Supply-side Factors of LPG Adoption and Usage Frequency in Ghana: Assessing the Validity of Subjective Distance to Refill

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Abstract

Despite numerous policy efforts to promote the transition to clean cooking fuels, the use of solid cooking fuel persists in developing countries. The scenario calls for a study on the factors influencing the adoption of clean cooking fuels. Hence, this study investigates the supply-side determinants of liquefied petroleum gas (LPG) adoption and usage frequency in Ghana. We conduct a survey among 904 households and 19 LPG refill stations and collect self-reported and geolocational data in the Ga South municipality and Ada West districts of Ghana to compare the validity of the subjective and objective measures of distance to refill stations. We find that the distance to refill stations negatively influences LPG's adoption and usage frequency, and the result is robust across different measures of distance. However, the provision of multiple services at refill stations increases household LPG use. Other key factors influencing usage frequency include policy interventions as well as behavioral and socio-economic characteristics of households. Our results support the validity of subjective estimates by respondents on the distance traveled to access a refill station. These findings have significant policy implications, particularly for developing countries facing challenges in infrastructure for the LPG distribution.

Keywords

Clean cooking fuel; Ghana; Liquefied petroleum gas; Measures of distance; Supply-side determinants; LPG refill station

1. Introduction

A large number of people in developing countries depend on traditional fuels, such as firewood, charcoal, and agricultural waste, for cooking daily meals (World Health Organization, 2018). The emissions from the combustion of these fuels comprise the main cause of household air pollution, which can affect household members' health. Particularly, the emissions from the combustion of wood fuels adversely affect the health of women and children (Adjei-Mantey and Takeuchi, 2021; Kurata et al., 2020). The situation is also manifested in Ghana. The Ghana living standards survey VII (GLSS 7) (the latest national household survey) indicates that about 75% of the households use firewood and charcoal as their primary energy sources for cooking. While there has been an increase in the share of liquefied petroleum gas (LPG) as the primary cooking fuel, the current share of 18.4% suggests the existence of a gap in the transition from dirty to clean cooking fuels.

Empirical studies have examined the pertinent issues surrounding fuel transition in developing countries such as Ghana, South Africa, Peru, and Indonesia. Some studies have focused on evaluating the success and impact of fuel transition programs (Adjei-Mantey et al., 2021; Calzada and Sanz, 2018; Imelda, 2020; Pollard et al., 2018), while others have focused on examining factors enhancing or inhibiting the adoption of clean fuels such as LPG (Adjei-Mantey and Takeuchi, forthcoming; Chindarkar et al., 2021; Karimu et al., 2016; Zahno et al., 2020). However, most of these studies have emphasized demand-side factors—that is, how household characteristics influence their choice of cooking fuel. Given that the supply network of clean cooking is weak and unstable in developing countries, an exploration of the supply-side features provides strong implications for the development of policies for the promotion of cooking fuel. Thus, this study examines how the supply-side features affect the adoption and usage frequency of LPG as a primary cooking fuel. Particularly, we focus on the following supply-side factors: the distance from households to refill stations as well as the provision of other services in addition to the sale of LPG at refill stations.

Since LPG is not supplied directly to users' homes in Ghana, the distance between the home locations and refill stations poses a key challenge to these users. Hence, people who use LPG for cooking purchase a cylinder that can be carried to the nearest refill station when it is empty. This system of LPG distribution to households causes potential inconveniences that may hinder LPG adoption. Previous studies have mostly relied on household-level surveys to examine the determinants of fuel choice. However, such surveys solicit responses to questions that may be subjective and prone to potential biases from self-reporting. A typical example is the distance to an LPG refill station. Adjei-Mantey et al. (2021), for instance, showed that the distance to refill stations negatively affects LPG adoption and positively impacts the willingness to pay for an improved LPG distribution service. Similarly, Dendup and Arimura (2019) indicated that the distance to the nearest market negatively affects the choice of clean fuel. In the aforementioned studies, distance is measured by the self-reported travel time (in minutes or hours). While self-reporting provides a useful means of measurement, there might be biases arising from households' inadvertently (or otherwise) inaccurate estimation of the distance. A more objective approach to capture the effect of distance on LPG adoption is to measure the actual distance (say in km), which is what we attempt in this study. Thus, this study compares the subjective measures of distance to with the objective measures to assesses the validity of the former in analyzing the determinants of LPG adoption.

This study also focuses on the provision of additional services that might help mitigate the impact of the distance between refill stations and households. By providing other services such as the sale of groceries, LPG equipment accessories, and the repair of LPG equipment, refill stations can improve their attractiveness and increase consumers' visits. We hypothesize that the provision of these additional services will help households to fulfill other household needs in the same trip that they make to refill their cylinders. This will save households' time and costs, and thereby increase their willingness to make trips to this refill station. This is opposed to the alternative scenario, where the sale of LPG at refill stations is not accompanied by additional services. In this scenario a household might need to make two separate trips—one to refill their cylinder, and the other may be to shop for the household's grocery needs. The latter scenario presents additional commuting costs to the household in terms of both time and money; and if they have to choose one of the two trips due to resource constraints, they will be more likely to prioritize the trip for groceries over the one for refilling the cylinder. Given that households in developing countries tend to stack fuel, an inability to refill the LPG cylinder may induce such households to use other fuels present in the household fuel mix. Therefore, we examine how these factors impact households' valuation of an LPG distribution model that facilitates the direct delivery of LPG to users' homes, thereby eliminating travel inconveniences and costs associated with the current LPG distribution system.

This study makes three contributions to the literature on the promotion of clean cooking fuel in developing countries. First, this study bridges the gaps in the literature because of the insufficient attention to the supply-side features in the studies on clean fuel transition. As previously mentioned, most of the studies focus on the demand-side factors, with little emphasis on supply-side factors (Adjei-Mantey and Takeuchi, forthcoming; Karimu et al., 2016; Kumar and Igdalsky, 2019; Mensah and Adu, 2015; Pope et al., 2018; Sehjpal et al., 2014). This study examines the effect of the location of LPG refill stations and the provision of additional services at refill stations on the adoption and use of LPG as the primary cooking fuel. Second, unlike the previous studies, this study examines the determinants of the use frequency of LPG. The adoption of LPG as a primary cooking fuel in user households may differ from its use frequency in households using multiple cooking fuels. By investigating the frequency or intensity of LPG use in households using alternative cooking, this study adds new and relevant insights to the cooking fuel transition literature and policy planning. Third, this study compares the subjective and objective measures of distance. Studies have argued that, in subjective estimation of values, such as in the case of the distance to refill, households tend to overestimate or underestimate their valuation in a bid to sway policy decisions in their favor[1]. In certain survey-based studies, households may find it difficult to report exact information associated with a past trip owing to their poor recollection of the trip. This may lead to incorrectly-reported values of a variable; for example, households may inaccurately estimate the travel time associated with a trip if they do not make that trip frequently. By comparing the subjective estimation of the distance to refill stations with the objective measures of the distance, we assess the validity of subjective measurements and suggest how to treat subjective responses to questions for which an objective measure may not be readily available.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature. Section 3 provides details on the data and the empirical methodology adopted to analyze the data, Section 4 presents the results and discusses the findings, and Section 5 concludes the study.

[1] For further discussion, refer to Amoah et al. (2019)

2. Literature Review

A limited number of studies have examined the supply-side factors influencing cooking fuel choices. Dendup and Arimura (2019) showed that the distance to the nearest market measured in travel hours negatively affected the choice of LPG in Bhutan. Affirming these findings, Adjei-Mantey et al. (2021) showed that the distance to access an LPG refill station in Ghana reduces the probability of choosing LPG as the main fuel and its use frequency. The study argues that the distance to a refill station might be a key determinant in the decision-making of households when choosing a primary cooking fuel, given that a longer distance to the refill station could represent significant inconvenience to households who might opt against choosing LPG. Conversely, Dalaba et al. (2018) found an insignificant association between owning LPG in Northern Ghana and the distance to refill stations. The study explained that homes located in the peripheral parts of the towns are larger and potentially owned by wealthier households who are unlikely to consider the accessibility of LPG an important barrier to their adoption of the fuel. Similarly, Sankhyayan and Dasgupta (2019) found that LPG's availability is not a key determinant of the uptake of LPG in India.

Wassie et al. (2021) found a significant association between the distance to firewood and the choice of cooking fuel in Ethiopia. The dependence on firewood as a primary cooking fuel reduces with an increase in the distance to wood, suggesting an increase in the cost of accessing wood fuel. This supports the findings of Jumbe and Angelsen (2011) on the importance of the proximity of wood sources to the choice of fuelwood and how longer distance to the forest for firewood drives the transition to cleaner fuels in Malawi. Karimu (2015) conducted a study and found that the availability of different fuel types influenced the fuel choice in Ghana. As measured by self-reported ranking, the availability of wood and LPG, positively influenced the choice of the respective fuels, while the availability of LPG negatively affected the choice of fuelwood. These studies show that proximity to fuel sources positively influence the fuel choice. Hence, in the case of developing countries, the effectiveness of policies to aid the transition to cleaner fuels can be enhanced by focusing on supply chain measures and easing the accessibility of different fuel types.

Besides the distance and availability of fuels, studies have discussed the type of cooking stoves supplied to households as another supply-side variable influencing LPG use. Shupler et al. (2021) found that, on an average, households with multiple burner stoves consumed more LPG than that of the households with single burner stoves. On an average, households with double and triple burner stoves annually consumed 8.2 kg/capita and 6.1 kg/capita, respectively, more LPG than that of households with single burner stoves. The increased LPG use by households owning multiple burner stoves can be attributed to the convenience offered by these stoves in preparing different foods simultaneously. These findings related to distance and availability indicate households' preference for greater convenience and time savings in their choice of cooking fuel.

Concerning the demand-side, another strand of literature has examined the demand-side determinants of LPG adoption.[2] Some of the key determinants investigated in these studies include the socio-economic, cultural, and behavioral factors and the policy intervention programs. Socio-economic characteristics include the households' income level or ability to afford, level of education or awareness, rural or urban location, and access to information. They have been found to influence LPG adoption in Ghana (Dalaba et al., 2018; Karimu et al., 2016; Karimu, 2015; Mensah and Adu, 2015), Cameroon (Pope et al., 2018); Bhutan (Dendup and Arimura, 2019); and India (Farsi et al., 2007; Zahno et al., 2020). Other factors include cultural factors (Malakar et al., 2018), behavioral factors (Adjei-Mantey and Takeuchi, forthcoming), and the effects of peers and communities (Bonan et al., 2021).

Policy interventions for the transition to cleaner cooking fuels have also been found key to motivating the use of clean cooking fuels (Adjei-Mantey et al., 2021; Andadari et al., 2014; Calzada and Sanz, 2018; Imelda, 2020; Kimemia and Annegarn, 2016; Pollard et al., 2018). These studies have argued that the transition to cleaner fuels have been quicker with interventions in the form of the provision of free LPG equipment, continuous subsidies on LPG fuel, and capping the maximum retail price of LPG. These studies provide evidence that the provisions take away the cost burden of the initial set up from households. They have also shown that subsidies increase the affordability of fuel, and thus increase the probability of LPG adoption. However, in the context of India, Gould et al. (2020) showed that, after LPG adoption, beneficiaries of an intervention program consumed less fuel per month than that of others. This is because LPG acquisition among households is driven by personal motivation, and hence households that switch to LPG on their own may not require external motivation or accompanying factors (e.g., price subsidies) to use

[2] For extensive literature reviews on the enablers and barriers for the adoption of clean cooking fuel choice, refer to Muller and Yan (2018), Puzzolo et al. (2016), Malla and Timilsina (2014), and Lewis and Pattanayak (2012).

them. However, households randomly selected as beneficiaries may have no personal motivation to use LPG. In this scenario, intervention programs may not be sufficient to promote regular use.

Our study is also related to the strand of literature comparing the subjective and objective measures of variables in statistical analyses of household behavior and welfare. In the context of the United States, Poor et al. (2001) compared the subjective and objective measures of water clarity in a hedonic property valuation model. They found that the objective measure of water clarity was either preferred or, at least, equally preferred to the subjective measure for explaining the variation in property prices. They found that the objective measure outperformed the subjective measure used to report water clarity. The authors attributed this underreporting of water clarity to the property owners' lack of attention or knowledge. However, they found that property owners' relative, subjective estimations of water clarity for different lakes were likely to be accurate, making a case for further investigations into similar validity assessments. Macků et al. (2020) found a relationship between the objective and subjective measures of life satisfaction. However, the broad nature of the concept of life satisfaction implied the variable nature of subjective measures. Hence, they found it difficult to make conclusive statements on the validity of subjective measures in the context of life satisfaction.

The literature review suggests that while the demand-side factors have received significant attention, there is much to be discovered from the supply side. To the best of our knowledge, the existing studies on the supply side have not examined the effect of the provision of additional services at LPG refill stations on LPG adoption and use. The other services provided at LPG refill stations can increase the attractiveness of the station and have a critical role in motivating households to visit the refill stations. The current study introduces this variable to fill the gap in the literature and examine its influence on LPG use. The study also provides insights into how this supply-side factor motivates the transition to cleaner cooking fuels. Finally, our study complements the literature on the validity of the subjective measures, relative to the objective measures in empirical research.

3. Data and Methodology

3.1 Data Collection

We collected primary data through face-to-face interviews in Ghana's Ga South municipality and the Ada West district. These districts have recently benefited from a government intervention where some residents received free LPG equipment as part of a cooking fuel transition program. Particularly, both the districts had complete information on the beneficiary households that allowed us a random sampling of households for the interviews. We also conducted interviews at all the active refill stations in each district. In terms of population, Ga South has a larger population of 411,377, with the majority comprising urban residents and only 10% comprising rural residents. Ada West has a lower population of 59,124, with the majority (70.3%) comprising rural residents. The population of households i.e., the total number of households in Ga South and Ada West are 100,701 and 11,642 respectively. (GSS, 2014a; 2014b). The number of active refill stations at the time of the survey was 12 and 7 in the Ga South and the Ada West respectively.

We conducted the field survey in August 2020, using the computer-assisted personal interviewing (CAPI). We also followed the standard field survey protocols, including the training of enumerators, the pilot survey of the questionnaire to test its suitability, the ease of comprehension on the part of both the enumerators and respondents, and appropriate revisions of the questionnaire before the main survey exercise. We conducted 904 successful household interviews—448 and 456 in Ada West and Ga South, respectively[3]. We also interviewed all the 19 LPG refill stations operating in the two districts at the time of the exercise. This is the total number of suppliers of LPG in both Ada West and Ga South at the time of the survey.

3.2 Variable Description

This study used two approaches to measure the distance to refill stations: subjective and objective measures. In the subjective approach, we asked the sampled households about the time taken (in minutes) to make a return trip to the nearest LPG refill station (travel time only). In the objective

[3] These numbers exceed the minimum sample size of 385 calculated at a 95% confidence level and a population proportion of 50%. The minimum sample sizes were calculated as follows: n=$\frac{z^2 p(1-p)}{e^2}$, where z is the z-score, p is the population proportion and e is the margin of error (Charan and Biswas, 2013).

approach, by employing a global positioning system (GPS), we recorded the geographical location of the households as well as those of the LPG refill stations, and calculated the distance (in km) between the households and the nearest refill station. However, we could not capture the GPS data for a few households located in the remote parts of the districts; this may be attributed to the poor telecommunication services in these parts. At the refill stations, the enumerators interviewed the station officials for collecting information on the range of services provided to customers.

Table 1 presents summary statistics of the data. It shows that the mean travel time to make a return trip to the nearest refill station is 42 minutes, with a mean distance of 7.9 km between the households and refill stations. Among the respondents, 62% were provided additional services by the nearest refill stations, besides the sale of LPG. Regarding the LPG usage, 43% of the respondents used LPG as their main fuel, and the LPG usage rate stood at an average of 52%. The LPG usage rate is defined as the ratio of the number of times LPG is used in a day to the number of times a household cook food.[4] Therefore, the mean rate of 52% implies that, on an average, one out of every two meals is cooked using LPG. It also shows that about 45% of the respondents have benefitted from the government intervention program on fuel transition.

Table 1: Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Distance (minutes – subjective)	836	41.62	29.34	1	240
Distance (km – objective)	802	7.88	5.71	0.059	21.302
Additional services	807	0.623	0.485	0	1
LPG is the main fuel	904	0.434	0.496	0	1
LPG usage rate	866	0.518	0.446	0	1
Education (years)	904	7.398	4.501	0	16
Occupation (1=agriculture)	904	0.281	0.450	0	1
Rural	904	0.774	0.418	0	1
Risk averse	904	0.772	0.420	0	1
Beneficiary of intervention	904	0.452	0.498	0	1
District (1=Ga South)	904	0.504	0.5	0	1
Household income (cedis)	904	1781.3	1697.7	0	22600

* Approximately, 1 Ghana cedi was equal to 0.17 US dollars at the time of the survey.

[4] For example, if a household cooks thrice a day and uses LPG once a day, then the LPG usage rate for this household is 0.33.

3.3. Empirical Methodology: LPG adoption and usage

A random utility framework is used to examine the factors influencing household LPG adoption and LPG use. The framework assumes that the utility associated with a particular choice alternative is a function of the observable and non-observable or stochastic components. Thus, a household *i* chooses its main fuel from j alternatives of cooking fuel, where the bundle j includes LPG and other fuels such as firewood and charcoal. Thus, with the *j* alternatives of cooking fuel available to the household, the household chooses LPG as its main cooking fuel if the utility obtained from using LPG is greater than the utility obtained from other fuels:

$$\Pr_i(LPG) = \Pr\left(U_{i,LPG} > U_{i,others}\right) \quad (1)$$

Based on the above equation, we specify the following model of the probability of adopting LPG as the main fuel for cooking as follows:

$$\Pr_i(LPG) = \beta_0 + \beta_1 D_i + \beta_2 AS_i + \beta_3 X_i + \varepsilon_i \quad (2)$$

where *D* is the distance to the nearest refill station, measured in both the subjective and objective terms. *AS* is an additional service offered by the nearest refill station such as the sale of groceries and LPG accessories and the repair of LPG equipment and accessories, and *X* is a vector of other factors such as occupation, income, education, and rural location. The dependent variable in this study is the adoption of LPG as the main cooking fuel. We employ the probit model to estimate equation (2) and report the marginal estimates at the means.

With respect to the usage frequency, we model the LPG usage frequency rate as follows:

$$LPG\ usage\ rate_i = \beta_0 + \beta_1 D_i + \beta_2 AS_i + \beta_3 X_i + \varepsilon_i \quad (3)$$

where *D, AS,* and *X* are as previously explained. The dependent variable is the LPG usage rate and indicates how often LPG is used in the household. We employ a linear model to estimate (3). A correlation test showed no strong correlation between any of the explanatory variables.

We expect the distance to the refill station to have a negative effect on LPG usage because households that are far from the refill stations may find it inconvenient and costly to refill their empty cylinders. The negative effect can be mitigated by providing additional services at the refill stations, such as the sale of groceries and LPG accessories and the repair of LPG equipment and accessories. It offers more convenience to households as they can complete multiple household tasks with minimum trips. Therefore, providing additional services is expected to have a positive effect on LPG adoption and use.

To confirm the validity of the subjective measures of distance, we compared the results obtained from the estimations under the subjective measure to those obtained under the objective measures. According to Carmines and Zeller (1979), it is crucial to obtain similar outcomes from both the subjective and objective approaches to measure a particular variable to conclude on the validity of the subjective measure. Thus, if the effect of distance is consistent across the two approaches, we can conclude that the subjective measure conveys reliable information. However, if the result obtained by the objective measure differs substantially from that obtained using the subjective measure, we will conclude that the subjective measure may have suffered significant personal biases and is less reliable.

4. Results and Discussion

4.1 Supply-side effects on LPG adoption and use

This section presents the estimation results and discusses the findings. Table 2 presents the main results from the probit estimation of the supply-side factors for the adoption of LPG as the main cooking fuel. Table 3 shows the results from the linear model estimation, which uses the frequency of LPG use in the household as the dependent variable. Columns (1) and (3) show the results with the subjective measures of distance without and with control variables respectively, while columns (2) and (4) show results with the objective measures without and with control variables respectively. District specific effects have been accounted for in all estimations.

Table 2: Probit analysis on the supply-side factors for LPG adoption as the main cooking fuel

	Dependent variable: LPG as the main cooking fuel			
Explanatory variables	(1)	(2)	(3)	(4)
Distance (min. – subjective)	-0.004***		-0.003***	
	(0.001)		(0.001)	
Distance (km – objective)		-0.026***		-0.021***
		(0.004)		(0.006)
Additional services	0.233***	0.155***	0.068	0.123**
	(0.042)	(0.048)	(0.066)	(0.060)
Other control variables	No	No	Yes	Yes
District effects	Yes	Yes	Yes	Yes
Observations	751	801	751	801

Coefficients are marginal effects. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3: Supply-side factors for LPG usage rate (Linear model)

	Dependent variable: LPG usage rate			
Explanatory variables	(1)	(2)	(3)	(4)
Distance (min – subjective)	-0.004***		-0.003***	
	(0.001)		(0.000)	
Distance (km – objective)		-0.024***		-0.022***
		(0.003)		(0.004)
Additional services	0.251***	0.192***	0.159***	0.194***
	(0.035)	(0.039)	(0.045)	(0.041)
Constant	0.548***	0.528***	0.451***	
	(0.047)	(0.051)	(0.095)	0.180**
				(0.086)
Other control variables	No	No	Yes	Yes
District effects	Yes	Yes	Yes	Yes
Observations	720	770	751	770
R-squared	0.163	0.194	0.345	0.377

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

As shown in Table 2, the effect of distance to refill stations on LPG adoption as the main fuel is negative and statistically significant. A one-minute increase in the distance decreases the probability of adopting LPG as the main fuel by 0.3% (column 3). The results from the models with the objective measures also confirm the negative impact of distance. A one-kilometer increase in the distance decreases the probability of adopting LPG as the main fuel by 2.1% (column 4). Similar results are found in Table 3 on the effect of distance on the frequency of LPG usage. A one-minute increase in the travel time to refill station reduces the LPG usage rate by 0.3% (column 3), while a one-kilometer increase in the distance reduces the LPG usage rate by 2.2% (column 4). As expected, longer distances to refill stations disincentivize LPG adoption, given that longer distances increase the costs and inconvenience associated with refilling the LPG cylinder. Our findings agree with those of Adjei-Mantey et al. (2021), Shupler et al. (2021), and Dendup and Arimura (2019). Adjei-Mantey et al. (2021) argued that the accessibility of refill stations plays a key role in motivating households to switch to LPG. Shupler et al. (2021) observed that 72% of their respondents who used LPG exclusively were at 10 minutes or less distance from an LPG retail point. For the same distance, the proportions of households that used LPG as a primary and secondary fuel accounted for 47% and 36%, respectively. Dendup and Arimura (2019) noted that the distance to the nearest market where a refill depot was likely to be located negatively affected the choice of LPG.

The provision of additional services at refill stations increased the probability of adopting LPG by 12.3% and the LPG use rate by 15.9%–19.4%, suggesting that the provision of additional services strongly influences the usage frequency of LPG in the household. In this scenario, households are likely to consume more LPG to cook more meals, given that they would be comfortable making regular trips to the refill station when they have an option to complete other tasks on the same trips they make to refill their cylinders. However, when additional services are not provided at the refill station, the need for a refill resulting from increased LPG use may imply users have to make trips to refill cylinders only and separate trips to other locations to perform other tasks such as shopping. Under such circumstances, households are less likely to use LPG than they would if additional services were offered at refill stations. Thus, while the effect of the additional service provision on the adoption of LPG as the main fuel is only evident when distance is measured objectively, it is consistent under the use frequency model, irrespective of the measure of distance. In summary, while additional services may not always play a role in driving LPG adoption as the main fuel, it is more likely to be important in how frequently LPG is used for households who own LPG stoves.

Other variables that are likely to affect household LPG adoption and use significantly and positively are income, education, and intervention programs. Agricultural workers negatively affect the adoption of LPG as the main fuel. This can be attributed to the fact that agricultural workers have easy access to wood fuel resources and agricultural waste, which they are more inclined to use as cooking fuel. Rural residents do not prefer LPG as the main fuel or the regular use of it. The results are shown in Table 4 and, with respect to these variables, they mostly conform to the findings in the literature (Calzada and Sanz, 2018; Choumert-Nkolo et al., 2019; Muller and Yan, 2018; Saksena et al., 2018). Except for risk aversion and occupation, the factors influencing the adoption of LPG also influence the usage frequency. This agrees with the findings of Gould et al. (2020), who also found similarities in the factors influencing the LPG adoption and use.

Table 4: Full model estimation

	Subjective measure		Objective measure	
VARIABLES	(1) LPG is main fuel	(2) LPG use rate	(3) LPG is main fuel	(4) LPG use rate
Distance (min – subjective)	-0.003***	-0.003***		
	(0.001)	(0.000)		
Distance (km – objective)			-0.021***	-0.022***
			(0.006)	(0.004)
Additional services	0.068	0.159***	0.123**	0.194***
	(0.066)	(0.045)	(0.060)	(0.041)
Agricultural worker	-0.097**	0.011	-0.100**	-0.003
	(0.048)	(0.032)	(0.046)	(0.031)
Income	0.006***	0.003***	0.005***	0.003***
	(0.002)	(0.001)	(0.002)	(0.001)
Education	0.028***	0.017***	0.028***	0.017***
	(0.005)	(0.003)	(0.005)	(0.003)
Risk averse	-0.067	-0.069**	-0.057	-0.057*
	(0.048)	(0.032)	(0.047)	(0.031)
Beneficiary of intervention	0.227***	0.279***	0.268***	0.314***
	(0.039)	(0.026)	(0.037)	(0.025)
Rural	-0.209***	-0.136***	0.005	0.065
	(0.072)	(0.050)	(0.101)	(0.067)
Constant		0.451***		0.180**
		(0.095)		(0.086)
District effects	Yes	Yes	Yes	Yes
Observations	751	720	801	770
R-squared		0.345		0.377

Coefficients for (1) and (3) are marginal effects from probit regression; (2) and (4) are estimates from a linear regression. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

4.2 Subjective vs objective measures of distance

The results of the subjective measurement (column 3 of Tables 2 and 3) were consistent with those of the objective measurement (column 4 of Tables 2 and 3). This finding suggests that the effect of distance can be captured by either subjective or objective measurement. Therefore, we affirm that subjective measurements of distance are valid estimates of the actual distance between the households and the refill stations. This means that, in the absence of the objective means of distance, households' self-reported responses in typical surveys could be reliable substitutes when the surveys are conducted under the right interview protocols. This is in line with the findings of Poor et al. (2001).

Our estimates also suggest that the coefficient of the objective measure is about seven times higher than that of the subjective measure. This indicates that the effect of the increase in the distance by 1 km roughly corresponds to the effect of increasing the travel distance by 7 minutes.

These results suggest that a more convenient system of LPG distribution can increase households' LPG adoption and use frequency. Our findings support those of Larsen et al. (2020), who estimated that a home delivery-based LPG distribution model has the potential to reduce costs by about 28% while increasing LPG consumption by about 37% among rural households.

4.3 Overestimating subjective measure

In this subsection, we examine which category of households is more likely to overstate its subjective distance. Based on the ratio of 1 km to 7 minutes discussed in the previous subsection, we compared the stated time in minutes with the expected time calculated from the objective measure. In other words, we converted the distance in kilometers for each household to minutes and compared it with the self-reported time to reach the nearest refill station. Subsequently, we specified the following model to identify which household is more likely to overestimate the distance.

$$\Pr_i(overestimate) = \beta_0 + \beta_1 LPG_i + \beta_2 X_i + \varepsilon_i \quad (4)$$

where *overestimate* is a dummy variable that takes one for households overstating their distance to the nearest refill station and zero otherwise, *LPG* refers to whether the household uses LPG as the main fuel or otherwise, and X is a vector of control variables. We estimated equation (4) using the probit model and presented the results in Table 5.

Table 5: Determinants of overestimation of the subjective measure

	Dependent variable: Overestimation of distance
Main fuel (1=LPG)	0.036
	(0.042)
Age	0.044**
	(0.020)
Agricultural worker	-0.071
	(0.046)
Income	0.001
	(0.001)
Education	-0.001
	(0.005)
Beneficiary of intervention	0.050
	(0.039)
Rural	-0.705***
	(0.045)
District effects	Yes
Observations	751

Coefficients are marginal effects. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5 shows that most explanatory variables are insignificant. This confirms our earlier results that subjective estimates are reliable and that overestimation is not likely to occur across the several classes of households. However, we found significant results for overestimation on the basis of household location—rural households are less likely to overstate the distance in their subjective estimation. Conversely, urban households are more likely to overstate the distance to refill stations. This suggests that urban residents are faced with challenges of urban living such as vehicular traffic jams, which increase their travel time. Such households spend more time than they should to travel to refill stations even if the distance in kilometers is reasonable. Hence, the bid to avoid the excess time taken to access refill stations can overtake households' willingness to use LPG as their primary fuel. This finding provides another reason the cylinder recirculation model of LPG delivery might be a better alternative to the current distribution system even in urban areas. We also found that older persons overstate the distance perhaps owing to a greater difficulty in mobility than younger persons. In general, an elderly takes more time to cover a kilometer of distance, particularly when they walk.

5. Conclusion

In developing countries, clean cooking fuels play an indispensable role in achieving sustainable development. While several studies have investigated the demand-side factors affecting LPG adoption and use, less attention has been paid to the supply-side factors. This study examined the effect of the supply-side factors on LPG usage. We found that the location of LPG refill stations is a significant factor that affects fuel choice—the distance traveled to access a refill station negatively affects LPG adoption and use. The provision of additional services at LPG refill stations, besides the sale of LPG, exerts a positive influence on the adoption and regularity of the use of LPG. In this case, the frequent visits of users to the refill station positively drives the usage frequency of LPG.

This study also compared a subjective measure of distance to an objective measure and confirmed the validity of the subjective measurements. Overall, we find evidence validating the use of the subjective measures of distance and, by extension, of other variables, in the absence of objective measurements. Therefore, this study affirms the reliability of subjective, self-reported measurements when information reported using these measurements is elicited under standard interview protocols. Based on our findings, we recommend the governments or LPG marketing companies to establish a well-structured distribution model that facilitates the home delivery of LPG. In scenarios where this distribution model may seem infeasible, governments should provide stimulus packages to refill stations. This will allow the latter to provide multiple services, such as the sale of groceries or services, meeting basic household needs, and thereby motivate households to visit refill stations.

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APPENDIX

Sampled communities

Ada West	Ga South	
Afiadenyigba	Paanor	Kofi Kwei
Anyaman	Kokrobitey	Tuba
Addokope	Bortianor	New Weija
Koluedor	Danchira	Gbemomo
Sege/Koni	Obom	Honi Ofadjator
Goi	Horbor	Jei Krodua
Wokumagbe	Weija	