ouedraogo, 2006; Barnes et al. 2005), and (2) works exploring the validity of the energy ladder hypothesis (Hosier and Dowd, 1987; Bello, 2011; Farsi and Filippini, 2007). Most of these studies identify income, fuel prices, education, household size, and access to modern infrastructure as the key factors determining household choice in cooking fuel.

On the other hand, some studies have attempted to examine the determinants of household energy expenditures. In the developed world, there is evidence of socioeconomic factors explaining energy expenditure patterns among households. For example, Longhi (2015) analyzes whether changes in household socioeconomic circumstances translate into changes in energy expenditure in the United Kingdom (UK). The study found that although socio-economic characteristics have a moderate impact, dwelling characteristics, such as household size have considerably larger impacts. This evidence highlights the importance of controlling for various socio-demographic and economic factors in explaining energy expenditure patterns, a finding supported by other studies including those of Meier and Rehdanz (2010) and Rehdanz (2007).

In the context of developing nations, Alkon et al. (2016) use nationally representative household data from India for 1987–2010 to reveal that households are willing and able to spend on energy when modern fuels are available. The study also shows that increases in monthly energy spending have not been driven by increases in household income. These results highlight the importance of improving access to modern fuels in both urban and rural areas. In most developing countries, the supply of modern fuels, such as LPG and electricity, is yet to be regulated given the frequent shortages. Further, even the wealthiest households face difficulties in purchasing modern cooking fuels and, thus, choose other fuels, such as charcoal, which is typically available in large quantities. In contrast, Khandker et al. (2012) reveal that income is key in increasing energy expenditures among Indian households in all but the most impoverished section of society. The variation in conclusions regarding income can be explained by the fact that these studies used different periods and datasets.[2]

Our study's contribution is that it employs the double-hurdle model,[3] which allows us to address fuel choice and fuel expenditure separately. Using a two-stage Heckman model, Kojima et al. (2011) examine the factors influencing household decisions to use LPG and the quantity consumed per person in six developing countries (Guatemala, India, Indonesia, Kenya, Pakistan, and Sri Lanka). Their findings suggest that in all six countries, household expenditure and education were essential in the decision to select LPG. However, the significance of household characteristics, such as urban residence and household size, differs by country. In the second stage estimation, they find household expenditure and LPG price to be positively and negatively related to the quantity of LPG consumption, respectively. Kojima et al.'s (2011) approach is thus closely related to the current study, despite the difference in methodologies adopted. In addition, in contrast to Kojima et al. (2011), our study focuses on energy spending in terms of understanding the burden on households total expenditure, given its significant policy implications.

3. Data Description

The data for this study are taken from the sixth round of the Ghana Living Standards Survey (GLSS VI), a multi-purpose, nationally representative household survey conducted by the Ghana Statistical Service (GSS) during 2012–2013. The sampling frame for the survey was the population living in private households[4] in Ghana, which was divided into primary and secondary sampling units. Census enumerated areas (EAs) were defined as the primary sampling unit, and households within each EA constituted the secondary sampling unit. According to the population in each region, the EAs were first stratified into the 10 administrative regions in Ghana. The GSS adopted a two-stage stratified random sampling design, in which 1,200 EAs were considered in the first stage to cover a nationally representative sample of 18,000 households. In this study, we use 16,041 out of the 16,772 households that were successfully interviewed because of missing data. The data on charcoal prices are adopted from the charcoal price tracking reports produced by the

[2] Khandker et al. (2012) used the 2004–2005 wave of the India Human Development Survey (IHDS), while Alkon et al. (2016) adopted five rounds of the National Sample Survey (NSS) data for 1987–2010.
[3] The Double hurdle model has been used in other studies, such as Newman et al. (2003), Ricker-Gilbert et al. (2011), and Jones (1989).
[4] Private households are defined in GLSS as a population that excludes institutional populations, such as schools and hospitals.

Energy Commission of Ghana. The reports present the findings of a series of surveys on charcoal pricing in selected charcoal markets across the 10 regions in Ghana for June 2012–December 2013. The data on LPG and kerosene prices are taken from the National Petroleum Authority (NPA) of Ghana.

3.1. Patterns of Household Energy Use and Expenditure

Table 1 reports the patterns of energy use and energy expenditures in Ghana. In particular, it shows that firewood is the most frequently used cooking fuel among Ghanaian households, followed by charcoal and LPG.[5] In addition, the results also indicate differences in energy use patterns between urban and rural households. Rural areas are highly reliant on traditional fuels, with about 80% of rural households using firewood as the primary cooking fuel. By contrast, 17% of urban households use traditional biomass. Use of modern fuels, such as LPG, among urban households is 32%, compared to 4% among rural households. As we discuss in more detail in Section 5.4, the table also reports the share of households who spend a positive amount on both LPG and charcoal. According to our definition, only a small percentage of households use multiple fuels at the same time. It is clear from these patterns of energy expenditure that urban households spend more than rural households on cooking fuels. For both urban and rural households, electricity is the highest energy expenditure, followed by LPG. For rural households, expenditures on firewood might be the highest energy expenditure, although data supporting this viewpoint are unavailable.[6] Data on firewood expenditure are difficult to collect, because the bulk of the firewood in Ghana is collected for free from its forests.

[5] The GLSS VI collects data on the main cooking fuels used by households.

[6] Although the bulk of firewood is collected for free from forests without any direct cost, it is anticipated that imputing the value of biomass fuel using market prices will render firewood expenditure as the highest energy-based expenditure.

Table 1: Household Energy Use Patterns

	Main Cooking Fuels					Multiple Fuels
	Traditional	Transition		Modern		
	Firewood	Kerosene	Charcoal	LPG	Electricity	LPG & Charcoal
Ghana (N = 16,041)						
Household users (%)	48.08	0.16	35.41	16.09	0.26	7.00
Average energy expenditure	-	4.82	4.47	10.36	20.50	19.44
Urban Areas (N =6,886)						
Household users (%)	17.25	0.22	44.58	32.14	0.54	13.66
Energy expenditure (GH¢/month)	-	5.28	5.92	12.60	24.36	19.90
Rural Areas (N = 9,155)						
Household users (%)	80.01	0.12	12.82	4.01	0.05	1.99
Energy expenditure (GH¢/month)	-	4.20	1.98	9.08	13.92	17.08

Source: Authors' calculations. GH¢1= US $0.60.[7]

In this study, we focus on LPG and charcoal expenditure for two reasons. First, LPG and charcoal are among the three main cooking fuels used in Ghana (Table 1). Second, data are readily available for these two fuels. Although we also have data on electricity and kerosene expenditures, they are among the least used cooking fuels in Ghana. Thus, any analysis results regarding kerosene and electricity expenditure will have limited implications. Tables A and B in the Appendix list all variables used in this study along with their respective definitions and descriptive statistics.

4. Methodology

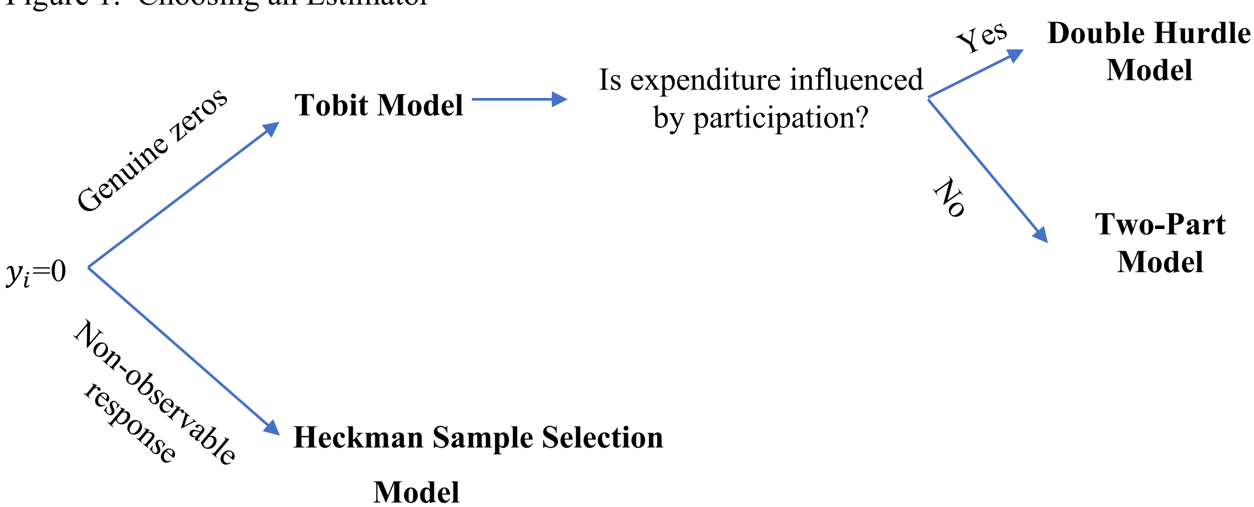
Survey data for expenditures in particular tend to contain zero values. Failure to choose an appropriate statistical or econometric method to deal with these zeros can lead to biased and inconsistent results. There are numerous econometric approaches that deal with the issue of the preponderance of zeros in survey data. Humphreys (2013) summarizes the key elements that

[7] The authors employ an average of the official exchange rate for 2011and 2012: https://data.worldbank.org/indicator/PA.NUS.FCRF?end=2012&start=2011&year_low_desc=false.

should be considered when choosing an appropriate econometric methodology (Figure 1). Suppose the variable of interest, y_i has a mass of zero observations. Then, the first step is to identify the reasons for the zeros in the data. There are three possible reasons: (1) genuine zeros resulting from a choice made by the agents in the survey; (2) the zeros represent a decision over which the agent has no control for a certain reason, and (3) the zeros represent missing or non-response outcomes. If the zeros in the data are attributable to reasons (1) and (2), then, the Tobit model is an appropriate estimator. If the Tobit model fails to work, either the double-hurdle or two-part models are preferred. However, if the zeros in the data result from the third reason, then the Heckman sample selection model is preferred.

In the GLSS VI data set, the observations of zero expenditure result from (1) the respondents' inability or unwillingness to respond to a particular question, (2) failure in data entry by the operator for a given question, or (3) a non-applicable question. These three reasons for a zero observation coincide with the first two reasons provided by Humphreys (2013), which fall under the "Genuine zeros" category in Figure 1. Accordingly, this study first employs the Tobit model, followed by the double-hurdle model. The Heckman sample selection model is employed as a robustness check. Thus, three different methodologies were utilized to explore the factors influencing energy spending on LPG and charcoal. All analyses were conducted using Stata 14.0 (StataCorp, College Station, TX).

Figure 1. Choosing an Estimator



Source: Humphreys (2013)

4.1. Tobit Model

The standard Tobit specification is defined as

$$y_i^* = x_i\beta + \varepsilon_i \text{ with } \varepsilon_i \sim N\ (0, \sigma^2) \text{ and } i = 1, 2 \ldots n \tag{1}$$

$$y_i = \begin{cases} y^*, & if\ y_i^* > 0 \\ 0, & if\ y_i^* \leq 0 \end{cases} \tag{2}$$

where y_i^* is a latent endogenous variable representing a household's desired level of expenditure and y_i is the actual observed level of expenditure. x_i is a set of household characteristics that explain the expenditure decision and β is the corresponding vector of parameters to be estimated. ε_i is assumed to be a homoscedastic, normally distributed error term. Eq. (2) states that the observed level of expenditure becomes a positive continuous value only if a positive expenditure amount is desired and is zero otherwise:

$$LL = \sum_0 In\left[1 - \Phi(\frac{x_i\beta}{\sigma_i})\right] + \sum_+ In\left[\frac{1}{\sigma_i}\phi\left(\frac{y_i - x_i\beta}{\sigma_i}\right)\right] \tag{3}$$

where "0" indicates summation over the zero observations in the sample ($y_i = 0$) and "+" denotes summation over positive observations ($y_i > 0$). Φ and ϕ are the cumulative distribution functions for the standard normal random variable and standard normal probability density functions.

4.2. Double-Hurdle Model

Cragg (1971) formulated the double-hurdle model, which offers an effective way of modeling the pattern of household expenditures on commodities. The model postulates that households must pass two separate hurdles before they are observed with a positive level of expenditure. The first hurdle is the decision to choose positive or zero spending (participation decision) and the second hurdle is deciding the amount to be spent conditional on having decided to spend the positive amount (expenditure decision). The double-hurdle model can be specified as follows:

$$y_{i1}^* = w_i\alpha + u_i \qquad \text{Participation Decision} \tag{4}$$

$y_{i2}^* = x_i\gamma + v_i$ Expenditure Decision (5)

$y_i = x_i\gamma + u_i$ if y_{i1}^*>0 and y_{i2}^*>0. (6)

$y_i = 0$ otherwise (7)

where y_{i1}^* is a latent endogenous variable representing a household's participation decision, y_{i2}^* is a latent endogenous variable denoting a household's expenditure decision; y_i is the observed level of expenditure; w_i is a set of household characteristics explaining the participation decision; x_i is a set of individual characteristics explaining the expenditure decision; and u_i and v_i are independent, homoscedastic, normally distributed error terms. As in the Tobit model, the log likelihood function of the double hurdle model in Eq. (8) is estimated by using maximum likelihood techniques:

$$LL_{DoubleHurdle} = \sum_0 In\left[1 - \varphi(w_i\alpha)\Phi(\frac{x_i\gamma}{\sigma_i})\right] + \sum_+ In\left[\Phi(w_i\alpha)\frac{1}{\sigma_i}\phi\left(\frac{y_{i-}x_i\gamma}{\sigma_i}\right)\right] \quad (8)$$

The results obtained from the maximum likelihood estimation are used to compute the marginal effects of each regressor on the dependent variable. Three different marginal effects can be calculated: the overall effect of each of the regressors on the dependent variable, which is the expected value of y_i for values of the regressors x, denoted by $E[y_i|x]$;[8] the conditional expectation, which is the expected value of y_i for values of the regressors x, conditional on $y_i >$ 0 and denoted by $E[y_i|x, y_i > 0]$; and the probability of a positive value of y_i for all values of the regressors, indicated by $P[y_i > 0|\, x]$.

The probability of participation and the level of expenditure conditional on participation are shown in Eq. (9) and Eq. (10), respectively:

$$P[y_i > 0|\, x] = \Phi(w_i\alpha)\, \Phi\left(\frac{x_i\gamma}{\sigma_i}\right) \quad (9)$$

$$E[y_i|x_i > 0, x] = x_i\gamma + \sigma_i\left(\frac{\emptyset\left(\frac{x_i\gamma}{\sigma_i}\right)}{\Phi\left(\frac{x_i\gamma}{\sigma_i}\right)}\right) \quad (10)$$

[8] The overall effect, also known as the unconditional expectation, $E[y_i|x]$, is decomposed into the conditional expectation, $E[y_i|x, y_i > 0\,]$ and the probability of a positive value of y_i, for all values of the regressors, $P[y_i > 0|\, x\,]$.

The marginal effects are estimated by taking the first derivative of Eq. (9) and Eq. (10) with respect to each regressor in Eq. (11) and Eq. (12).

$$\frac{\partial P[y_i>0|\, x]}{\partial x_j} = \alpha_j \emptyset(w_i\alpha)\Phi\left(\frac{x_i\gamma}{\sigma_i}\right) + \gamma_j \Phi(w_i\alpha)\emptyset\left(\frac{x_i\gamma}{\sigma_i}\right) \quad (11)$$

$$\frac{\partial E[y_i\,|y_i>0,x]}{\partial x_j} = \gamma_j - \gamma_j * \left[\frac{\emptyset\left(\frac{x_i\gamma}{\sigma_i}\right)}{\Phi\left(\frac{x_i\gamma}{\sigma_i}\right)}\right] * \left[\frac{x_i\gamma}{\sigma_i} + \frac{\emptyset\left(\frac{x_i\gamma}{\sigma_i}\right)}{\Phi\left(\frac{x_i\gamma}{\sigma_i}\right)}\right] \quad (12)$$

where α_j and γ_j are the coefficients of the regressor x_j from the participation and expenditure equations, respectively.

4.3. Heckman Sample Selection Model

As Figure 1 shows, the Heckman model is a better choice if the zero expenditures result from non-observable responses. The Heckman model assumes that the participation decision (first hurdle) dominates the expenditure decision (second hurdle), which is also known as the first hurdle dominance. This dominance implies that zero expenditures reflect the household's decision to not participate in the fuel market. For example, the Heckman model assumes that a household's expenditure on LPG is zero only because the household does not use LPG. The key difference between the Heckman model and double-hurdle models is that the former does not account for households with zero expenditure even though they participate in the market, whereas the latter model includes such households. The Heckman sample selection model states that the expenditure variable (y_{i2}^*) is only observed if the participation variable (y_{i1}^*) is positive. In the Heckman model, a probit model is estimated in the first stage. Then, the unbiased estimates from the first stage are used to obtain the second stage. The Heckman model specification takes the same form as the double-hurdle model, except for the expenditure decision, which is as follows:

$$y_i^{***} = \begin{cases} y_{i2}^*, & if\ y_{i2}^* > 0 \\ not\ observed \end{cases} \quad (13)$$

The Heckman model assumes that the error terms in the participation and expenditure decisions are dependent. Hence, $u_i \sim N\ (0,1)$ and $v_i \sim N(0, \sigma^2)$ have a bivariate normal distribution:

$$\begin{pmatrix} u_i \\ v_i \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho\sigma \\ \rho\sigma & \sigma^2 \end{pmatrix}\right) \qquad (14)$$

where ρ is the correlation coefficient between the error terms u_i and v_i. A sample selection bias in the OLS estimator emerges if ρ is non-zero. The log likelihood for Heckman's selection model is

$$LL_{Heckman} = \sum_0 In[1 - \varphi(w_i\alpha)] + \sum_+ In\left[\Phi\left(\frac{(w_i\alpha)+\frac{\rho}{\sigma}(y_{i-}x_i\gamma)}{\sqrt{1-\rho^2}}\right)\frac{1}{\sigma}\phi\left(\frac{y_{i-}x_i\gamma}{\sigma}\right)\right] \qquad (15)$$

5. Results and Discussion

5.1. Diagnostic Tests on Tobit Model

We begin our empirical estimations by employing the Tobit model.[9] The main restrictions of the Tobit model are its strong normality and homoscedasticity assumptions, which bias the results if violated. According to Cameron and Trivedi (2010), failure of the normality and homoscedasticity assumptions have serious consequences for the Tobit model estimates. Table 2 presents the results for the normality and homoscedasticity tests using the Lagrange multiplier test. For both the LPG and charcoal expenditure models, the null hypothesis of the normality and homoscedasticity assumptions is rejected. This outcome suggests that the Tobit model is not appropriate for analyzing these data. Failure of the normality and homoscedasticity assumptions also implies that a single process does not determine the choice between y =0 and y >0 as well as the value of y, given y >0. Thus, it is necessary to use a model that separately deals with both decisions. Therefore, we employ the double hurdle model instead of the Tobit model.

[9] Table C in the Appendix reports the full results of the Tobit model for both LPG and charcoal expenditures.

Table 2: Model Diagnostics

Test Type	Computed χ^2	p-value/critical χ^2	Decision
LPG Expenditure			
Normality	8,341.32	prob > chi2 = (0.000)	Reject null
Homoscedasticity	2,432.87	prob > chi2 = (0.000)	Reject null
Tobit vs. double hurdle	4,712.31	χ^2(0.05, 2) = [5.991]	Reject Tobit
Double hurdle vs. Heckman	0.001	N (0,1) = [1.96]	Double = Heckman
Charcoal Expenditure			
Normality	7,492.10	prob > chi2 = (0.000)	Reject null
Homoscedasticity	2,097.75	prob > chi2 = (0.000)	Reject null
Tobit vs. double hurdle	3,822.67	χ^2(0.05, 3) = [7.815]	Reject Tobit
Double hurdle vs. Heckman	0.004	N (0,1) = [1.96]	Double = Heckman

5.2. Double-Hurdle Model Results

Table 3 reports the results for the double-hurdle model for both LPG and charcoal; all reported values are marginal effects. Comparison of the second and third columns shows clearly that the factors influencing the decision of households to participate in the LPG market differ from those influencing how much to spend on LPG. Similarly, comparison of the fifth and sixth columns reveals that the factors influencing the decision to participate in the charcoal market vary from those influencing how much households spend on charcoal. All of the marginal effects except for the kerosene price are significant in terms of a household's decision to participate in the LPG market. However, variables such as the charcoal and kerosene prices, reliable firewood supply, and employment and occupancy status are not significant in influencing LPG expenditure once the decision to participate in the LPG market is made. In the case of charcoal expenditure, variables such as LPG and kerosene prices, gender and age of household head, income, and employment and occupancy status are not significant in a household's decision to participate in the charcoal market. In contrast, variables such as charcoal price, reliable charcoal supply, reliable LPG supply, age of household head, urban residence location, electricity, number of rooms, and household size are significant in influencing charcoal expenditure once the decision to participate in the charcoal market is made. These findings mean that the Tobit model is not appropriate because it assumes that the variables influencing the decision to participate in a fuel market are the same as those influencing how much to spend.

Income is a statistically significant factor influencing the probability of a household participating in the LPG market and LPG expenditure once the decision to participate is made. For example, income increases the probability of participating in the LPG market by 1% and LPG expenditure by 4.5% conditional upon LPG market participation. This is in line with our expectations because LPG is one of the most expensive cooking fuels in Ghana; consequently, market participation and spending will be highly influenced by household income. In the charcoal expenditure model, however, income is found to be insignificant. This outcome reflects the different role income plays in the uptake of modern fuels, such as LPG, compared with transition fuels (e.g., charcoal).

The household head often controls decisions regarding expenditures, and this influence might, therefore affect fuel adoption and spending. We find that having a male as a household head decreases the probability of participating in the LPG market by 1.4% and increases LPG expenditure by 6.9% conditional on LPG market participation. This is consistent with the findings of Karimu et al. (2016), who finds evidence that female-headed households in Ghana are more likely to adopt LPG than male-headed households. Karimu et al. (2016) explain that this negative relationship reflects the differences in decision making by female and male-headed households in terms of preferences, welfare, and opportunity cost of time. In the case of charcoal, the gender of the household head negatively affects only charcoal expenditure conditional on charcoal market participation. Once the decision to use charcoal is made, female-headed households are more likely to increase charcoal expenditure by 6.9% compared to male-headed households.

In addition, we examined the effects of supply-side constraints on the probability of household participation in the LPG and charcoal markets as well as expenditure for both fuels. As expected, the results show that a reliable LPG or charcoal supply increases the probability of participating in these markets as well as expenditure. In particular, the estimated marginal effects indicate that the reliable supply of LPG increases a household's probability of participating in the LPG market by 13% and increases its LPG expenditure by 24% conditional on LPG market participation. Similarly, the results indicate that the reliable supply of charcoal increases the likelihood of a household's charcoal market participation by 47.1% and increases its charcoal expenditure by 30.9%, also conditional upon market participation. On the other hand, reliable supplies of substitute fuels generally decrease the probability of both participation and expenditure. For example, reliable firewood and kerosene supplies decreases the probability of participating in the LPG market and LPG expenditure, and similarly, a reliable LPG supply decreases the probability of a household participating in the charcoal market and its charcoal expenditure. In the LPG case, however, the estimated marginal effects on the reliable charcoal supply are positive and significant. A possible reason is that richer households are more likely to use LPG and will continue to use and spend on LPG despite an available supply of charcoal. However, this is not the case in the charcoal model because the marginal coefficient on the reliable LPG supply is found to be negative.

The results also show that education levels have significant and positive effects on the probability of participating in the LPG market and LPG expenditure. The estimated marginal effects on basic, secondary, and tertiary levels of education increase the probability of LPG market participation by 3.7%, 5.8%, and 8.9%, respectively. Furthermore, the estimated marginal effects on basic, secondary, and tertiary levels of education increase LPG expenditure, conditional on LPG market participation, by 19.8%, 17.3%, and 27.6%, respectively. These findings imply that a household in which the head is educated has a high likelihood of participating in the LPG market and increase its LPG expenditure. In the case of charcoal, a higher level of education, i.e., education beyond the secondary level, decreases the probability of household participation in the charcoal market. None of the three education levels affect charcoal expenditure. These results suggest that highly educated household heads are more likely to participate in the LPG market than in the charcoal market. A possible explanation could be knowledge about the opportunity costs, such as health and time costs, associated with using charcoal

We find a negative relationship between the LPG price and the probability of household participation in the LPG market. In particular, a 1% increase in the LPG price decreases the probability of households participating in the LPG market by 3.9%. The price effect of LPG on LPG expenditure is also negative and statistically significant, suggesting that a 1% increase in the price leads to a 15.3% decrease in expenditure. The results imply that a fall in the price of LPG will increase the probability of households using LPG as well as increase the expenditure of households. Therefore, a price subsidy to promote usage of LPG might lead to an increase in expenditure burden on households. Among the price effects of various fuels on LPG expenditure, only the LPG price is statistically significant. This result indicates that households with positive LPG expenditures are indifferent to the prices of other fuels. Similarly, in the case of charcoal, only charcoal price is the only significant price variable influencing both participation in the charcoal market and expenditure on charcoal. These results indicate that any policy targeting fuel prices will affect both the participation and expenditure of the fuel in question, but will have no impact on household decisions regarding other fuels.

Table 3: Estimated Elasticities for the Double Hurdle Model

Variable	LPG Expenditure: Prob. $P[y_i > 0 \mid x]$	LPG Expenditure: Cond. Mean $E[y_i \mid x, y_i > 0]$	LPG Expenditure: Uncond. Mean $E[y_i \mid x]$	Charcoal Expenditure: Prob $P[y_i > 0 \mid x]$	Charcoal Expenditure: Cond. Mean $E[y_i \mid x, y_i > 0]$	Charcoal Expenditure: Uncond. Mean $E[y_i \mid x]$
Log LPG price	-0.039***	-0.153*	-0.221***	-0.076	0.019	-0.04
	(0.01)	(0.08)	(0.07)	(0.14)	(0.12)	(0.07)
Log charcoal price	0.041***	0.183	0.285***	-0.102**	-0.053**	-0.172***
	(0.01)	(0.17)	(0.05)	(0.02)	(0.01)	(0.05)
Log kerosene price	-0.008	-0.324	-0.097	-0.142	0.086	-0.267
	(0.03)	(0.29)	(0.23)	(0.17)	(0.17)	(0.17)
Reliable charcoal	0.012*	0.136***	0.093***	0.471***	0.309***	0.815***
supply	(0.01)	(0.05)	(0.03)	(0.01)	(0.07)	(0.02)
Reliable firewood	-0.04***	-0.058	-0.253***	-0.096***	0.073	-0.143***
supply	(0.004)	(0.04)	(0.02)	(0.01)	(0.02)	(0.02)
Reliable kerosene	-0.02***	-0.116***	-0.117***	0.072***	0.033	0.152***
supply	(0.004)	(0.03)	(0.02)	(0.01)	(0.03)	(0.02)
Reliable LPG supply	0.130***	0.238***	0.108***	-0.463***	-0.090***	-0.177***
	(0.006)	(0.05)	(0.04)	(0.03)	(0.03)	(0.02)
Male head	-0.014***	-0.069**	-0.099***	-0.110	-0.069*	-0.221***
	(0.003)	(0.04)	(0.02)	(0.009)	(0.03)	(0.02)
Age head	-0.0004**	0.004*	-0.002***	0.0004	0.002***	0.002***
	(0.0001)	(0.002)	(0.001)	(0.0003)	(0.001)	(0.001)
Log income	0.010***	0.045***	0.070***	0.005	0.011	0.014
	(0.001)	(0.01)	(0.008)	(0.003)	(0.01)	(0.01)
Employment status	0.065***	-0.042	0.337***	0.091	-0.091	0.094
	(0.024)	(0.26)	(0.099)	(0.07)	(0.15)	(0.14)
Urban	0.012***	0.036*	0.080***	0.211***	0.240***	0.555***
	(0.003)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)
Electricity	0.065***	0.239*	0.398***	0.170***	0.139***	0.374***
	(0.005)	(0.09)	(0.03)	(0.01)	(0.03)	(0.02)
Occupancy status	-0.022***	-0.019	-0.138***	-0.016	-0.015	-0.156***
	(0.004)	(0.04)	(0.02)	(0.02)	(0.03)	(0.02)
Number of rooms	0.012***	0.049***	0.083***	-0.021***	0.022**	-0.031***
	(0.002)	(0.02)	(0.01)	(0.004)	(0.01)	(0.01)
Household size	-0.002***	0.075***	-0.004	0.021***	0.060***	0.063***
	(0.001)	(0.01)	(0.005)	(0.002)	(0.005)	(0.004)
Basic education	0.037***	0.198***	0.262***	0.053***	0.042	0.116***
	(0.004)	(0.06)	(0.03)	(0.01)	(0.03)	(0.02)
Secondary education	0.058***	0.173*	0.445***	0.044***	-0.010	0.074*
	(0.005)	(0.07)	(0.04)	(0.158)	(0.04)	(0.03)
Tertiary education	0.089***	0.276***	0.773***	-0.027**	-0.010	-0.057
	(0.006)	(0.06)	(0.05)	(0.01)	(0.04)	(0.04)
N	16,041	2,412	16,041	16,041	5,621	16,041

Notes: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.3. Fuel Stacking Model Results

Analyses so far considered households using only one cooking fuel, i.e. using only LPG or charcoal. In this sub-section, we attempt to explore the households that use multiple cooking fuels based on the fuel stacking model (Masera et al., 2000). In Ghana, some households, especially those in the urban areas, have been observed to use more than one cooking fuel (Mensah and Adu, 2015). Therefore, it is important to extend the analysis to include these households. However, the dataset used in this paper (GLSS VI) elicits information on only the main cooking fuel of households, and thus, does not allow us to investigate household behavior that uses several cooking fuels at the same time. Notwithstanding this limitation, we use a different approach to identify households using multiple cooking fuels. We interpret that households reporting positive amounts for both charcoal and LPG expenditure in the dataset are using multiple cooking fuels. With this assumption, we are able to identify 1,123 households that use multiple cooking fuels. Since this sample represents only 7% of the total number of households, the relative share of multiple cooking fuel users is small based on our definition. Among multiple cooking fuel users, 84% are urban households and 16% are rural households, which coincides with the observation that fuel stacking is mostly practiced by urban households in Ghana.

We then investigate factors that affect becoming multiple cooking fuel users and their total expenditure on LPG and charcoal, by using the double-hurdle model. Table 4 shows the results of the analysis. Similar to the results in the previous subsection, multiple cooking fuel users are responsive to only LPG and charcoal prices, and indifferent to the prices of other fuels, like kerosene. Moreover, key factors, such as income, residential location, and reliable fuel supply are all significant in the fuel stacking model. Nevertheless, we observe some notable differences between the analysis based on the energy ladder model and the fuel stacking model. First, a comparison of Tables 3 and 4 reveal that the marginal effects on reliable fuel supply in the former are larger than those in the latter. Specifically, the results in Table 3 indicate that the reliable supply of charcoal and LPG increases its charcoal and LPG expenditure by 30.9% and 24%. In Table 4, on the other hand, the reliable supply of charcoal and LPG increases the total expenditure on LPG and charcoal by 13.5% and 18.5%, respectively. The smaller marginal effects can be attributed to the easier substitution between LPG and charcoal in the case of multiple fuel users as compared to single fuel users. Multiple fuel users can easily substitute LPG for charcoal or vice versa, and hence, the availability of one fuel has less effect on total expenditure.

Second, the marginal effects of the income variable in Table 4 are much larger than that in Table 3. For example, in Table 3, income increases the probability of participating in the LPG market by 1% and LPG expenditure by 4.5% conditional upon LPG market participation. On the other hand, in Table 4, income increases the probability of participating in the multiple fuel use by 6.45% and total expenditure to LPG and charcoal by 8.2% conditional upon participation. The larger marginal effects indicate the importance of income in the adoption and spending behaviors of multiple cooking fuel users.

Last but not least, only a level of education beyond a secondary education has a statistically significant and positive effect in Table 4, in contrast to Table 3 that illustrates the significant positive effect of all three levels of education. The implication is that a household head education level below tertiary education has no effect on the adoption and expenditure for multiple fuels. It suggests that only highly educated households use multiple cooking fuels.

Table 4: Estimated Elasticities for the Fuel Stacking Model

Charcoal and LPG expenditure

Variable	Prob. $P[y_i > 0 \mid x]$	Cond. Mean $E[y_i \mid x, y_i > 0]$	Uncond. Mean $E[y_i \mid x]$
Log LPG price	-0.019***	-0.118**	0.568
	(0.006)	(0.009)	(0.110)
Log charcoal price	-0.331***	-0.309***	-0.322***
	(0.067)	(0.060)	(0.068)
Log kerosene price	-0.023	0.246	0.163
	(0.016)	(0.192)	(0.204)
Reliable charcoal supply	0.372***	0.135***	0.027**
	(0.122)	(0.046)	(0.007)
Reliable firewood supply	-0.017***	-0.163***	-0.117***
	(0.002)	(0.031)	(0.033)
Reliable kerosene supply	-0.020	-0.116	-0.115***
	(0.075)	(0.128)	(0.034)
Reliable LPG supply	0.122***	0.185***	0.159***
	(0.091)	(0.026)	(0.029)
Male head	0.096	0.094***	0.066**
	(0.073)	(0.031)	(0.027)
Age head	0.004*	-0.001	0.00004
	(0.002)	(0.001)	(0.001)
Log income	0.064***	0.082***	0.093***
	(0.023)	(0.009)	(0.012)
Employment status	3.618	0.219	0.095
	(5.223)	(0.191)	(0.183)
Urban	0.291***	0.207***	0.262***
	(0.074)	(0.029)	(0.032)
Electricity	0.153*	0.278***	0.301***
	(0.079)	(0.028)	(0.035)
Occupancy status	0.006**	0.108***	0.160***
	(0.002)	(0.031)	(0.029)
Number of rooms	0.021	0.115***	0.114***
	(0.041)	(0.013)	(0.015)
Household size	0.024	0.027***	0.032***
	(0.017)	(0.006)	(0.007)
Basic education	0.003	0.207	0.197***
	(0.078)	(0.127)	(0.039)
Secondary education	0.041	0.352	0.344***
	(0.124)	(0.246)	(0.045)
Tertiary education	0.477***	0.641***	0.708***
	(0.159)	(0.042)	(0.047)
N	16,041	1,123	16,041

Notes: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.4. Rural and Urban Households

Consistent with previous studies on Ghana, such as those by Karimu (2015) and Karimu et al. (2016), the results in Table 3 indicate that, on average, urban households have a higher probability of participating in the charcoal and LPG markets compared with rural households. In this subsection, to investigate the differences in the factors explaining energy expenditure, we further decompose the full sample into rural and urban households. We present the results of the double hurdle model for the urban sample (Table 5) and rural sample (Table 6). The findings are similar to the full sample model reported in Table 3, albeit with certain differences. Comparing the marginal effects of fuel prices reveals higher effects for the urban sample than the rural sample. For example, a 1% increase in the LPG price decreases urban households' participation in the LPG market by 12.4%, whereas the drop in rural household's participation is only 0.8%. Similarly, a 1% increase in the charcoal price decreases urban households' participation in the charcoal market by 17.2%, but it decreases rural households' participation only by 3.4%. These results suggest that in terms of participation, urban households are more responsive than rural households to changes in the fuel price. Therefore, promotion of modern energy sources via price-related policies might be more effective for urban residents than for rural residents.

The results also indicate income may play different roles in expenditure decisions between rural and urban residents. For rural households, income is highly significant in both LPG and charcoal expenditure decisions. However, for urban households, income is only significant in LPG expenditure decisions. A possible explanation is that, because LPG is far more expensive to use than charcoal, household income will play a significant role in LPG expenditure decisions, irrespective of household location. On the other hand, because charcoal is cheaper and the purchase of this fuel constitutes a smaller share of the income of urban households, it does not play a significant role in charcoal expenditure decisions by urban households.

Table 5: Estimated Elasticities for the Double Hurdle Model for Urban Households

Variable	**LPG Expenditure**			**Charcoal Expenditure**		
	Prob. $P[y_i > 0\|x]$	Cond. Mean $E[y_i\|x, y_i > 0]$	Uncond. Mean $E[y_i\|x]$	Prob $P[y_i > 0\|x]$	Cond. Mean $E[y_i\|x, y_i > 0]$	Uncond. Mean $E[y_i\|x]$
Log LPG price	-0.124***	-0.159*	-0.406***	-0.058	-0.026	0.035
	(0.035)	(0.088)	(0.145)	(0.051)	(0.128)	(0.125)
Log charcoal price	0.168***	0.198	0.672***	-0.172***	-0.054***	-0.386***
	(0.031)	(0.159)	(0.123)	(0.034)	(0.049)	(0.081)
Log kerosene price	0.111	-0.417	0.281	-0.218	-0.316	-0.610*
	(0.106)	(0.361)	(0.318)	(0.115)	(0.196)	(0.263)
Reliable charcoal supply	0.018	0.110***	0.095*	0.675***	0.492***	1.317***
	(0.019)	(0.042)	(0.056)	(0.031)	(0.147)	(0.027)
Reliable firewood supply	-0.126***	-0.075*	-0.497***	-0.104***	0.020	-0.192***
	(0.012)	(0.045)	(0.047)	(0.015)	(0.024)	(0.032)
Reliable kerosene supply	-0.073***	-0.101***	-0.300***	0.037*	0.065**	0.138***
	(0.013)	(0.038)	(0.058)	(0.016)	(0.031)	(0.030)
Reliable LPG supply	0.409***	0.164***	1.640***	-0.090***	-0.129***	-0.265***
	(0.012)	(0.063)	(0.043)	(0.014)	(0.028)	(0.034)
Male head	-0.028**	-0.080**	-0.128***	-0.082***	-0.046*	-0.181***
	(0.012)	(0.041)	(0.047)	(0.015)	(0.026)	(0.036)
Age head	-0.014***	0.004**	-0.004**	0.001*	0.004***	0.005***
	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Log income	0.025***	0.044***	0.106***	0.002	0.013	0.012
	(0.004)	(0.013)	(0.016)	(0.005)	(0.009)	(0.013)
Employment status	0.228***	-0.182	0.695***	0.070	-0.001	0.093
	(0.078)	(0.333)	(0.211)	(0.085)	(0.147)	(0.175)
Electricity	0.185***	0.086	0.637***	0.059***	0.139***	0.199
	(0.025)	(0.154)	(0.072)	(0.020)	(0.037)	(0.044)
Occupancy status	-0.048	-0.001	-0.173***	-0.064***	-0.018	-0.153***
	(0.013)	(0.047)	(0.051)	(0.015)	(0.031)	(0.038)
Number of rooms	0.046***	0.045**	0.180***	-0.037***	0.027	-0.062***
	(0.007)	(0.020)	(0.023)	(0.008)	(0.018)	(0.018)
Household size	-0.005	0.087***	0.008	0.048***	0.086***	0.149***
	(0.003)	(0.011)	(0.011)	(0.003)	(0.005)	(0.009)
Basic education	0.107	0.165***	0.437***	-0.014	-0.022	0.034
	(0.015)	(0.059)	(0.055)	(0.016)	(0.028)	(0.034)
Secondary education	0.150***	0.077	0.598***	0.006	-0.025	-0.014
	(0.184)	(0.072)	(0.071)	(0.023)	(0.047)	(0.049)
Tertiary education	0.235***	0.220***	1.044***	0.126	-0.036	-0.288***
	(0.017)	(0.063)	(0.081)	(0.122)	(0.050)	(0.060)
N	6,886	2,028	6,886	6,886	3,776	6,886

Notes: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Estimated Elasticities for the Double Hurdle Model for Rural Households

Variable	**LPG Expenditure**			**Charcoal Expenditure**		
	Prob. $P[y_i > 0 \mid x]$	Cond. Mean $E[y_i \mid x, y_i > 0]$	Uncond. Mean $E[y_i \mid x]$	Prob $P[y_i > 0 \mid x]$	Cond. Mean $E[y_i \mid x, y_i > 0]$	Uncond. Mean $E[y_i \mid x]$
Log LPG price	-0.008***	-0.153**	-0.219***	-0.117	0.343	0.147
	(0.005)	(0.077)	(0.073)	(0.074)	(0.328)	(0.121)
Log charcoal price	-0.001	0.183	0.278***	-0.034***	-0.381***	-0.488***
	(0.004)	(0.168)	(0.051)	(0.010)	(0.102)	(0.020)
Log kerosene price	-0.031	-0.314	-0.072	-0.139*	0.734	-0.484
	(0.01)	(0.296)	(0.235)	(0.077)	(0.295)	(0.314)
Reliable charcoal supply	0.003	0.137***	0.101***	0.270***	0.184***	1.138***
	(0.002)	(0.049)	(0.026)	(0.013)	(0.093)	(0.058)
Reliable firewood supply	-0.005***	-0.063	-0.268***	-0.076***	0.167***	-0.308***
	(0.002)	(0.420)	(0.025)	(0.010)	(0.047)	(0.035)
Reliable kerosene supply	0.002	-0.115***	-0.111***	0.054***	-0.002	0.207***
	(0.001)	(0.034)	(0.023)	(0.009)	(0.043)	(0.035)
Reliable LPG supply	0.024***	0.248***	1.152***	0.007	0.103	0.028
	(0.003)	(0.048)	(0.035)	(0.013)	(0.056)	(0.052)
Male head	-0.005***	-0.070*	-0.102***	-0.096***	-0.156***	-0.361***
	(0.002)	(0.039)	(0.025)	(0.010)	(0.046)	(0.040)
Age head	-0.0001	0.004**	-0.002***	-0.001**	-0.002	-0.001
	(0.00004)	(0.002)	(0.001)	(0.0003)	(0.001)	(0.001)
Log income	0.003***	0.045***	0.070***	0.011***	0.070***	0.047***
	(0.001)	(0.011)	(0.008)	(0.003)	(0.015)	(0.013)
Employment status	-0.006	-0.042	0.335***	0.062	-0.853	0.206
	(0.013)	(0.261)	(0.100)	(0.138)	(0.587)	(0.561)
Electricity	0.012***	0.249***	0.418***	0.141***	0.110**	0.563***
	(0.002)	(0.092)	(0.025)	(0.008)	(0.044)	(0.035)
Occupancy status	-0.008***	-0.021	-0.146***	-0.057***	-0.002	-0.244***
	(0.002)	(0.042)	(0.018)	(0.009)	(0.042)	(0.037)
Number of rooms	0.002***	0.048***	0.082***	-0.00003	0.036	0.002
	(0.001)	(0.018)	(0.010)	(0.004)	(0.020)	(0.016)
Household size	-0.001**	0.076***	-0.004	0.003	0.016*	0.011
	(0.0003)	(0.010)	(0.005)	(0.002)	(0.010)	(0.008)
Basic education	0.007***	0.198***	0.266***	0.049***	0.107**	0.207
	(0.002)	(0.055)	(0.027)	(0.010)	(0.046)	(0.039)
Secondary education	0.015***	0.173***	0.453***	0.065	0.009	0.260
	(0.003)	(0.068)	(0.039)	(0.018)	(0.080)	(0.073)
Tertiary education	0.023***	0.276***	0.784***	0.114	0.051	0.445
	(0.003)	(0.059)	(0.051)	(0.018)	(0.074)	(0.072)
N	9,155	2,412	9,155	9,155	1,845	9,155

Notes: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.5. Robustness checks

The Heckman model is used in this section to carry out robustness checks. As explained in Section 4, the Heckman model can be used if zero expenditure represents missing or non-response outcomes. Thus, we exclude all households that use LPG or charcoal, but have no positive expenditure. That leaves us with a total of 15,346 households. For these remaining households, zero expenditure clearly represents the non-usage of a particular fuel, which is consistent with the Heckman model's assumptions. The results reported in Table 7 are largely consistent with those of the double hurdle model. For example, income is statistically insignificant in the charcoal case, a finding consistent with the results of the double-hurdle model. As the third and fifth columns of Table 7 show, households are indifferent to prices of other fuels when they make expenditure-related decisions.

To further confirm the robustness of our results, we conduct diagnostic tests to compare the results of the double-hurdle and Heckman models. The double-hurdle model is tested against the Heckman model using Vuong's test.[10] The results in Table 2 indicate that the Vuong test does not reject the null hypothesis that the two models are equivalent. The Tobit model results were also tested against those of the double hurdle model using the likelihood ratio (LR) test statistic. We found that the Tobit model was rejected in favor of the double-hurdle model.

[10] The Vuong test is used to test one non-nested model against another. More specifically, it tests the null hypothesis that the expected value of the log-likelihood ratio of the two non-nested models equals zero.

Table 7: Estimated Elasticities for the Heckman model

Variable	LPG Expenditure Prob. $P[y_i > 0 \mid x]$	LPG Expenditure Cond. Mean $E[y_i \mid x, y_i > 0]$	Charcoal Expenditure Prob. $P[y_i > 0 \mid x]$	Charcoal Expenditure Cond. Mean $E[y_i \mid x, y_i > 0]$
Log LPG price	-0.062***	-0.284**	-0.071	0.241
	(0.01)	(0.11)	(0.02)	(0.15)
Log charcoal price	0.046***	0.081	-0.282***	-0.261***
	(0.01)	(0.153)	(0.07)	(0.10)
Log kerosene price	-0.086	-0.355	-0.173	-0.255
	(0.35)	(0.32)	(0.01)	(0.25)
Reliable charcoal supply	0.008**	0.114**	0.474***	1.837***
	(0.004)	(0.05)	(0.01)	(0.28)
Reliable firewood supply	-0.037***	0.027	-0.092***	-0.083
	(0.005)	(0.06)	(0.01)	(0.06)
Reliable kerosene supply	-0.018***	-0.078*	0.070***	0.216***
	(0.004)	(0.04)	(0.01)	(0.05)
Reliable LPG supply	0.132***	0.131*	-0.076***	-0.272***
	(0.01)	(0.01)	(0.01)	(0.05)
Male head	-0.015***	-0.035	-0.108***	-0.244***
	(0.003)	(0.04)	(0.01)	(0.06)
Age head	-0.001***	0.005***	0.001	0.004***
	(0.0001)	(0.001)	(0.0002)	(0.001)
Log income	0.010***	0.021**	0.005	0.021
	(0.001)	(0.001)	(0.03)	(0.04)
Employment status	0.052**	-0.160	0.086	-0.100
	(0.004)	(0.31)	(0.07)	(0.25)
Urban	0.015***	0.013**	0.228***	0.799***
	(0.004)	(0.001)	(0.01)	(0.12)
Electricity	0.063***	0.057	0.170***	0.536***
	(0.004)	(0.13)	(0.01)	(0.10)
Occupancy status	-0.021**	-0.028	-0.073	-0.192***
	(0.003)	(0.05)	(0.01)	(0.05)
Number of rooms	0.013***	0.024	-0.020***	-0.022
	(0.001)	(0.02)	(0.004)	(0.02)
Household size	-0.003***	0.082***	0.021***	0.103***
	(0.001)	(0.01)	(0.002)	(0.01)
Basic education	0.035***	0.094**	0.052**	0.164***
	(0.004)	(0.001)	(0.01)	(0.04)
Secondary education	0.058***	0.016**	0.044***	0.079
	(0.01)	(0.002)	(0.02)	(0.06)
Tertiary education	0.096***	0.052**	-0.025***	-0.077
	(0.006)	(0.01)	(0.01)	(0.70)
constant		4.016***		-2.056
		(0.61)		(0.70)
Lamda		-0.319*		1.109***
		(0.17)		(0.249)
N	15,346	2,412	15,942	5,621

Notes: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6. Conclusions

This study attempted to investigate whether the factors determining a household's decision to participate in a fuel market differ from those determining how much to spend on that fuel after the participation decision is made. To answer this question, three estimation methodologies were used: the Tobit, double-hurdle, and Heckman models. Diagnostic checks led to the rejection of the Tobit model, because both the normality and homoscedasticity assumptions were violated. Our main discussion drew on the results from the double-hurdle, with the Heckman model used as robustness check.

The analysis yielded several interesting results. First, the factors influencing the household decision to participate in either the LPG or charcoal market differ from those influencing how much is spent. Therefore, to be able to adequately address these differences in decision-making, a methodology capable of addressing these decisions should be adopted. Second, households already using and spending positive amounts on LPG or charcoal are indifferent to prices of other fuels. The finding suggests that any policy that affects the price of a cooking fuel will have impact on its own users, but not on users of other fuels. Third, although income plays a role in the LPG expenditure of rural and urban residents, it is insignificant in terms of charcoal expenditures of urban residents. This result indicates the critical role that income plays in modern cooking fuel choice and spending, as compared to transition fuels.

Our results have several policy implications regarding the transition to modern fuels. First, different policy designs might be necessary for households that use LPG and those that do not. For example, it is necessary to focus on making LPG affordable to encourage households already using LPG to maintain its usage and increase related spending. In other words, LPG price is key in motivating LPG users to maintain their spending. To enhance the uptake of LPG and spending among those that do not use LPG, a possible solution is policy measures to improve their livelihoods, which could encourage charcoal users to switch to a modern fuel such as LPG. This can be achieved by intensifying poverty reduction schemes to improve with the goal of reducing poverty. Second, our results showed that there are positive returns to education for both single fuel users (LPG or charcoal) or multiple fuel users (LPG and charcoal). It suggests that intensifying awareness on the positive effects of LPG use and spending could affect behavioral patterns, thereby increasing the uptake of cleaner cooking fuels. Third, policies that increase access to modern fuels should be mainly focused on urban households. Urban households have a considerably higher purchasing power, and thus, are more likely to adopt and spend on LPG contingent on a more reliable supply. In contrast, such policies might not be sufficient for rural households given their access to firewood, which is freely available in most cases. Here, a free supply of LPG cylinders might be helpful for rural households. For example, in 2014, the Rural LPG promotion program was established to facilitate the distribution of 350,000 LPG cylinders and stoves with all related accessories in 13 Ghanaian districts.[11] Unfortunately, this program was abruptly stopped owing to financial constraints and could not achieve its intended target of distributing 350,000 LPG cylinders and stoves in the rural districts by the end of 2016. In the case of charcoal use, particularly among urban households, policies should be designed to limit the fuel supply to reduce its use and spending. Such tailor-made policies are important to increase the usage of modern fuels in Ghana.

[11] https://www.graphic.com.gh/news/general-news/govt-launches-lpg-cook-stove-programme.html

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Appendix

Table A: List of variables and definitions

Variables	Definition
Dependent Variables:	
Binary Dep. Variable (First Hurdle)	
LPG	Dummy (participant=1, others=0)
Charcoal	Dummy (participant=1, others=0)
Monthly Expenditure (Second Hurdle)	
Log monthly LPG expenditure	Monthly amount spent in Ghana cedi
Log monthly charcoal expenditure	Monthly amount spent in Ghana cedi
Independent Variables	
Household Characteristics	
Sex of household head (Male head)	Dummy (male=1, female=0)
Age of household head	Continuous
Log monthly household income	Continuous
Household size	Continuous
Employment status	Dummy (employed=1, otherwise=0)
Basic education	Dummy (basic=1, no formal education=0)
Secondary education	Dummy (secondary=1, no formal education=0)
Tertiary education	Dummy (tertiary=1, no formal education=0)
Urban	Dummy (urban=1, rural=0)
Electricity	Dummy (yes=1, no=0)
Occupancy status	Dummy (owning=1, otherwise=0)
Number of rooms	Number of rooms the household occupies
Fuel Characteristics	
Reliable LPG supply	Dummy (yes=1, no=0)
Reliable kerosene supply	Dummy (yes=1, no=0)
Reliable firewood supply	Dummy (yes=1, no=0)
Reliable charcoal supply	Dummy (yes=1, no=0)
Log charcoal price (cedi/kg)	Continuous
Log LPG price (cedi/kg)	Continuous
Log kerosene price(cedi/liter)	Continuous

Table B: Summary Statistics of Variables

Variable	Obs.	Mean	S.D.	Min.	Max.
LPG	16,041	0.16	0.37	0.00	1.00
Charcoal	16,041	0.35	0.44	0.00	1.00
Log LPG expenditure	2,412	4.46	0.83	0.69	8.25
Log Charcoal expenditure	5,621	2.41	0.83	0.18	5.63
Log charcoal and LPG expenditure	1,123	4.66	0.73	2.07	7.63
Age head	16,041	45.61	15.52	15.00	99.00
Male head	16,041	0.72	0.45	0.00	1.00
Log income	16,041	8.16	1.39	-3.00	14.03
Household size	16,041	4.26	2.78	1.00	29.00
Basic education	16,041	0.30	0.46	0.00	1.00
Secondary education	16,041	0.08	0.28	0.00	1.00
Tertiary education	16,041	0.10	0.30	0.00	1.00
Urban	16,041	0.43	0.49	0.00	1.00
Electricity	16,041	0.60	0.49	0.00	1.00
Occupancy status	16,041	0.54	0.50	0.00	1.00
Number of rooms	16,041	1.90	1.29	1.00	17.00
Reliable LPG supply	16,041	0.30	0.46	0.00	1.00
Reliable kerosene supply	16,041	0.49	0.50	0.00	1.00
Reliable firewood supply	16,041	0.58	0.49	0.00	1.00
Reliable charcoal supply	16,041	0.80	0.40	0.00	1.00
Log charcoal price	16,041	0.42	0.06	0.20	0.63
Log LPG price	16,041	0.47	0.09	0.26	0.86
Log kerosene price	16,041	0.03	0.05	-0.09	0.39

Note: "S.D." denotes standard deviation, "Obs." represents number of observations, and "Min." and "Max." are minimum and maximum.

Table C: Tobit Estimation Results

Variables	LPG expenditure	Charcoal expenditure
Log LPG price	-1.120***	-0.520
	(0.34)	(0.37)
Log charcoal price	1.574***	-0.735***
	(0.34)	(0.20)
Log kerosene price	-0.500	-1.188**
	(1.09)	(0.65)
Reliable charcoal supply	0.600***	4.889***
	(0.17)	(0.15)
Reliable firewood supply	-1.367***	-0.737***
	(0.13)	(0.08)
Reliable kerosene supply	-0.550***	0.698***
	(0.13)	(0.08)
Reliable LPG supply	5.180***	-0.704***
	(0.14)	(0.09)
Male head	-0.505***	-0.968***
	(0.121)	(0.08)
Age head	-0.014***	0.006*
	(0.004)	(0.003)
Log income	0.378***	0.054*
	(0.04)	(0.03)
Employment status	2.328**	0.582
	(0.870)	(0.61)
Urban	0.519***	2.18***
	(0.14)	(0.09)
Electricity	2.764***	1.720***
	(2.03)	(0.09)
Occupancy status	-0.785***	-0.682***
	(0.126)	(0.08)
Number of rooms	0.434***	-0.173***
	(0.06)	(0.04)
Household size	0.015	0.212***
	(0.02)	(0.02)
Basic education	1.586***	0.506***
	(0.15)	(0.09)
Secondary education	2.328***	0.415***
	(0.19)	(0.14)
Tertiary education	3.342***	-0.164
	(0.17)	(0.13)
Constant	-11.55***	-9.868***
	(1.00)	(0.70)
Sigma	3.631***	3.651***
	(0.06)	(0.04)
N	16,041	16041

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table D: Collinearity Diagnostics

Variable	VIF LPG expenditure	VIF Charcoal expenditure
Log LPG price	1.09	1.02
Log charcoal price	1.02	1.07
Log kerosene price	1.08	1.02
Reliable charcoal supply	1.32	1.06
Reliable firewood supply	1.42	1.26
Reliable kerosene supply	1.50	1.28
Reliable LPG supply	1.15	1.27
Male head	1.12	1.19
Age head	1.40	1.22
Log income	1.16	1.17
Employment status	1.01	1.01
Urban	1.16	1.27
Electricity	1.05	1.17
Occupancy status	1.32	1.27
Number of rooms	1.85	1.72
Household size	1.67	1.59
Basic education	2.70	1.37
Secondary education	2.20	1.29
Tertiary education	2.84	1.30