sustainability

MDPI

Article

Affordability, Accessibility, and Awareness in the Adoption of Liquefied Petroleum Gas: A Case-Control Study in Rural India

Praveen Kumar [1,*], Robert Ethan Dover [2], Antonia Díaz-Valdés Iriarte [3], Smitha Rao [1], Romina Garakani [4], Sophia Hadingham [5], Amar Dhand [6,7], Rachel G. Tabak [8], Ross C. Brownson [8,9] and Gautam N. Yadama [1]

1 Boston College School of Social Work, Chestnut Hill, MA 02467, USA; smitha.rao@bc.edu (S.R.); yadama@bc.edu (G.N.Y.)
2 University of Pennsylvania Law School, Philadelphia, PA 19104, USA; edover@pennlaw.upenn.edu
3 Society and Health Research Center, Humanities Faculty—Universidad Mayor, Santiago 7750000, Chile; antonia.diazvaldes@umayor.cl
4 Boston College, Chestnut Hill, MA 02467, USA; garakani@bc.edu
5 Thom Boston Metro Early Intervention, Amory Street, Jamaica Plain, MA 02130, USA; shadingham@thomchild.org
6 Department of Neurology, Harvard Medical School/Brigham and Women's Hospital, Boston, MA 02115, USA; adhand@bwh.harvard.edu
7 Network Science Institute, Northeastern University, Boston, MA 02115, USA
8 Prevention Research Center in St. Louis, Brown School, Washington University in St. Louis, St. Louis, MO 63130, USA; rtabak@wustl.edu (R.G.T.); rbrownson@wustl.edu (R.C.B.)
9 Division of Public Health Sciences, Washington University School of Medicine, Washington University in St. Louis, St. Louis, MO 63110, USA
* Correspondence: praveen.kumar@bc.edu

Received: 14 April 2020; Accepted: 8 June 2020; Published: 11 June 2020

Abstract: Interventions in the clean cooking sector have focused on improved biomass stoves in a bid to address household air pollution (HAP) in low- and middle-income countries. These initiatives have not delivered adequate health and environmental benefits owing to the less than optimal performance of improved biomass stoves. There is an urgency to transition communities to cleaner cooking systems such as liquefied petroleum gas (LPG) to reduce the prevalence of HAP. Adoption of LPG also has challenges. This case-control cross-sectional study with 510 households examines how affordability, accessibility, and awareness (3As) are associated with LPG adoption in rural poor households of Andhra Pradesh, a state of India. Using binomial logistic regression analyses, the study examines the association of 3As with LPG adoption, adjusting for demographic predictors. Results show disparities in LPG adoption owing to affordability, accessibility, and awareness. Household income is positively associated with LPG adoption. Easy availability of biomass deters households from adopting LPG. Concerns for LPG safety reduces likelihood of LPG adoption. On the other hand, attending awareness campaigns on clean cooking benefits is strongly associated with LPG adoption. Awareness drives, primarily targeted marketing campaigns, could help expand LPG coverage among poorer households. This paper offers insights into the determinants of clean fuel adoption with implications for resource-poor settings across the world to advance energy justice and address energy poverty.

Keywords: household air pollution; energy poverty; cleaner cooking; LPG; adoption

1. Introduction

Energy poverty is a crucial problem especially in low- and middle-income countries (LMICs) such as India, with rural poor households particularly impacted by this challenge [1]. Household air pollution (HAP) is a direct consequence of energy poverty in these communities. Adoption and sustained use of liquefied petroleum gas (LPG) are central to addressing HAP in rural poor communities of India and key to achieving energy justice and advancing the Sustainable Development Goals [2–4].

In the context of this study, adoption is defined as the presence of an LPG stove in a household (not necessarily its use or disuse) [5–8]. Evidence shows that high cost of LPG connection and refills, sometimes beyond communities' affordability, prevents adoption and sustained use. Adoption and sustained use of LPG are crucial for securing health and environmental benefits of cleaner cooking especially in resource-poor settings [9–11]. Considerable evidence exists on the relationship between affordability and adoption of LPG by households. Sustained use indicates the degree to which LPG is used and integrated into the daily behavior of users [5–7]. Sustained users of LPG are those who make a complete switch to LPG with no intention of reverting to traditional stoves or fuels [5]. Stackers, on the other hand, routinely use both LPG and traditional stoves [6].

A review of existing literature shows that research on adoption of LPG has a key deficit. While a growing number of studies examine LPG adoption and the role that factors of affordability, accessibility, and awareness (3As) play, there are few that examine all three factors concurrently in a single model [7,12]. It is critical to study how these known barriers to adoption and sustained use of cleaner fuels simultaneously impact outcomes so as to identify potential leverage points for policy interventions. Variables pertaining to affordability, accessibility, and awareness [12], therefore, need to be analyzed concurrently to examine the key covariates of LPG adoption. The current manuscript fills this gap in the clean cooking literature.

For this study, the terms affordability, accessibility, and awareness are defined as follows. Affordability of LPG refers to the capacity of households to pay for LPG services [13]. It is a factor of household level variables: (1) income; (2) financial autonomy among women to access clean cooking technologies; (3) membership with self-help groups (SHGs); and (4) government policies on LPG subsidies [14,15]. Accessibility of LPG indicates factors impacting a household's ability to procure LPG cylinders (tanks) and stoves when needed. Accessibility includes the following variables: (1) distance to rural LPG distribution center; (2) road connectivity from habitations to local distribution centers; and (3) accessibility to sources of free biomass. Awareness refers to the degree of knowledge and perception of LPG adoption and use [16]. Scattered evidence suggests that low information and rumors on LPG safety issues may act as a deterrent to uptake and use of LPG by these rural households. Awareness could also be determined by households attending awareness campaigns on clean cooking [12,17].

Research Questions and Hypothesis

The research presented here is part of a larger case-control study on adoption and sustained use of LPG in resource-poor settings of rural India. For a detailed protocol of the larger study, see Kumar et al. [18]. The overall goal of the larger case-control study is to derive new insights on the reach of LPG among the poor in rural India, factors that influence adoption (initial uptake) and sustained use of LPG in below poverty line (BPL) households in rural India. The results reported in the current manuscript focus only on determinants of adoption of LPG (aim 1 of the larger study) [18]. Aim 2 of the study examines the question of stacking, and its results will be disseminated in subsequent work.

Specifically, the study seeks to understand how rural LPG adopters vary from other rural households on factors of affordability, accessibility, and awareness (3As) of LPG. To examine the concurrent association of the 3As on LPG adoption, multiple variables across the 3As are examined. The following hypotheses based on these variables (Table 1) across the 3As are tested to examine adoption of LPG.

Table 1. List of variables and corresponding codes.

Outcome Variable	**Codes**
LPG Adoption	1 = Yes/0 = No
Demographic predictors	**Codes**
Age	Years
Marital status	1 = Married/2 = Unmarried (ref)/3 = Divorced/4 = Widow
Literacy: Highest level of education completed	0 = None (ref)/1 = Below or up to class 4/ 2 = Class 5 to class 8/3 = Class 9 to class 10/ 4 = Class 11 to class 12/5 = College
Caste	0 = General (Ref)/1 = Other backward castes (OBC)/ 2 = Scheduled castes/scheduled tribes (SC/ST)/ 3 = Other religious minorities
Key predictors	
Affordability	**Codes**
Membership of self-help groups (SHGs)	1 = Yes/0 = No
Monthly income of the household	Indian national rupee (INR), squared root transformed for normality
Accessibility	**Codes**
Nearest paved road from the household	Kilometers (km), square root transformed for normality
Availability of free biomass near the household	1 = Yes/0 = No
Distance of the biomass source	Kilometers (km), square root transformed for normality
Preference for smaller LPG cylinders	1 = Yes/2 = No (ref)/3 = Can't say
Decision making capacity to purchase new stove	1 = Respondent (ref)/2 = Spouse of respondent/ 3 = Respondent and spouse of the respondent/ 4 = Respondent, spouse of the respondent, and others/ 5 = Respondent and other but not the spouse/6 = Others but not the respondent or the spouse of the respondent
Awareness	**Codes**
Perception of LPG explosion (LPG safety)	1 = Yes/0 = No
Campaigns attended	1 = Yes/0 = No

Note: Ref indicates the reference category for categorical variables with more than two responses. LPG—liquified petroleum gas.

(1) Affordability

Hypothesis 1 (H1). *Households whose respondents are members of self-help groups (SHG) are more likely to adopt LPG.*

Hypothesis 2 (H2). *Households with higher gross income are more likely to adopt LPG.*

(2) Accessibility

Hypothesis 3 (H3). *Increased distance to paved roads from a household reduces the likelihood of household adoption of LPG.*

Hypothesis 4 (H4). *There is a lower likelihood of LPG adoption when the respondents feel that biomass is easily available near their households.*

Hypothesis 5 (H5). *Increase in the distance to the source of biomass from the households increases their likelihood to adopt LPG.*

Hypothesis 6 (H6). *There is a lower likelihood to adopt LPG in households when the respondents prefer smaller LPG cylinders over the larger cylinders in circulation.*

Hypothesis 7 (H7). *When women in the households are involved in decision-making around purchasing a new stove, there is a higher likelihood for that household to adopt LPG.*

(3) Awareness

Hypothesis 8 (H8). *There is a lower likelihood that households adopt LPG when respondents feel that LPG cylinders are unsafe.*

Hypothesis 9 (H9). *Households that attended at least one LPG awareness campaign in person are more likely to adopt LPG than other households.*

2. Materials and Methods

This case-control study was conducted in the rural habitations of Thambalapalle and Peddamandyam mandals (blocks) in the Chittoor district of Andhra Pradesh state in Southern India. Using a multistage random sampling, 35 habitations from these two blocks were selected, and then a total sample of 510 households from these 35 habitations were included. A sample size of 255 households each for case (LPG adopter households) and control (LPG non-adopter households) was selected. A sample size of 510 households at a 95% confidence level (alpha = 0.05) provided a statistical power of >80% to examine this aim of the study [18]. Kumar et al., 2017 [18], have published a protocol paper detailing the approach and sampling for this study.

The inclusion criteria for the study participants were: rural household with an adult female member (>18 years), woman respondent who was able to provide consent for the study, was the primary cook of the house, residing in the household for the last 12 months, and planned to reside in the household for at least 12 months from the date of enrollment for the study. An additional inclusion criterion for the case group (LPG adopter households) was: household received the first LPG connection ever in the last 12 months from the date of enrollment in the study.

2.1. Operationalization of Variables

The operationalization of the variables for affordability, accessibility, and awareness is discussed below.

The construct affordability includes the following two variables: (1) square root of household monthly income; (2) membership of the respondents in self-help groups (SHGs).

The construct accessibility includes the following five variables: (1) Nearest paved road from the household: The distance of the nearest paved road from the household is measured in kilometers (km). The data were provided by the household and triangulated with routine observation by the enumerators; (2) Preference of the household for smaller LPG cylinders: Tare weight of one LPG cylinder (tank) used in households is 15.3 kg (kg). When filled with LPG fuel to its capacity, the gross weight of the LPG cylinder is 29.5 kg. Heavy cylinders are cumbersome to carry from local distribution agencies to respective rural households. This exacerbates when the households are located in the interiors of the habitations. Thus, the preference of the household for smaller LPG cylinders is assessed; (3) Availability of biomass near the household: This variable gauges the perception or mental models of the respondents on whether the biomass is easily available in proximity to their respective households. Anecdotal evidence has shown that perception on easy availability of biomass reduces likelihood to adopt cleaner cooking technologies; (4) Distance to the biomass source from the household: All the sample households are traditional stove users. Respondents (women) collect biomass from proximal forests. This variable explores the distance (in km) to the closest biomass source from the respondent's household; (5) Autonomy of the respondent (women) on purchasing cooking systems: measured by administering a standard question on who makes the decision to procure/purchase clean cooking systems for the households.

The construct awareness includes two variables: (1) LPG safety: This variable examined the perception of safety when using LPG. Anecdotal evidence suggests that households that perceive that LPG cylinders are unsafe have a lower likelihood to adopt LPG; (2) Awareness campaigns: assessed by respondents having attended at least one in person awareness campaign on clean cooking benefits.

The variables and their corresponding codes (shown in Table 1) across the 3As to assess the covariates of LPG adoption were adapted from three standard instruments: (1) Demographic Health Survey (DHS) questionnaires; (2) National Sample Survey Organization (NSSO) of India; and (3) Census of India 2011 questionnaires.

Data collection for this cross-sectional research was through a structured household adoption questionnaire. Data were collected for this aim of the larger study during July through November 2016. The questionnaire collected data on social, economic, and demographic characteristics of the household in addition to eliciting information on affordability, accessibility, and awareness (3As) of LPG. The binary outcome variable was adoption of LPG at the time of data collection. The outcome variable was self-reported. The response to the outcome variable was verified by checking the participants' LPG log-book received by the LPG distribution agencies. The adoption questionnaire was administered to all 510 households in the study.

2.2. Data Analysis

Multiple hypotheses were tested to determine the association of affordability, accessibility, and awareness with adoption of LPG. First, univariate analysis was undertaken to describe the data and sample as shown in Table 2. Second, two multivariate logistic regression models were constructed, controlling for the clustering of the data at the habitation level. This was important so as to cluster standard errors to account for possible community level correlations in explanatory variables and outcomes. Two regression models were developed (see Table 3). Model 1 included only demographic predictors. Model 2 included all the predictors of 3As to examine the research hypotheses. Corresponding Akaike's Information Criteria (AIC), Bayesian Information Criteria (BIC), and pseudo R^2 were calculated to assess relative fit and model comparison among the two regression models. The alpha value or the significance level for this study is fixed at 0.05. Predictors with p-values below 0.05 were considered statistically significant for this study. Stata SE 15.1 was used for all statistical analyses. Sensitivity analysis indicated that multilevel modeling was not adequate. The proportion of variability explained at the second level indicated a poor fit of the model [Intraclass Correlation Coefficient (ICC) for the conditional and full model was 0.17] [19].

A forward selection stepwise regression approach was utilized. This approach involves sequential addition of variables based on pre-defined criteria (i.e., the set of hypotheses for this manuscript) until a final model is built. For this analysis, stepwise regression was useful in two ways: (1) to explore the association of affordability, accessibility, and awareness (3As), while adjusting for the demographic variables; and (2) to examine the relative contribution of 3As when all the measures of 3As were included in the model, while adjusting for the demographic variables compared to a model with only demographics.

Table 2. Univariate analysis of outcome and predictor variables (N = 510).

Variables	Mean (Standard Deviation)	Percent of Response (Frequency)
Outcome variable		
LPG Adoption		
Yes		50% (255)
No		50% (255)
Independent variables	**Mean (Standard Deviation)**	**Percent of Response (Frequency)**
Demographic		
Age	40.34 (13.32)	
Marital Status		
Married		87.25% (445)
Unmarried		0.58% (3)
Widow		12.16% (62)
Literacy: Highest level of education completed		
None		65.88% (336)
Below or up to class 4		6.67% (34)
Class 5 to class 8		13.53% (69)
Class 9 to class 10		10.39% (53)
Class 11 to class 12		1.96% (10)
College		1.57% (8)
Caste		
General		14.51% (74)
OBC		48.63% (248)
SC/ST		35.88% (183)
Other Religious Minorities		0.98% (5)
Affordability		
Membership of SHG		
Yes		66.86% (341)
No		33.14% (169)
Monthly income of the household (INR)	2912.69 (2270.64)	
Accessibility		
Nearest paved road from the household (km)	0.67 (0.98)	
Availability of free biomass near the household		
Yes		12.75% (65)
No		87.25% (445)
Distance of biomass source (Km)	2.36 (1.37)	
Preference for smaller LPG cylinders		
Yes		1.37% (7)
No		92.16% (470)
Can't say		6.47% (33)
Decision making capacity to purchase new stove		
Respondent		28.82% (147)
Spouse of respondent		46.27% (236)
Respondent and spouse of the respondent		20.20% (103)
Respondent, spouse of the respondent, and others		0.98% (5)
Respondent and others but not the spouse		1.96% (10)
Others but not the respondent or the spouse of the respondent		1.76% (9)
Awareness		
Perception of LPG explosion (LPG safety)		
Yes		8.82% (45)
No		91.18% (465)
Campaigns Attended		
Yes		7.84% (40)
No		92.16% (470)

Note: Response rate of households was 100%. This means that all the households who were approached to participate in this study consented to be a part of the study.

Table 3. Binomial logistic regression analyses with outcome variable: LPG adoption (controlled by clustering of the data at the habitation level).

	Model 1	**Model 2**
	OR (95% CI)	**OR (95% CI)**
Demographic predictors		
Age (years)	0.98 (0.96–0.99) **	0.99 (0.97–1.01)
Marital status (Reference: unmarried)		
Married	1.96 (0.40–10.70)	10.97 (1.81–66.65) **
Widow	1.91 (0.28–12.78)	10.01(1.37–74.08) **
Literacy: Highest education of the respondent (Reference: No education)		
Below or up to class 4:	0.60 (0.25–1.42)	0.54 (0.17–1.67)
Class 5 to class 8:	0.84 (0.55–1.27)	0.79 (0.51–1.26)
Class 9 to class10:	1.43 (0.71–2.88)	1.08 (0.53–2.23)
Class 11 to class 12:	2.10 (0.79–5.57)	3.67 (0.34–40.09)
College:	1.01 (0.21–4.92)	0.74 (0.04–14.93)
Caste (Reference: General)		
OBC	0.64 (0.28–1.47)	0.60 (0.27–1.31)
SC/ST	0.11 (0.04–0.29) ***	0.08 (0.28–0.30) ***
Other religious minorities	0.34 (0.04–3.13)	0.16 (0.02–1.22) *
Affordability		
Membership with SHG (Reference: No)		
Yes		1.37 (0.76–2.47)
Square root of Income of the household		
INR		1.0003 (1.00008–1.0005) *
Accessibility		
Nearest paved from the household (square root)		
km		0.76 (0.52–1.11)
Preference for Smaller LPG cylinders (Reference: Yes)		
No		2.00 (0.06–65.94)
Can't say		0.49 (0.02–15.08)
Availability of free biomass near the household (Reference: No)		
Yes		0.01 (0.001–0.13) ***
Distance of the biomass source (square root)		
km		1.16 (0.89–1.54)
Decision making capacity to purchase new stove (Reference: Respondent)		
Spouse of respondent		0.59 (0.39–0.92) *
Respondent and spouse of the respondent		0.79 (0.43–1.45)
Respondent, spouse of the respondent, and others		1.27 (0.08–20.52)
Respondent and others but not the spouse		1.68 (0.45–6.25)
Others but not the respondent or the spouse of the respondent		1.05 (0.25–4.38)
Awareness		
Perception of LPG explosion (LPG safety) (Reference: No)		
Yes		0.125(0.06–0.39) ***
Campaigns attended (Reference: No)		
Yes		11.68 (2.27–59.84) **
Goodness of fit		
AIC	630.31	404.35
BIC	681.12	500.51
Pseudo R^2	0.14	0.37

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; Ref: Non-adoption of LPG.

3. Results

3.1. Model Comparison

Table 3 provides the results for the logistic regression models. AIC and BIC values help in the selection of the most fitted model. Model 2 (3As) with lowest AIC (404.35) and BIC values (500.51) is the best and most fitted model, as supported by the reduction of error of the model. Model 2 tests the contribution of the affordability, accessibility, and awareness to the variation in LPG adoption, after adjusting for the demographic predictors and clustering at the habitation level. The discussion and implications of the study are drawn from model 2.

3.2. Demographic Predictors and LPG Adoption

Caste is significant in model 2 (3As). General caste mainly comprises three classes in the Hindu Varna system: Brahmins, Kshatriyas, and Vaishyas, considered the least disadvantaged groups. Scheduled tribes (STs) are traditionally marginalized and are called scheduled tribes as they have been added under a "schedule" of the constitution of India. Scheduled Castes (SCs) are economically and socially backward communities. They have also been traditionally marginalized. Other backward castes or OBCs form a large group that is heterogeneous and is considered by the constitution of India as being "economically and socially backward". Adjusting for all other variables in the model, the predicted odds of SC/ST caste groups to adopt LPG is 92% lower than the General caste groups (OR = 0.08, 95% CI 0.28–0.30). The predicted odds of other religious minorities to adopt LPG is 84% lower than the General caste groups (OR = 0.16%, 95% CI 0.02–1.22). OBC groups have no significant association with LPG adoption. Marital status also has a significant association with LPG adoption. Married women respondents (OR = 10.97, 95% CI 1.81–66.65) and widowed women respondents (OR = 10.01, 95% CI 1.37–74.08) are more likely to adopt LPG than unmarried women respondents. Age and literacy status are not significantly associated with LPG adoption in model 2.

3.3. Affordability and LPG Adoption

Membership in SHGs (H1) has no significant association with adoption of LPG. Household Income (square root transformed) (H2), is significantly associated with LPG adoption; however, the magnitude of odds ratio is not substantial (OR = 1.0003 95% CI 1.00008–1.00054).

3.4. Accessibility and LPG Adoption

Respondents who perceive that biomass is easily available to them (H4) have a lower likelihood to adopt LPG by predicted odds of 0.99 compared to those households who perceive that biomass is not available easily (OR = 0.01, 95% CI 0.001–0.13). Model 2 also shows that if the decision of purchasing new stove rests with the spouse of the women respondents (H7), then the likelihood to adopt LPG reduces by 41% (OR: 0.59, 95% CI 0.39–0.92). However, distance to paved roads (H3), distance to biomass source (H5), and preference for smaller LPG cylinders (H6) are not associated with LPG adoption.

3.5. Awareness and LPG Adoption

Adjusting for affordability, accessibility, and demographic predictors, association of awareness on LPG adoption was assessed by two variables: (1) LPG safety: Perception that LPG cylinders explode and hence are unsafe; and (2) Awareness campaigns attended in-person. Adjusting for other predictors in the model, respondents who perceived LPG as unsafe (H8) have 88% lower odds of taking up LPG, compared to those respondents who did not perceive LPG as unsafe (OR = 0.125, 95% CI 0.06–0.39). Therefore, households that were concerned about LPG cylinder explosions had lower propensity to adopt LPG. Attending awareness campaigns (H9), on the other hand, is strongly associated with LPG adoption. Adjusting for other predictors in the model, respondents who attended at least one in-person

awareness campaign on clean cooking are 11.68 times more likely to adopt LPG than those respondents who did not attend any awareness campaign on clean cooking (OR = 11.68, 95% CI 2.27–59.84).

4. Discussion

The findings are consistent with previous studies on clean cooking adoption and present further nuance as the 3As are considered concurrently. As shown in Table 3, LPG adoption is associated with the 3As, affordability, accessibility, and awareness. Affordability: income of respondents and income of the households are positively associated with LPG adoption. Likelihood to adopt LPG decreases if the decision to purchase new stoves rests with the spouse (husbands) of the respondents. Accessibility: Easy availability of free biomass proximal to households is negatively associated with LPG adoption. Awareness: Concerns for LPG safety are negatively associated with LPG adoption. However, participation in awareness campaigns is positively associated with LPG adoption. Our findings extend the current understanding of the determinants of evidence based cleaner cooking systems by energy-poor communities.

4.1. Caste and LPG Adoption

Findings show that there are disparities in adoption of LPG between SC/ST households and the General caste households. This is consistent with findings from earlier clean cooking adoption studies [13,20–22]. The study sample households were new beneficiaries of national or state level LPG welfare schemes (Prime Minister's Ujjwala scheme or Andhra Pradesh state government's Deepam scheme). These government-led LPG programs base their implementation criteria on household income with no explicit motive to benefit a particular caste group. However, the findings suggest that LPG adoption status, in part, could be explained by the caste of the respective households even after adjusting for affordability, accessibility, and awareness-related factors. Social inequalities in rural poor communities exist sometimes despite a lack of inequality in economic status [23]. General caste households leverage their social status, take relatively higher risks, and show a higher propensity to adopt innovations such as cleaner cooking systems. Adoption of LPG could be seen as a "class differentiator" [20]. OBC households have a dominant presence among the communities in the study sites. OBC households in these mandals (blocks) have a relatively stronger representation in gram panchayats (local self-governments) than SC/ST households and other religious minorities. Representation of OBCs in local self-governments has reduced social inequality, at least between the OBCs and the General caste groups, in these communities. However, the inequality persists between the OBCs and the SC/ST and other religious minorities. This could explain the non-significant difference in LPG adoption status between General caste households and OBC caste households in these communities, but a significant difference of SC/ST and other religious minorities from General caste households in terms of LPG adoption.

4.2. Affordability and LPG Adoption

The findings from the association between income and LPG adoption are consistent with existing studies on clean cooking adoption [7,20,24–27]. The energy-poor households in these rural communities experience sporadic livelihood shocks, which impact their income and its regularity [22]. Livelihood risks constrain households from substituting traditional cooking with modern cooking practices especially when there is limited economic incentive. Adoption of relatively expensive cooking systems, such as LPG, requires households to have a relatively higher income. [24,28]. The findings show that higher gross income of households increases the propensity of the households to shift to LPG. The rate of change in the likelihood of LPG adoption with changes in household income, however, is low. This shows that: (1) income is a significant but inadequate predictor of LPG adoption; and (2) likelihood of adoption of LPG is significantly explained by other predictors unrelated to income. It is, thus, conceivable that while affordability-related measures determine LPG adoption,

the likelihood of LPG adoption is also significantly explained by other predictors pertaining accessibility and awareness.

4.3. Accessibility and LPG Adoption

Findings demonstrate that perception regarding easy availability of biomass for cooking impacts the adoption behavior of respondents. If the respondents feel that the biomass is easily available proximal to their households, this mental models deter such households from adopting cleaner cooking systems, such as LPG stoves. Forests are proximal to the study habitations. Hence, there is no variation in the adoption behavior due to the distance to the biomass source. While the distance to the biomass source that triggers adoption of LPG might not be relevant, it can still be clearly conceived that easy accessibility to biomass from proximal forests deters rural households from adopting LPG [29]. The local LPG distribution centers deliver the LPG cylinders to corresponding households. Thus, distance to proximal paved road from the households was not relevant for the households.

The model also shows that there is a lower likelihood of purchasing new stoves if the decision rests with the spouse (husband) of the respondents. The responsibility of collecting biomass in rural households falls primarily on women. Time used in collecting biomass could be utilized in alternative economic activities, which could lead to overall improved well-being of the household [28]. Even in cases where opportunities are available, rural households tend to undervalue the loss of opportunity cost of women's labor when there is easy and free access to biomass [30]. In addition, discontinuing biomass positively impacts women's health and safety. However, women in rural households tend to prioritize collection of biomass over their health or economic alternatives for a variety of reasons: (1) lack of adequate awareness of health implications of biomass use; (2) traditional practices dictating women to shoulder the drudgery of collecting biomass; (3) to save money on cleaner fuels; and (4) lack of economic opportunities for women in these communities.

4.4. Awareness and LPG Adoption

Anecdotal evidence shows that in rural India, irrespective of affordable and accessible LPG, adoption is low due to inadequate awareness of cleaner cooking [11,16,31]. Some surmise that gas leaks, while extremely infrequent, could be fatal due to an LPG cylinder explosion [13]. Suspicion around safety issues of LPG could contribute to limited adoption among poor households [20,32]. The non-adopters are concerned about LPG safety and consequences of an LPG explosion. Findings show that this is indeed a contributing factor in dissuading them from adopting LPG. Awareness generation is a gradual process but requires targeted efforts. Rural households have an inadequate understanding of LPG safety protocols that could allay their concerns about its safety. Even though media exposure is pervasive among rural communities, the findings show that respondents who attended in-person awareness campaigns are more likely to adopt LPG than the respondents that did not attend such campaigns. In addition to media as an effective means of communication, in-person awareness campaigns are crucial [10,13,21,33]. Such campaigns provide personalized demonstrations of effective LPG handling. They are central in expediting LPG adoption. Targeted campaigns on awareness help communities gain confidence in LPG, address contextual social barriers, and inform communities on detrimental effects of HAP [34–37].

4.5. Marginal Effects on LPG Adoption

Our findings demonstrate that the effect of income on LPG adoption is shaped by awareness. This is clearly illustrated in Figure 1.

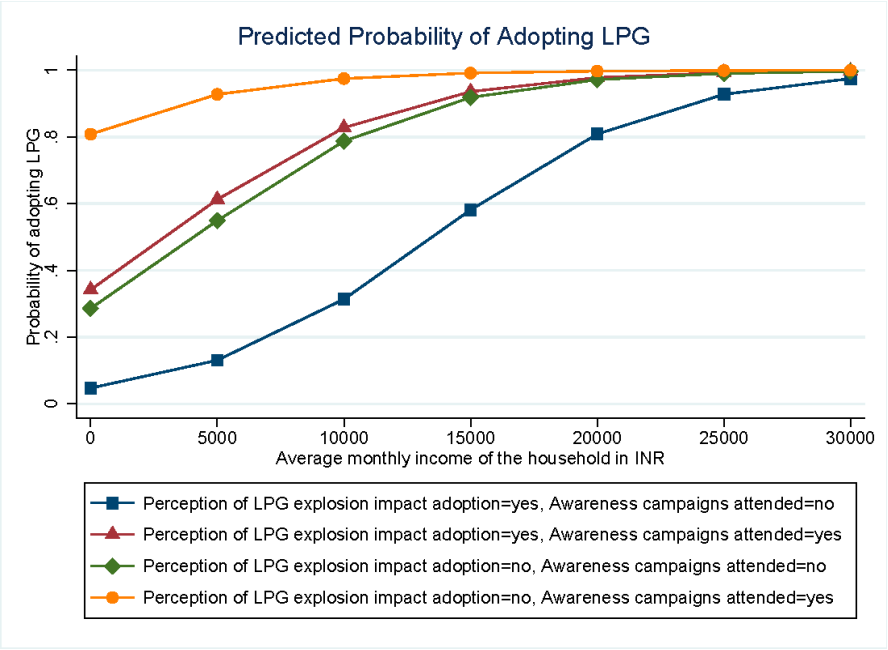

Figure 1. Association of income of households with LPG adoption shaped by awareness.

Figure 1 shows the average (untransformed) monthly income of the household on the *X*-axis and the predicted probability of LPG adoption on the *Y*-axis. There is an overall increased probability of LPG adoption with increase in household income, but there are some differences owing to different levels of awareness. Probability of LPG adoption increases with increase in affordability but is shaped by their level of awareness on LPG. Those respondents who feel that LPG is unsafe and have also not attended any in-person awareness campaigns are least likely to adopt LPG at all income levels for both the income variables.

5. Limitations of the Manuscript

There are a few limitations to our study. Each limitation is considered below:

1. Analyses for this study were based on a retrospective design. The retrospective nature of the study for LPG adopters might have led to decreased response validity due to issues of memory retention. Recall bias may further limit the accuracy of participants' responses.
2. The findings are from a case-control study and based on cross-sectional data. Thus, this one single study has limited implications on generalizability. Typical of a case-control study, findings also do not establish a causal relationship between independent and dependent variables. However, this study could be foundational for undertaking a larger longitudinal study on LPG adoption in energy-poor communities.
3. Both adoption and sustained use of LPG could be a function of affordability, accessibility, and awareness of BPL rural communities, and are necessary to address challenges of HAP. The present study focused on the adoption component and analyzed only one of the aims of the larger study. Results for sustained use and its determinants will be published separately.
4. Implementation studies on adoption and sustained use of evidence based interventions merit analyses at multiple levels [38,39]. Both individual and community level determinants could be associated with LPG adoption. This study accounted for individual level factors and explored 35 habitations. Statistical power was low for a multilevel examination.

6. Conclusions

HAP is a crucial environmental health problem and includes socio-economic and gender dimensions especially in low- and middle-income countries [12]. This study distills insights into the reach of LPG among the rural poor communities in India focusing on affordability, accessibility, and awareness as determinants of LPG adoption to present implications for ensuring energy equity and justice. While the study focuses on rural India, the findings also have purchase for energy-poor communities in other countries of the Global South [27,32,40]. This study presents potential intervention points for practitioners working on energy policy and delivery to address the needs of communities affected by energy poverty, particularly in LMICs [1]. Further, our findings suggest that such measures need to be adopted in tandem with interventions that ameliorate long standing socioeconomic inequalities, as embodied by the UN Sustainable Development Goals framework [4]. Particularly SDG 7, "Ensure access to affordable, reliable, sustainable and modern energy for all" posits that a transition to clean fuels is critical to tackle energy poverty, with immediate gains in health benefits for women and children [4,41,42]. Increasing the adoption of clean fuels among the poorest households can therefore have far-reaching positive returns. Robust policy mechanisms that incentivize the otherwise price prohibitive switch to LPG, coupled with increased awareness around the need for cleaner cooking, are pivotal to LPG adoption among the energy-poor in the Global South and to advance energy justice, an integral component of equitable, sustainable development, and provision of opportunity to all communities.

Author Contributions: Formal analysis, P.K., R.E.D., A.D.-V.I. and S.R.; Funding acquisition, A.D., R.G.T., R.C.B. and G.N.Y.; Methodology, P.K.; Writing—original draft, P.K., S.R., S.H. and G.N.Y.; Writing—review & editing, P.K., S.R., R.G., S.H., A.D., R.G.T., R.C.B. and G.N.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This study is funded by the Clean Cooking Implementation Science Network (ISN) led by the Fogarty International Center (FIC) with support from the National Institutes of Health (NIH) Common Fund. This study was also supported by the National Institute of Diabetes and Digestive and Kidney Diseases of the National Institutes of Health (award numbers P30DK092950 and P30DK020579), the National Cancer Institute of the National Institutes of Health (award number 1P50CA244431), and the Centers for Disease Control and Prevention (Cooperative Agreement number U48DP006395-01). The content is solely the responsibility of the authors, and does not necessarily represent the official view of the funders.

Acknowledgments: We are grateful to the communities that participated in this study, and to the Foundation for Ecological Security (FES) for enabling community access and helping to facilitate collection of data. In particular, we thank Kaushal, Raksha, Hemalatha, Noorjan, Shaheensha, Geetha, and Rahul.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Scarpellini, S.; Sanz Hernández, M.A.; Llera-Sastresa, E.; Aranda, J.A.; López Rodríguez, M.E. The mediating role of social workers in the implementation of regional policies targeting energy poverty. *Energy Policy* **2017**, *106*, 367–375. [CrossRef]
2. Jenkins, K.; McCauley, D.; Heffron, R.; Stephan, H.; Rehner, R. Energy justice: A conceptual review. *Energy Res. Soc. Sci.* **2016**, *11*, 174–182. [CrossRef]
3. Rao, N.D.; Pachauri, S. Energy access and living standards: Some observations on recent trends. *Environ. Res. Lett.* **2017**, *12*. [CrossRef]
4. Bruce, N.G.; Aunan, K.; Rehfuess, E.A. *Liquefied Petroleum Gas as a Clean Cooking Fuel for Developing Countries: Implications for Climate, Forests, and Affordability*; KfW Entwicklungsbank: Frankfurt, Germany, 2017.
5. GACC. How do We Define and Measure Adoption? Available online: http://cleancookstoves.org/about/news/02-18-2016-how-do-we-define-and-measure-adoption.html (accessed on 8 December 2019).
6. GACC. Defining and Measuring 'Adoption' of Clean Cookstoves and Fuels. Available online: http://cleancookstoves.org/about/news/05-22-2015-defining-and-measuring-adoption-of-clean-cookstoves-and-fuels.html (accessed on 8 December 2019).

7. Kumar, P.; Mehta, S. Poverty, gender, and empowerment in sustained adoption of cleaner cooking systems: Making the case for refined measurement. *Energy Res. Soc. Sci.* **2016**, *19*, 48–52. [CrossRef]
8. Kumar, P.; Chalise, N.; Yadama, G.N. Dynamics of sustained use and abandonment of clean cooking systems: Study protocol for community-based system dynamics modeling. *Int. J. Equity Health* **2016**, *15*, 70. [CrossRef]
9. Rosenthal, J.; Balakrishnan, K.; Bruce, N.; Chambers, D.; Graham, J.; Jack, D.; Kline, L.; Masera, O.; Mehta, S.; Mercado, I.R.; et al. Implementation Science to Accelerate Clean Cooking for Public Health. *Environ. Health Perspect.* **2017**, *125*, A3–A7. [CrossRef]
10. Nishesh, C.; Praveen, K.; Pratiti, P.; Gautam, N.Y. Dynamics of sustained use and abandonment of clean cooking systems: Lessons from rural India. *Environ. Res. Lett.* **2018**, *13*, 035010.
11. Kumar, P.; Igdalsky, L. Sustained uptake of clean cooking practices in poor communities: Role of social networks. *Energy Res. Soc. Sci.* **2019**, *48*, 189–193. [CrossRef]
12. Kumar, P.; Kaushalendra Rao, R.; Reddy, N.H. Sustained uptake of LPG as cleaner cooking fuel in rural India: Role of affordability, accessibility, and awareness. *World Dev. Perspect.* **2016**, *4*, 33–37. [CrossRef]
13. Jain, A.; Agrawal, S.; Ganesan, K. *Rationalising Subsidies, Reaching the Underserved*; Council on Energy, Environment and Water: New Delhi, India, 2014.
14. Sehjpal, R.; Ramji, A.; Soni, A.; Kumar, A. Going beyond incomes: Dimensions of cooking energy transitions in rural India. *Energy* **2014**, *68*, 470–477. [CrossRef]
15. Hoop, T.D.; Brody, C.; Tripathi, S.; Vojtkova, M.; Warnock, R. *Economic Self-Help Group Programmes for Improving Women's Empowerment, 3ie Systematic Review Summary 11*; International Initiative for Impact Evaluation (3ie): London, UK, 2019.
16. Lewis, J.J.; Pattanayak, S.K. Who adopts improved fuels and cookstoves? A systematic review. *Environ. Health Perspect.* **2012**, *120*, 637–645. [CrossRef]
17. Hollada, J.; Williams, K.N.; Miele, C.H.; Danz, D.; Harvey, S.A.; Checkley, W. Perceptions of Improved Biomass and Liquefied Petroleum Gas Stoves in Puno, Peru: Implications for Promoting Sustained and Exclusive Adoption of Clean Cooking Technologies. *Int. J. Environ. Res. Public. Health* **2017**, *14*, 182. [CrossRef] [PubMed]
18. Kumar, P.; Dhand, A.; Tabak, R.G.; Brownson, R.C.; Yadama, G.N. Adoption and sustained use of cleaner cooking fuels in rural India: A case control study protocol to understand household, network, and organizational drivers. *Arch. Public Health* **2017**, *75*, 70. [CrossRef] [PubMed]
19. Koo, T.K.; Li, M.Y. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.* **2016**, *15*, 155–163. [CrossRef]
20. Srinivasan, S.; Carattini, S. Adding fuel to fire? Social spillovers in the adoption of LPG in India. *Ecol. Econ.* **2020**, *167*, 106398. [CrossRef]
21. Lewis, J.J.; Bhojvaid, V.; Brooks, N.; Das, I.; Jeuland, M.A.; Patange, O.; Pattanayak, S.K. Piloting Improved Cookstoves in India. *J. Health Commun.* **2015**, *20*, 28–42. [CrossRef]
22. Yadama, G.N. *Fires, Fuel, and the Fate of 3 Billion: The State of the Energy Impoverished*; Oxford University Press: Oxford, UK, 2013.
23. Ali, I. Inequality and the imperative for inclusive growth in Asia. *Asian Dev. Rev.* **2007**, *24*, 1.
24. El Tayeb Muneer, S.; Mukhtar Mohamed, E.W. Adoption of biomass improved cookstoves in a patriarchal society: An example from Sudan. *Sci. Total Environ.* **2003**, *307*, 259–266. [CrossRef]
25. Pine, K.; Edwards, R.; Masera, O.; Schilmann, A.; Marrón-Mares, A.; Riojas-Rodríguez, H. Adoption and use of improved biomass stoves in Rural Mexico. *Energy Sustain. Dev.* **2011**, *15*, 176–183. [CrossRef]
26. Geremew, K.; Gedefaw, M.; Dagnew, Z.; Jara, D. Current Level and Correlates of Traditional Cooking Energy Sources Utilization in Urban Settings in the Context of Climate Change and Health, Northwest Ethiopia: A Case of Debre Markos Town. *Biomed Res. Int.* **2014**, *2014*, 572473. [CrossRef]
27. Gould, C.F.; Urpelainen, J. LPG as a clean cooking fuel: Adoption, use, and impact in rural India. *Energy Policy* **2018**, *122*, 395–408. [CrossRef]
28. Cecelski, E. *The Role of Women in Sustainable Energy Development*; NREL/SR-550-26889; National Renewable Energy Laboratory: Golden, CO, USA, 2000.
29. Sharma, A.; Parikh, J.; Singh, C. Transition to LPG for cooking: A case study from two states of India. *Energy Sustain. Dev.* **2019**, *51*, 63–72. [CrossRef]
30. Pachauri, S.; Rao, N.D. Gender impacts and determinants of energy poverty: Are we asking the right questions? *Curr. Opin. Environ. Sustain.* **2013**, *5*, 205–215. [CrossRef]

31. Kar, A.; Pachauri, S.; Bailis, R.; Zerriffi, H. Using sales data to assess cooking gas adoption and the impact of India's Ujjwala programme in rural Karnataka. *Nat. Energy* **2019**. [CrossRef]
32. Wang, Y. Negotiating Access: The Social Process of Liquefied Petroleum Gas (LPG) Cookstove Dissemination Intervention in Himachal Pradesh, India. *Trop. Resour. Bull.* **2014**, *32–33*, 37–42.
33. Alam, A.; Tawale, N.; Raynes-Greenow, C. Household air pollution intervention implications: Findings from qualitative studies and a field trial of clean cookstoves in two rural villages in India. *Int. J. Environ. Res. Public Health* **2016**, *13*, 893. [CrossRef]
34. Malakar, Y. Studying household decision-making context and cooking fuel transition in rural India. *Energy Sustain. Dev.* **2018**, *43*, 68–74. [CrossRef]
35. Schunder, T.; Bagchi-Sen, S. Understanding the household cooking fuel transition. *Geogr. Compass* **2019**, e12469. [CrossRef]
36. Puzzolo, E.; Pope, D.; Stanistreet, D.; Rehfuess, E.A.; Bruce, N.G. Clean fuels for resource-poor settings: A systematic review of barriers and enablers to adoption and sustained use. *Environ. Res.* **2016**, *146*, 218–234. [CrossRef]
37. Quinn, A.K.; Bruce, N.; Puzzolo, E.; Dickinson, K.; Sturke, R.; Jack, D.W.; Mehta, S.; Shankar, A.; Sherr, K.; Rosenthal, J.P. An analysis of efforts to scale up clean household energy for cooking around the world. *Energy Sustain. Dev.* **2018**, *46*, 1–10. [CrossRef]
38. GOI. Pradhan Mantri Ujjwala Yojana. 2019. Available online: https://pmuy.gov.in/ (accessed on 10 November 2019).
39. Acemoglu, D.; Ozdaglar, A.; Yildiz, E. Diffusion of innovations in social networks. In Proceedings of the 2011 50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC 2011), Orlando, FL, USA, 12–15 December 2011; pp. 2329–2334.
40. Glasgow, R.E.; Vogt, T.M.; Boles, S.M. Evaluating the public health impact of health promotion interventions: The RE-AIM framework. *Am. J. Public Health* **1999**, *89*. [CrossRef] [PubMed]
41. World LPG Association. *LPG and the Global Energy Transition: A study on behalf of the World LPG Association*; World LPG Association: Paris, France, 2015.
42. Kumar, P.; Rao, S.; Yamada, G.N. *Energy Poverty in India*; NASW Press: Washington, DC, USA; Oxford University Press: Oxford, UK, 2019. [CrossRef]