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The Role of Education and Attitudes in Cooking Fuel Choice: Evidence from two states in India

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Abstract

Widespread adoption of clean cooking fuels is a necessary step toward reducing household air pollution and improving population health. Here we use large-scale surveys (10,000 households) from two Indian states, Kerala and Rajasthan, to examine how education and attitudes toward cooking associate with the adoption of liquefied petroleum gas (LPG), India's most popular clean cooking fuel. We report three main results. First, education is a strong predictor of LPG adoption. Second, perceptions that LPG is good and affordable and progressive health-related perceptions are associated with LPG ownership. Third, and surprisingly, education does not predict positive attitudes toward clean cooking fuels. These results suggest that education leads to LPG adoption, but not through attitudinal changes. Further research should examine the mediators of the observed robust education-adoption association.

Keywords

India; energy poverty; clean cooking; technology adoption; behavior change

1 Introduction

Exposure to household air pollution (HAP) from the combustion of solid fuels for daily cooking and heating remains one of the greatest environmental health risks in the world, affecting nearly 3 billion people and leading to millions of premature deaths each year (GBD 2017 Risk Factor Collaborators, 2018; Bonjour et al., 2013). Importantly, HAP exposure is a modifiable risk factor amenable to cleaner cooking. Clean cooking fuels like gas and electricity are a promising alternative capable of reducing HAP exposure in homes currently relying on solid fuel combustion to meet their daily energy needs. India - where air pollution ranks as the leading risk factor for early death and injury (GBD MAPS Working Group, 2018) - has led an ambitious effort towards a large-scale transition from solid fuel combustion to clean cooking fuels. In this study, we illuminate important factors associated with the very first step in the process towards the reduction of HAP exposure: clean cooking fuel adoption.

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While there has been tremendous global effort to improve health outcomes by promoting clean cooking transitions, a large proportion of the world's low-income households still cook with solid fuels. The adoption of clean cooking technologies and/or fuels is a crucial step toward clean household air. However, solid fuels are a persistent low-cost and easily-available alternative cooking fuel for many and the adoption and use of clean cooking technologies, particularly clean fuels, remains low. There has been substantial research on the factors associated with cleaner biomass-burning cookstove adoption and use (Lewis and Pattanayak, 2012; Rehfuess et al., 2014; Muller and Yan, 2018). However, the need to make regular fuel purchases after adoption makes sustained liquefied petroleum gas (LPG) - the most promising clean fuel globally - adoption and use a potentially unique process. In countries with a large number of poor communities, especially poor and rural communities, empirical evidence describing the adoption of clean energy remains limited (Quinn et al., 2018).

Prior work synthesizing the evidence about the adoption of cleaner cooking technologies (e.g., (Lewis and Pattanayak, 2012; Puzzolo et al., 2016; Quinn et al., 2018)), points to four patterns. First, the cost of clean fuels (i.e., the cost of the stove and then the regular cost of the fuel) is a critical factor affecting initial stove adoption, sustained fuel use, and the continued side-by-side use of traditional stoves (Farsi, Filippini, and Pachauri, 2007; Jingchao and Kotani, 2012). Second, access to clean cooking fuels affects both adoption and use, especially for poor and rural households for whom clean fuel access may be infrequent and challenging (Quinn et al., 2018; Pattanayak et al., 2019; Pillarisetti et al., 2019). Third, characteristics of each cooking technology play an important role in deciding adoption and use (Budya and Arofat, 2011). Cleaner cooking technologies have positive aspects, like quick cooking, low emissions, and cleanliness (Gould and Urpelainen, 2018). At the same time, solid fuel stoves also have positive characteristics that contribute to their continued use, like the ability to cook large dishes, traditional dishes, and multiple dishes (Ruiz-Mercado and Masera, 2015). In many cases, non-cooking end uses like space heating and water heating are also carried out using solid fuels (Martínez-Negrete et al., 2013). Finally, there are numerous household socio-demographic factors that have shown association with clean cooking intervention uptake and use. Among these, wealth (Gupta and Köhlin, 2006; Baiyegunhi and Hassan, 2014), education (Gupta and Köhlin, 2006; Farsi, Filippini, and Pachauri, 2007; Baiyegunhi and Hassan, 2014), and gender (Pachauri and Rao, 2013; Rahut, Behera, and Ali, 2016) have been consistent across numerous geographic and cultural contexts. Attitudes, norms, and habits may all mediate the relationship between household characteristics and clean cooking adoption (Kar and Zerriffi, 2018). However, the precise process through which each of these factors influence the adoption and use of clean cooking facilities remains unclear.

In this study we explore the role of formal education and perceptions related to cooking, tradition, and health in explaining LPG ownership in two Indian states. The importance of formal education in improving livelihoods and contributing to economic and social progress has long been known (Schultz, 1988; Lantz et al., 1998). Increased education has been robustly linked to numerous individual and household well-being indicators and practices around the world (Glanz and Bishop, 2010; Elo, 2009), like life expectancy (Cutler, Deaton, and Lleras-Muney, 2006), and increased child survival (Kristyna Solawetz Hulland et al.,

2015). Yet, the mechanism through which education impacts this wide range of outcomes remains an important research question. One possible mechanism for increased education to improve health is through augmenting one's ability to acquire health-improving technologies, such as Water, Sanitation, and Hygiene (WASH) interventions (World Health Organization, 2014) and clean cooking interventions (Lewis and Pattanayak, 2012). The precise pathway through which increased education leads to the adoption of health-improved technologies is an area of active research, whether it is through increased wealth, having more health-related information, improved critical decision-making, or changes to attitudes related to health and the technology (Elo, 2009).

To explore the potential pathway between education and LPG adoption through attitudinal variables, we use comprehensive survey data on 10,000 households - both urban and rural - from two Indian states with distinct profiles: Kerala and Rajasthan. By controlling for known covariates of household energy choice, we assess the association of both chief wage earner (CWE) and female educational attainment with LPG adoption. We report three main results. First, education is strongly associated with LPG ownership. Across several socio-economic strata, CWE and female educational achievement are strongly positively associated with LPG ownership independent of other household characteristics. Second, perceptions that LPG is good and affordable and progressive health-related perceptions are associated with LPG ownership. In particular, perceived costs of LPG cooking and the benefits of traditional woodfuels were strongly associated with LPG ownership in both samples. Next, and more surprisingly, education is largely not associated with positive attitudes toward LPG ownership or progressive health attitudes. Finally, investigation of the mediation of the association between educational achievement and LPG ownership by perceptions reveals that while education is robustly associated with LPG adoption, it is unlikely that the pathway involves attitudinal shifts. We show evidence that some perceptions shift *after* LPG adoption, be it as a result of learning or as a post-hoc rationalization. Nonetheless, there are several other perceptions that appear to be independent of the length of time of LPG ownership, suggesting their shifts may precede adoption. These attitudes, in particular related to health and cooking, may therefore be facilitators in the LPG adoption process.

The positive association between both CWE and female educational achievement and LPG adoption was robust even when comparing the association across households of different wealth and across urban and rural samples. Given the gendered nature of cooking and decision-making, our paired analysis of CWE (91–97% male) and female educational achievement is unique and shows the potential for improved well-being through increases in female educational level, independent of covariates like expenditures, caste, and household size. Though our results suggest that education may not be acting through attitudinal shifts, there are nonetheless other avenues through which increased educational achievement may increase likelihood of LPG adoption, such as increased financial literacy or increased opportunity cost from solid fuel collection.

This study responds to gaps in the clean energy literature by leveraging a large-scale energy access survey administered in two distinct geographic settings to discuss the role of education on clean cooking fuel adoption. LPG is a popular clean cooking fuel with the potential to scale-up use around the world. The precise determinants of clean cooking fuel

adoption merits more study given its promise to decrease household air pollution and yield large population health improvements. Here we assess one potential pathway with the aim of elucidating the adoption process outside an intervention context to develop informed and targeted policies.

2 Background and Literature

Clean cooking has received large research and policy support around the world. While improved biomass-burning stoves may play some role as an interim technology, recent evidence suggests that clean cooking fuels are needed to achieve clean household air and low personal exposures to minimize health risk (Pope et al., 2017; Sambandam et al., 2015). The recent focus on the importance of clean cooking fuels—as opposed to cleaner biomass-burning stoves—means investigation of the determinants of clean cooking fuel adoption and use is in demand but remains somewhat limited. Here, we add to this body of empirical evidence by investigating the drivers of LPG adoption in two Indian states.

2.1 Clean Cooking Adoption

The body of research studying the determinants of household energy choices has already been summarized elsewhere (e.g., (Lewis and Pattanayak, 2012; van der Kroon, Brouwer, and van Beukering, 2013; Rehfuess et al., 2014; Stanistreet et al., 2014; Malla and Timilsina, 2014; Ruiz-Mercado and Masera, 2015; Puzzolo et al., 2016)). Qualitative and quantitative evidence of factors relating to the adoption of clean cooking technologies point towards the importance of several domains: (i) Fuel technology and characteristics; (ii) Household characteristics; (iii) Knowledge, perceptions, and attitudes; and (iv) External socio-cultural and economic environment. Each of these domains is an important determinant of households' decision-making processes; further, the domains are interrelated and can jointly as well as independently affect the clean cooking technology adoption process.

Fuel and technology characteristics.—New fuels and technologies must provide benefits over traditional cooking and meet the needs of households to be adopted and used consistently. While clean cooking fuels are popular, they are expensive and often have problems of accessibility, especially in comparison to biomass which is regularly monetary-cost-free and readily available (Kumar, Rao, and Reddy, 2016). In addition, in some cases, clean fuel cookstoves cannot match the end uses that traditional stoves meet. For example, traditional cookstoves may be beneficial because they can provide space heating and they often support the cooking of large or multiple dishes (Dickinson et al., 2019). While the limitations of clean cooking fuels may not prohibit adoption, they often lead to fuel stacking as traditional stoves and fuels are retained to ensure a household can meet all of its energy end uses (Ruiz-Mercado and Masera, 2015).

Household characteristics.—This domain captures the socio-economic, demographic, and structural characteristics of households. Higher socio-economic status, as related to income, assets, or expenditures, is commonly positively associated with clean cookstove adoption (Heltberg, 2004; Gupta and Köhlin, 2006; Rao and Reddy, 2007). Similarly,

increased education, in terms of years of schooling or educational attainment, of the head of the household is associated with increased adoption (Farsi, Filippini, and Pachauri, 2007; Gupta and Köhlin, 2006; Baiyegunhi and Hassan, 2014). Educational achievement of females or the primary cook has received less study, though has shown positive associations with clean cooking technology adoption as well (Pandey and Chaubal, 2011; Miller and Mobarak, 2013).

Knowledge, perceptions, and attitudes.—Primary cooks' and household decision-makers' knowledge, perceptions, and attitudes regarding cooking, health, and new cooking technologies have an important role in the decision to adopt. Perceptions and attitudes extend past the new cooking technology and include individuals' notions of the impacts of cooking on their health and safety, home cleanliness, social influence, local environment, and traditions and culture (Kar and Zerriffi, 2018; Kowsari and Zerriffi, 2011). Important considerations may include the adverse health effects of exposure to biomass smoke, cleaner cookware and utensils after adoption of clean fuels, perceived difficulty of solid fuel collection, aspirations of owning LPG and social status benefits, and attitudes about the importance of traditional cooking practices (Hollada et al., 2017; Bhojvaid et al., 2014; Troncoso et al., 2007).

External economic, market, and geographic environment.—This is a broad domain that captures factors external to the cooking technology and household environments. Ease of access and frequency of access to both clean and solid fuels is an important consideration in a household's determination of how often to use a fuel (Ramirez et al., 2012). Here, important considerations include programs to promote clean cooking and their impact on stove and fuel costs and availability (Rehfuess et al., 2014; Kumar, Rao, and Reddy, 2016). Programs may provide stoves for free, subsidize fuels, and create more effective supply chains to facilitate access and promote cleaner cooking. There have been numerous initiatives by the Government of India to improve LPG availability and reduce costs over the past decade (Smith and Jain, 2019). For example, *Pradhan Mantri Ujjwala Yojana* (PMUY), the largest of India's LPG programs, has provided LPG connections for more than 70 million Indian households in the past three years on its way to meeting its stated goal of 80 million new LPG connections by 2020. PMUY tackles initial affordability by providing financial assistance of 1,600 rupees. PMUY has also sought to improve accessibility by increasing the number of LPG distributors, in particular in rural areas (Smith and Jain, 2019).

2.2 Education, Attitudes, Technology Adoption, and Health-Improving Behavior

Education is robustly associated with increased adoption of health-promoting environmental interventions in low- and middle-income countries, including cleaner cookstoves (Nutbeam, 2000; Grantham-McGregor et al., 2007; Hahn and Truman, 2015; Lewis and Pattanayak, 2012). Research has pointed towards multiple avenues through which increased education has improved health and economic development around the world, with no clear answer emerging (Ross and Wu, 1995; Paasche-Orlow and Wolf, 2007; Cutler and Lleras-Muney, 2006). Education is an important measure of socio-economic status and increased individual and household wealth (Desai and Alva, 1998; Filmer and Pritchett, 2001). However,

education may differ from income and work beyond financial gains (Cutler and Lleras-Muney, 2006). Indeed, increased education can lead to increased opportunity for employment and earnings and result in freedom from poverty and economic hardship that can have negative implications for health (Ross and Wu, 1995). Education also teaches people to learn and use analytic skills to solve complex problems and accumulate skills and resources (sometimes termed “human capital enhancement”) (Mirowsky and Ross, 2003; Meierhofer and Landolt, 2009; Elo, 2009). Education is intertwined with “health literacy,” which is the ability of individuals to obtain and understand health information to make health-related decisions (Nutbeam, 2000). Therefore, education may increase an individual’s ability to take part in health-improving behaviors (Brunello et al., 2015). There is some evidence that health literacy acts in some part through health-related perceptions, which themselves can mediate health-related behavior (Fernandez, Larson, and Zikmund-Fisher, 2016).

Increased education has been linked to the adoption of health-promoting innovations like WASH interventions or clean cookstoves (Garn et al., 2017). However, there is little consensus about the pathway through which increased education leads to adoption. For several decades, WASH interventions have emphasized health literacy alongside technical interventions improving sanitation with the theory that greater education of the health benefits of an intervention and of its use may lead to increased adoption, though evidence of this association remains limited (Kolsky, 1993; Fewtrell et al., 2005; Garn et al., 2017; Thurber et al., 2013; Rehfuess et al., 2014).

While education has been widely positively associated with clean cookstove adoption, the pathway through which increases in education leads to clean cookstove adoption has been less explored (Muller and Yan, 2018). In some cases, studies have suggested that higher education leads there to be greater opportunity costs associated with time-intensive activities associated with traditional cooking practices, like fuel collection and processing (van der Kroon, Brouwer, and van Beukering, 2013; Puzzolo et al., 2016). Education may further lead to increased awareness of the negative consequences of cooking with solid fuels (van der Kroon, Brouwer, and van Beukering, 2013; Bhojvaid et al., 2014). Recently, Kar and Zerriffi (2018) have suggested that objective conditions (like level of formal education) influence behavioral constructs (like perceptions and attitudes) and may predict clean cooking adoption. In this framework, the effect of education (or other objective measures like income) on increased likelihood of clean cooking adoption is mediated by attitudes (Kar and Zerriffi, 2018). These perceptions and attitudes may include notions of the safety of cookstoves, health risks associated with cooking fuels, the “value” of cookstoves, or the ability to acquire a new technology (Troncoso et al., 2007; Bhojvaid et al., 2014; Khandelwal et al., 2017; Bruce et al., 2018; Kar and Zerriffi, 2018).

Yet, attitudes related to cooking technologies remain poorly explained and rarely assessed using objective measures (Puzzolo et al., 2016; Khandelwal et al., 2017; Jagadish and Dwivedi, 2018). The human dimension of cooking - primarily attitudes and perceptions - has been emphasized as a potential catalyst of energy transitions (Kowsari and Zerriffi, 2011; van der Kroon, Brouwer, and van Beukering, 2013; Thurber et al., 2013; Ruiz-Mercado and Masera, 2015). However, there has not yet been formal discussion of mechanisms or

pathways of influence for perceptions. Policy makers, program designers, and researchers, then, are expected to recognize the importance of attitudes and perceptions but left little explanation for how these dimensions are formed and changed to affect clean cooking adoption. In this study, we investigate one potential pathway for increased education to impact adoption through the change of health and cooking attitudes.

2.3 LPG in India

More than 90% of India's residents are estimated to live in areas exceeding the World Health Organization Interim Target-1 for fine particulate matter ($PM_{2.5}$) exposure (35 $\mu g/m^3$) (Balakrishnan et al., 2019). In 2015, residential solid fuel combustion for cooking and heating was responsible for an estimated 267,700 deaths in India, accounting for one-quarter of all air pollution related deaths in that year (GBD MAPS Working Group, 2018). Recently, the Government of India and several major oil marketing companies have begun substantial programs to promote LPG to the poor. The growth rate of household LPG connections has doubled in the last two years, with uptake in poor households accounting for the majority of the increased growth. Now, approximately 90% of the Indian households have an LPG connection, shifting the health policy focus in India from clean cookstove adoption to promoting exclusive use of LPG or other clean fuels (The Times of India, 2019). India's clean cooking programs have resulted in the largest national transition to date and may indeed yield substantial population health benefits.

In this study, we use data from Kerala and Rajasthan to assess the determinants of LPG adoption. Descriptive statistics from the Indian national Census and the Indian Central Statistical Organization for the two states are available in Table A1. Kerala and Rajasthan have divergent profiles in several respects.

Briefly, Kerala is a relatively small coastal state in southern India and one of India's most developed states, with the highest literacy rate, life expectancy, and Human Development Index. The southern region of India has the highest LPG coverage, and indeed Kerala has among the highest LPG adoption rates in the country. In the 2011 census, 36% of households reported using LPG or piped natural gas as their primary cooking fuel, but recently the National Family Health Survey (NFHS-4, 2015–2016) reported LPG use in 55% of households (Ministry of Health and Family Welfare and Government of India, 2015). Rajasthan is India's largest state by area, but in comparison to Kerala and the rest of India it is poorer, less educated, and more rural. Data from NFHS-4 showed that only 32% of households in Rajasthan cooked primarily with LPG (Ministry of Health and Family Welfare and Government of India, 2015).

The NFHS-4 reports that approximately 42% of Indian households were using LPG as their primary cooking fuel in 2015. In comparison, Kerala has a slightly higher percentage of households using LPG (56%) and Rajasthan a slightly lower percentage of households (32%) (International Institute for Population Sciences and ICF International, 2018*a*,b). Across India, a higher fraction of urban households have LPG than rural households. According to the NFHS-4 reportedly 64% of households cooked primarily with LPG in Kerala and in Rajasthan 80% (Ministry of Health and Family Welfare and Government of India, 2015). Nonetheless, these data do not report on secondary cooking fuel use so

exclusive use of a clean cooking fuel is unknown. Given the close relationship between household socio-economic factors and clean cooking, exploring the determinants of LPG adoption in these two states may be illustrative of the way education affects clean cooking fuel adoption in households across distinct settings. In doing so, we can assess whether a positive association between increased education and LPG adoption persists in a more education sample as well as a less educated, poorer sample of households, or whether the association changes in some way.

3 Research Design

Previous studies have suggested that educational achievement and household perceptions may both affect clean cooking fuel adoption. However, the joint relationship of these three variables remains untested and largely unexplained. Here we test a potential pathway for education to increase LPG adoption through household perceptions. This potential pathway is diagrammed in Supporting Information Figure A1, a directed acyclic graph where we describe our theories about the relationship between education, perceptions, and LPG adoption.

Our analytic approach took five steps. First, we tested the association between chief wage earner (CWE) education and LPG ownership using logistic regressions. Second, we tested the association between cooking-related perception indices and LPG ownership first through correlations and then using logistic regressions. Third, we tested the association between CWE education and perception indices using linear regressions. Fourth, we assessed mediation of the association between CWE education and LPG ownership by perception indices by including both CWE education variables and perception indices in logistic regressions with the outcome LPG ownership. Then, we compared the coefficients for CWE education in steps one and four to assess potential mediation. Reflective of the gendered nature of both cooking and household decision-making, we repeated these analyses replacing CWE education with the level of female educational achievement. Finally, we assessed the potential for reverse causation of shifts in perception to occur after LPG ownership by regressing perceptions on the number of years owning LPG. Here, we expect that if shifts in perceptions occur after owning LPG, then these shifts will be more pronounced the longer a household has owned LPG.

We assessed the consistency of observed associations by repeating analyses among subsets of households divided along key covariates: first, by above and below median household expenditure and second, by urban and rural households. Through this subgroup analysis, we are able to assess whether households that are more or less wealthy and those that are urban as compared to those that are rural demonstrate a different association between educational achievement and LPG adoption. In an additional analysis, we combined the Kerala and Rajasthan sub-samples and then assessed the association between CWE education and LPG ownership among overall urban and rural sub-samples.

All analyses included control variables (described in Section 3.5). Furthermore, analyses were conducted with and without district-level fixed effects (District FEs). We include District FEs to account for potential residual spatial confounding of the association between

education and LPG ownership. Such residual spatial confounding may result from different access to educational opportunities or to LPG. In addition, we carried out an alternative model specification where we used conditional logistic regressions.

We present odds ratios (ORs) in our analyses with binary dependent variables. ORs compare the relative odds of the dependent variable of interest (for example, owning LPG) given having the explanatory variable of interest occur (for example, the CWE having a primary school education) as compared to the odds of LPG adoption given the baseline explanatory variable (for example, no formal education).

All analyses were carried out in R (R Core Team, 2018). Conditional logistic regressions were carried out using the package *survival* (Therneau, 2015).

3.1 Data

Commissioned by the Clean Cooking Alliance (formerly the Global Alliance for Clean Cookstoves), Nielsen India Private Limited carried out surveys in urban and rural households in Kerala (May 2015 to October 2015) and Rajasthan (July 2015 to December 2015). The survey was intended to characterize the household and socio-economic factors that facilitate or inhibit the adoption of clean fuels and cookstoves. Therefore, importantly, all households in this study used solid fuels (e.g., woodfuel, agricultural residue, dung cakes) for cooking. Elsewhere, the exclusive use of clean cooking fuels in rural India households has been rare (e.g., (Gould and Urpelainen, 2018)), which suggests these inclusion criteria may not yield a substantially different sample of households than random sampling without criteria. The dearth of data regarding multiple cooking fuel use in urban Indian households means it is hard to assess how different this study sample may be from other urban households in Kerala and Rajasthan.

The study framework followed a sequential approach, with quantitative surveys carried out based on the results of a preceding exploratory qualitative module. In this first step, thirty focus group discussions (Kerala: $N = 16$; Rajasthan: $N = 14$) were carried to understand local cookstove and fuel use patterns and perceptions. Findings from the focus groups informed the development of structured surveys that were administered in 3,929 households in Kerala across 8 districts and 6,077 households in Rajasthan across 20 districts. Surveys were administered to the household's primary cook (18 years and older). Summary statistics for the overall study samples can be found in Table 1.

3.2 Outcome Variable: LPG Ownership

Respondents described all cookstoves they had in the household. In our primary analysis of adoption, we focus on the binary variable LPG ownership. Patterns of LPG ownership diverged between Kerala and Rajasthan: in Kerala, 73% of households had an LPG cookstove whereas the fraction of households in Rajasthan with LPG is 24% (see Figure A3 for a map of study districts and LPG ownership).

3.2.1 Secondary Outcome Variable: Days to consume an LPG cylinder—

Our primary research question assesses LPG ownership as the outcome. However, the use of a clean fuel after adoption is an important determinant of the benefits gained from cleaner

cooking. We conducted a secondary analysis to assess the association of education level with LPG consumption in our study sample. While self-reported frequency of use is a common outcome for assessing fuel use, there was relatively little heterogeneity in responses to this question. In Kerala, 90% of respondents stated that they used their stoves regularly (9% reported occasional use). Self-reported frequency of use was somewhat lower in Rajasthan: 48% of participants said they used their stoves regularly and 50% said they used their stoves occasionally.

Therefore, we utilized responses to the question, “On average how many days it takes to consume one full cylinder?” The distributions of days to consume a cylinder are shown in Figure A4. In Kerala, the median number of days to consume a cylinder was 60 (interquartile range (IQR): 60–90 days; mean (standard deviation (SD)): 72 days (29)). The number of days to consume a cylinder was similar in Rajasthan (median (IQR): 60 days (30–75); mean (SD): (60 days (32)).

3.3 Explanatory Variable: Household Perceptions and Attitudes

Respondents were asked a series of 30 questions to assess their perceptions and attitudes towards cooking and fuel use, generated during the study’s formative focus group discussions. Owing to different emergent themes during focus group discussions, participants in Kerala and Rajasthan were asked to respond to somewhat different perceptions. Nonetheless, several themes overlapped across the two states. A full list of the perceptions is available in Supporting Information Table A7. Responses were coded on a scale of 1 to 5 (1=Completely Disagree, 2=Disagree, 3=Neither Disagree or Agree, 4=Agree, 5=Completely Agree).

In our primary analyses, individual perceptions were collapsed thematically into indices by summing coded numerical responses, ensuring that perceptions within indices were “oriented” in the same direction such that greater agreement meant greater acceptability of clean cooking fuels. Consider the following example: A participant is asked whether they agree or disagree with the following statements, “When firewood is scarce, we have to travel further to get it” and “Firewood is used because it is free.” In the first statement, our model takes greater agreement (higher values) to mean greater acceptability and desire for clean cooking fuels; however, there is a need to reverse the values for the second statement to achieve the same result. So, a participant responding with “4=Agree” to the statement “Firewood is used because it is free” would be coded in a new variable “Firewood is used because it is free (reversed)“ as a “2.” Then, we summed the results from these perceptions, along with three other similar statements, into the overall perception index “Woodfuels are not available and inconvenient to use.”

To facilitate comparability between indices despite differing numbers of contributing individual perceptions, indices were normalized such that the minimum value became 0 and the maximum value became 1. This process resulted in six indices in Kerala and five indices in Rajasthan described below. While several themes covered by the perception indices were shared between Kerala and Rajasthan, some of the individual perceptions differed. Therefore, even indices with the same name should not be directly compared. The normalized distribution of the indices is shown in Figure A5.

- *Chulha and woodfuel are valuable (Kerala and Rajasthan):* Traditional cookstoves and cooking on woodfuels can hold a unique position within households because of their importance in traditional cooking practices, belief systems, and food taste.
- *Using the chulha is difficult (Kerala):* Lighting woodfuels, cleaning the ash from traditional cookstoves, and cooking on the chulha itself can be time consuming and challenging.
- *Woodfuels are not available and inconvenient to use (Kerala and Rajasthan):* In some cases woodfuels are increasingly scarce, requiring long collection journeys carrying heavy loads. Furthermore, cooking with woodfuels can be difficult, requiring constant tending and frequent cleaning of blackened pots and utensils.
- *LPG is good and affordable (Kerala) / LPG is desirable, but expensive (Rajasthan):* For many households, clean fuels like LPG are highly desired but remain out of financial reach either because of the initial cost of the cookstove or the recurring cost of cylinders.
- *LPG is good quality cooking and beneficial (Rajasthan):* Cooking with LPG may provide several benefits over traditional forms of cooking, such as ease of cooking, reduced cooking times, and more leisure time for cooks.
- *Health attitudes in cooking (Kerala and Rajasthan):* Many principal cooks recognize the short-and long-term health impacts they and their families face from the smoke produced by cooking with woodfuels and the potential benefits of clean fuels.
- *General health attitudes: progressive (Kerala):* Seeking medical attention when ill and trusting medical professionals can be indications of general health-improving practices that may reflect increased likelihood of adopting clean fuels, themselves potentially viewed as a health-improving technology.

In addition to our main analyses using indices, we carried out an exploratory analyses utilizing individual perceptions rather than indices to see if individual perceptions are more or less associated with education or LPG ownership. We accounted for multiple hypothesis testing using the Benjamini-Hochberg method for controlling for False Discovery Rate (FDR < 0.10).

3.4 Explanatory Variable: Education Level

Respondents provided the completed educational level of the CWE in nine categories.[1] These categories were reduced to four groups based on sample size and similarity in characteristics between education levels.[2] Households in Kerala had CWEs with high formal education; nearly two-thirds of households had a CWE that had completed middle or high

[1]Full education categories: 1=Illiterate, 2=Literate (without formal schooling), 3=Primary School (1st standard – 5th standard), 4=Middle School (6th standard – 7th standard), 5=High School (8th standard – 10th standard), 6=Senior Secondary School / Intermediate / Pre-University (11th standard – 12th Standard), 7=Diploma/Certificate, 8=Graduate, and 9=Post-Graduate and above.
[2]Reduced education categories: 1=Illiterate / No Formal Schooling, 2=Primary School, 3=Middle / High School, and 4=Greater than High School.

school, with another 13% of CWE's completing some level of education greater than high school. Less than five percent of households had a CWE without formal schooling or who was illiterate. In Rajasthan, CWE educational achievement was much lower; almost half of households were headed by a CWE without formal education or who was illiterate. Summary statistics for Kerala and Rajasthan households by CWE education category are shown in Supporting Information Table A2. A higher proportion of households in both samples with great levels of CWE educational attainment have LPG. Additionally, households with higher CWE educational attainment have younger primary cooks, a greater proportion of households belonging to the general caste category, and higher monthly expenditures.

Respondents also provided information about educational achievement by females in the household according to the nine original education categories. However, the data provided differ somewhat. In Kerala, households reported the number of females to have achieved each level of education. In this analysis, we utilize the highest education level achieved by a female as our explanatory variable, categorized into the same four categories as CWE education level. Households that did not report female education level were dropped from this secondary analysis (N=164 dropped). In Rajasthan, the households were asked to provide the education level of the respondent or the CWE's spouse. Households where the CWE is female were dropped from this analysis (N=185). Summary statistics by female educational level obtained are available in Supporting Information Tables A5 (Kerala) and A6 (Rajasthan). The same trends observed with increasing CWE education are observed among household subsets of female education: households of higher socio-economic status have females with higher education levels.

3.5 Control Variables

Our selection of control variables drew from reviews of the existing literature (Lewis and Pattanayak, 2012; Muller and Yan, 2018; Quinn et al., 2018), case studies of the determinants of clean cooking adoption, and the study data. We ran univariate regressions between covariates and both education and LPG ownership to assess for confounding. We retained the following covariates that were significantly correlated with both education and LPG ownership. Figure A2 shows that there is relatively little correlation among the covariates.

- *Monthly household expenditures (logarithmized):* Household wealth is a prominent driver of clean cooking adoption in India and around the world (Muller and Yan, 2018; Lewis and Pattanayak, 2012). Here, as in many cases when surveying rural and poor households, a monthly income is unavailable so we utilize monthly expenditures in Indian Rupees as a proxy for wealth (Klasen, 2000; Muller and Yan, 2018). We have logarithmized the variable to account for the heavily right-tailed data distribution.
- *Age of the respondent:* Age has been associated with cleaner cookstove and clean cooking fuel adoption (Gupta and Köhlin, 2006; Baiyegunhi and Hassan, 2014; Abebaw, 2008). We use the age of the respondent (here, the principal cook) in years completed in analysis.

- *Household size and composition:* We include both the number of adults (defined as 18 years and older) and the number of children, (defined as under 18 years old) as covariates in analysis, supported by previous case studies (Heltberg, 2004; Alem et al., 2016).
- *Caste of the household:* Here we include the caste of the head of household, as in previous studies of cooking fuel choice in India (Menghwani et al., 2019; Saxena and Bhattacharya, 2018). Baseline category is belonging to the general caste category.
- *Religion of the household:* Past studies of household energy technology adoption in India have shown that religion can influence cooking and cookstove adoption patterns (Menghwani et al., 2019; Bhojvaid et al., 2014). Baseline category is Hindu, which comprises the majority of households in both study samples.
- *Household area, urban or rural:* Household cooking patterns and access to fuels - both solid and clean fuels - may differ by households that are urban or rural (Rao and Reddy, 2007). Baseline category is urban households.

3.5.1 Sensitivity Analysis: Accounting for LPG costs—

The costs associated with LPG - installation costs, monetary costs of refilling cylinders, and acquisition costs - have a role in both LPG adoption and use. Previous studies have shown that the anticipation of high costs itself may be a deterrent to LPG ownership (Gould and Urpelainen, 2018). After acquisition, higher LPG costs have also been associated with less use (Quinn et al., 2018; Muller and Yan, 2018).

Figure A6 shows the distribution of self-reported prices paid by LPG-owning participants for their last LPG cylinder. Figure A7 shows the same as a district-level map. Overall, prices paid are similar both within states and districts. In Kerala, the median price paid an LPG cylinder was 680 rupees (IQR: 650–700) and in Rajasthan prices were slightly lower (median (IQR): 600 rupees (600–630)).

In sensitivity analyses we include the average district-level LPG cylinder costs as a covariate in our main regression assessing the association between formal education level and LPG ownership. Then, we include individual LPG cylinder cost as a covariate in regressions assessing the association between formal education level and the number of days a household takes to consume a cylinder.

Notably, there is relatively heterogeneity in LPG cylinder prices across India because prices are set by state-run oil companies and revised only on a monthly basis.

Outliers where participants reported paying more than 1,500 rupees for a cylinder of LPG were removed due to implausibility ($N = 3$).

4 Results

We present our results following our analytic design. First, we characterize the association between CWE and female education and LPG ownership in both samples. Then, we describe

the association between attitudes and LPG ownership. Next, we link education and attitudes. Then, we assess the relationship between education and LPG ownership after adjusting for potential mediation by attitudes. Next, we assess the potential for reverse causation whereby LPG ownership leads to shifts in attitudes. Finally, we report on secondary outcomes, robustness checks, and sensitivity analyses.

4.1 Education and LPG Ownership

Increased CWE educational achievement was strongly associated with LPG ownership, after controlling for covariates and district-level differences (i.e., different access to LPG), in both the Kerala and Rajasthan samples (Figure 1). In the Kerala sample, after accounting for district fixed effects, in comparison to households where the CWE was illiterate or lacked formal schooling, when the CWE had completed primary school the odds of LPG ownership 1.81 times higher (OR 95% CI: 1.23–2.65), middle or high school 3.19 times higher (OR 95% CI: 2.22–4.59), and greater than high school 5.47 times higher (OR 95% CI: 3.55–8.47). Similar trends were observed in the Rajasthan sample, though with a slightly smaller effect size. In addition, greater monthly household expenditures (logarithmized) was strongly associated with increased LPG ownership and rural households had lower odds of LPG ownership than their urban counterparts in both samples. Conditional logistic regressions did not show differences dependent on model specification (Figure A8). In subsequent analyses, we only report models that used district fixed effects.

4.1.1 Female Education and LPG Ownership—

Next, we turned to female educational achievement. In both samples, CWE education and female educational achievement were positively correlated (Kerala r=0.24, P<0.001; Rajasthan r=0.40, P<0.001). Tables A3 and A4 summarize the distribution of CWE and female education level pairs in Kerala and Rajasthan households, respectively.

Female educational achievement was positively associated with LPG ownership (Figure 2); however the association was somewhat weaker than that between CWE education and LPG ownership. In Kerala, in comparison to households where no females had a formal education, households where a female has achieved a primary education had 1.33 times higher odds of owning LPG (95% CI: 1.02–1.75), a middle or high school education 1.36 higher odds (95% CI: 1.07–1.76), and a greater than a high school education 2.29 times higher odds (95% CI: 1.62–3.32). Analysis of female education in Rajasthan is not directly comparable to analysis in Kerala because the educational level may refer to individuals with different positions in the household (Section 3.4). At the same time, female education was positively associated with LPG ownership in the Rajasthan sample (Figure 2). Similar to the Kerala sample, female respondent education had a somewhat weaker association with LPG ownership than CWE education in Rajasthan households. These results suggest that because males have more of the decision-making power, their education level is more important.

4.2 Perceptions and LPG Ownership

Household perceptions of cookstoves and fuels were only weakly associated with LPG ownership in both Kerala and Rajasthan (Figure 3). In Kerala, perceptions regarding woodfuels and LPG as a fuel were most strongly correlated with LPG ownership. Health

attitudes, including the perception that cooking fuel type is related to health, were also statistically significantly correlated with LPG ownership. In Rajasthan, perceptions that "LPG is desirable, but expensive" was weakly negatively correlated with LPG ownership. Perceptions regarding the importance or difficulty of using chulha stoves were not at all associated with LPG ownership.

Next, we tested the association of perception indices with LPG ownership after accounting for covariates (Figure 4). Here, perception indices showed stronger associations with LPG ownership. In Kerala, the perception that "LPG is good and affordable" was strongly positively associated with LPG ownership. In addition, health attitudes - both related to cooking and having progressive general health attitudes - were positively associated with LPG ownership in Kerala. "LPG is desirable, but expensive" was negatively associated with LPG ownership in Rajasthan. In addition, "LPG is good quality cooking and beneficial" was weakly positively associated with LPG ownership and "Chulha and woodfuels are valuable" had a weak negative association.

Then, we explored the association of all individual perceptions and LPG ownership. In doing so we were able to explore heterogeneity in the associations between individual perceptions and LPG ownership within indices. The results showed a wide distribution of positive and negative associations (Figures A9 and A10).

Several individual perceptions had strong associations with LPG ownership in both samples. The strongly positively associated individual perceptions in Kerala were "With LPG we don't have smoke issues," "Cooking with LPG is easy, it takes less time," "When the kids are sick, we take them to the doctor," and "LPG adoption will be automatic among the next generation." In Rajasthan we saw similar positive associations: "Cooking using LPG is a much cleaner and healthier method of cooking", again "LPG adoption will be automatic among the next generation," and "Women who use LPG get more time for themselves."

In Kerala negatively associated perceptions concerned the costs of LPG cooking and the benefits of the chulha: "LPG or induction is unaffordable entirely," "Firewood is used because it is free," "Food tastes better on the chulha," and "Chulha in the kitchen is needed, especially during holidays and with guests." Furthermore, a non-progressive health perception "I don't tell people if I'm sick" was strongly negatively associated with LPG ownership. In Rajasthan, "I use a chulha because I just don't any other alternative" and "My family cannot afford LPG cylinder/induction stove at all" were strongly negatively associated with LPG ownership.

4.3 Education and Perceptions

We assessed the associations between perceptions and CWE and female education in both Kerala and Rajasthan (Figure 5). Education achievement of the CWE was largely not associated with perception indices in both samples. In Kerala, only the perception "Chulha and woodfuel are valuable" displayed a clear (negative) trend with increasing CWE education. These results suggest that household perceptions are largely independent of CWE educational achievement. Greater female education was positively associated with progressive health attitudes and negatively associated with the perception that woodfuels are

readily available in Kerala. The coefficients remain relatively small, but we show here that household perceptions of cooking and health may be more influenced by female education level than the Chief Wage Earner's.

Next, we investigated the associations between individual perceptions and CWE and female education level in Kerala and Rajasthan. The results from these regressions indicated that while indices varied only marginally with changes in education level, some individual perceptions were associated with educational attainment (Figures A11 and A12). While there were relatively few coefficients that reached statistical significance after controlling for FDR, several perceptions showed consistent trends with increasing education. In Kerala, health- and smoke-related perceptions such as "We inhale a lot of smoke, sometimes it is suffocating," "Sometimes smoke irritates the eyes, gives headache, and backache," and "I don't tell people If I'm sick" were all negatively associated with CWE and female education. Fewer individual perceptions varied with changes in education in Rajasthan. The perceptions "I use a chulha because I just don't have any other alternative" and "My family cannot afford LPG cylinder/induction stove at all" were negatively associated with CWE education.

4.4 Mediation of Education and LPG Ownership Association by Perceptions

Having seen that educational achievement was strongly associated with LPG ownership and certain perceptions were also associated, we next carried out a mediation analysis to assess whether perceptions explained the educational associations. Figure 6 shows the results of including perception indices in regressions testing the association of educational attainment (both CWE and female) and LPG ownership in Kerala and Rajasthan. The models showed similar associations across all perceptions, with little or no variation when including or excluding perception indices (not shown in this plot, but can be found in Figures 1 and 2). Therefore, there is little evidence of perceptions mediating the association between education and LPG ownership in the Kerala and Rajasthan samples. In addition, the associations between perception and LPG ownership were not reduced when education variables are included in the models, suggesting that perceptions and education are associated with LPG ownership in unrelated pathways.

Mediation analyses using the full set of individual perceptions from Kerala and Rajasthan are shown in Figures A13 and A14. There was no evidence of mediation by perceptions in Kerala households. In Rajasthan households, two perceptions slightly mediated the association between education and LPG ownership: "My family cannot afford LPG cylinder/induction stove at all" and "I use a chulha because I just don't have any other alternative."

4.5 Assessing Changes in Perceptions with Longer LPG Ownership Time

Our previous analyses showed that some perceptions were associated with LPG ownership. To better determine the nature of this association, we assessed the association of the number of years of LPG ownership and changes in perception indices among households owning LPG. In this analysis, we may think that LPG ownership leads to changes in perceptions if there is a strong trend in the years of LPG ownership and consistent changes in perceptions. Figure 7 shows the main results from this analysis using perception indices and Figures A15 and A16 show the results using individual perceptions.

There were no strong associations between perception indices and years of LPG ownership in either study sample. There is a weak negative trend of greater years of LPG ownership and the perception "Woodfuels are unavailable, inconvenient" in both samples. In Rajasthan, differences in this perception were evident after 1–2 years of ownership (baseline category) and showed no greater change in the perception with more years of ownership. Analyses using individual perceptions revealed some heterogeneity, though few associations reached statistical significance. Some positive perceptions of woodfuels and the chulha were negatively associated with increasing years of LPG ownership: "Chulha smoke purifies the home" in Kerala and "The food cooked in the chulha is good for health," "In case of large family it's important to have the chulha which allows simultaneous cooking of multiple dishes," "A few traditional dishes like dalbati can be cooked only in the chulha, so we have to keep a chulha at home" in Rajasthan. This suggests that there are some perceptions related to traditional cooking practices and cleaner fuels like LPG that change after LPG is adopted; yet there are many perceptions that were associated with LPG ownership that do not change after adoption (e.g., health attitudes).

4.6 Analysis of the Association between Education and LPG Use

There was a negative association between CWE education and days to consume an LPG cylinder in Kerala (Figure A17). That is, households where the CWE has achieved a higher education consume LPG faster, accounting for all covariates and district-level variability. For example, households where the CWE has achieved an education Greater than High School consume LPG cylinders 10 days faster than those where the CWE has no formal education (95% CI: 4–17 days faster). Furthermore, higher monthly expenditures and more adults and children in the household were also significantly positively associated with faster LPG cylinder consumption. Conversely, households not belonging to the general caste category and rural households consumed LPG cylinders over more days. CWE education in Rajasthan and female education in both states was not significantly associated with days for full LPG cylinder consumption (Figure A18).

4.7 Robustness of Results to the Inclusion of LPG Cylinder Cost

Our main results showing the association between CWE education and LPG ownership were robust to the inclusion of the average cost of LPG cylinders in their village (Figure A19). There was no association between village-level average LPG cylinder cost and LPG ownership in Rajasthan, but in Kerala a 100 rupee higher cost was associated with 1.28 times higher odds of having LPG (OR 95% CI: 0.99–1.47).

Results from the analysis of LPG use did not change substantively when we include LPG cylinder cost paid by LPG-owning participants (Figures A20 and A21). The cost of an LPG cylinder paid by LPG-owning participants was not associated with the self-reported number of days it takes to consume an LPG cylinder in Rajasthan. In Kerala, however, a 100 rupee higher cost is associated with consuming LPG 0.77 days faster (95% CI: 0.12–1.42 days faster). Still, the association between education and LPG consumption has a much larger magnitude: households where the CWE has achieved a Greater than High School education consume LPG cylinders 11 days faster than their counterparts where the CWE has no formal education (95% CI: 4–18 days faster).

4.8 Sensitivity Analysis in Subsets of Study Households

We repeated the main analyses assessing the associations between CWE and female education achievement among subsets of both the Kerala and Rajasthan samples. The positive association between educational achievement and LPG ownership remained consistent in terms of both the direction and the magnitude of association across the above/below median expenditure and rural/urban sub-samples. One exception is that the association between female educational level and LPG ownership diminished in the rural and below median expenditure sub-samples. In these cases, only households where a female had achieved an educational level Greater than High School had greater odds of owning LPG as compared to households where no females had a formal education. In addition, when we combined the Kerala and Rajasthan datasets to assess overall sensitivity we observed robust results among the rural and urban combined sub-samples. Results from these sensitivity analyses can be found in Supporting Information A4.7.

5 Conclusion

In this study we show that CWE educational achievement is highly positively associated with LPG ownership across two substantially different study samples in India, independent of common covariates to LPG adoption and after accounting for district-level variability. We additionally use measures of female educational achievement in the household and show that these are also positively associated with LPG ownership, though more weakly than CWE educational achievement. Furthermore, we show that both educational associations are robust by assessing them rigorously in sub-samples of study households.

Then, we use measures of household perceptions related to cooking to assess the associations between household educational achievement, perceptions, and LPG ownership. We show that some cooking-related household perceptions are associated with LPG ownership. In particular, the perception that “LPG is good and affordable” was strongly positively associated with LPG ownership in the Kerala sample and the perception that “LPG is desirable, but expensive” was negatively associated with LPG ownership in the Rajasthan sample. In addition, we show that progressive health attitudes and the perception that cooking fuel choices affect health were positively associated with LPG ownership in Kerala. Although we find no relationship between CWE educational achievement and perceptions, results show that perceptions are somewhat more related to female educational achievement. Through assessments of mediation, though, we are unable to show that greater education influences increased LPG adoption through changes in these cooking-related perceptions. Finally, we show that there are some perceptions that change after LPG ownership and with increasing years of ownership and others that are unaffected by years owning LPG. In sum, we demonstrate that there are likely two distinct pathways associated with LPG ownership. The first through increased educational achievement and the second through certain cooking-related perceptions.

While our primary analyses utilize perception indices, we also carry out an alternative approach using the individual perceptions. We see several important perceptions emerge in these models. In Kerala - where a larger fraction of households own LPG and households have higher socioeconomic status in comparison to Rajasthan - perceptions relating to the

inconvenience of woodfuels because of smokiness and collection times were strongly associated with LPG ownership. Related, results show a strong association between progressive health attitudes, like “When my kids are sick we take them to the doctor” and “We trust the advice of doctors,” and perceptions that cooking fuel choices affect health like “We inhale a lot of smoke, sometimes it is suffocating” were all positively associated with LPG ownership. In comparison, perceptions in the Rajasthan sample with strong associations with LPG ownership focused primarily on the costs of cooking: “My family cannot afford LPG cylinder/induction stove at all” and “I use the chulha because I just don’t have any alternative” were negatively associated with LPG ownership. Several of the perceptions significantly associated with LPG ownership may result from reverse causation; that is, perceptions shift after LPG is adopted. In particular, certain notions about the costs of cooking with woodfuels and their relative benefits (e.g., “Chulha smoke purifies the home,” “A few traditional dishes like dalbati can only be cooked on the chulha so we have to keep a chulha at home”) appear to shift away from traditional cooking practices after several years of LPG ownership. Yet, several perceptions - like health-related perceptions and perceptions about the costs of clean cooking - seem to be unaffected by length of time owning LPG, suggesting shifts in these perceptions may indeed precede LPG adoption.

This study has several strengths. First, this study benefits from robust data and a large sample size obtained through two large household surveys administered in households of different socioeconomic profiles. Households in Kerala and Rajasthan differ along variables consistently associated with clean cooking adoption: wealth, education, and urbanicity. Indeed, a much larger fraction of households in Kerala own LPG than in Rajasthan. Nonetheless, we find remarkably similar associations between formal educational level, perceptions, and LPG ownership across both study samples. Second, we use both chief wage earner (nearly all males) and female educational attainment variables. While the two variables are somewhat correlated, there remains heterogeneity across household CWE-female education level pairings. Indeed, results show that higher female educational attainment is positively associated with LPG ownership. Nonetheless, we do find that CWE educational level seems to have a stronger association with LPG ownership than female education. Furthermore, results indicate that only CWE education - not female education - is associated with LPG ownership in sub-samples of households below the median income and also rural households. Finally, we use data on individual perceptions regarding cooking, tradition, health, and values. Still, the exact joint relationship between all three variables is not yet clear.

Our study has a few limitations worth noting. We rely on self-reported, closed-response data to report on individual attitudes. While the perceptions discussed in the household survey were developed from numerous focus groups, they may not completely capture the most important health- and cooking-related attitudes in the LPG adoption process. Though our analysis of the proposed pathway benefits from quantitative data, qualitative analysis is likely also an appropriate methodological approach for the discussion of the impact of attitudes on LPG adoption. In addition, this study leverages household- and individual-level data; however, it is possible that there are important external attitudes and perceptions that vary at the community-level. Though somewhat studied (Akintan, Jewitt, and Clifford, 2018;

Hollada et al., 2017; Bhojvaid et al., 2014; Rhodes et al., 2014; Troncoso et al., 2007), the effect of community norms on transitions to clean cooking fuels remains poorly understood.

Furthermore, we focus on formal education in this study. However, non-formal and informal learning are important in their own right (Coffield, 2000). These activities can be defined as education along formal systems of education and training that do not lead to certifications, for instance in a workplace, (non-formal) and learning that takes place in everyday life, including unintentional learning (informal) (Commission of the European Communities, 2000). The importance of non-formal and informal learning in socio-economic development, skill building, and creating social norms in India and around the world has been noted in previous studies (Krishna, 2005; Latchem, 2014; Pilz and Wilmshöfer, 2015; Koops and Pilz, 2019), but has received little attention in the study of clean cooking and environmental health interventions. Future studies may be enhanced by evaluating the role of non-formal and informal learning in decision-making surrounding cooking fuel choice.

In addition, while we use district-level fixed effects - and conditional logistic regressions in an alternate model specification - to account for geographic differences within our sample, future analyses may seek to include market-related factors to LPG adoption and use, like fuel availability. We include cylinder costs in additional analyses; still, access and availability of cylinders are challenges that can limit both LPG adoption and use. Furthermore, future studies could assess the relative importance of individual and contextual factors and the way in which these relationships vary across regions. For example, perhaps attitudes are relatively more important when fuel costs are low and access is high, but under other circumstances these external contextual factors take precedence.

For research on energy access, our findings offer a few important guidelines. Most importantly, understanding the mediators of the education-adoption linkage is crucial. Attitudinal considerations were a natural and intuitive hypothesis, but our current results suggest that the answer might be elsewhere. Panel data and detailed surveys could offer insights into the different channels through which education leads to adoption. Understanding these pathways would both help explain the fundamental psychology of household cooking decisions and lead to concrete insights into how governments and non-governmental organizations can encourage the adoption of cooking fuels in India, and with appropriate contextualization, elsewhere in the world.

Related, the policy implications are significant. While we clearly identify education as a potential driver of LPG adoption, we find a lack of support for mediation by attitudes. The present analysis is just one study in a specific context and the results do not suggest that efforts to shift attitudes will not yield behavior change regarding clean cookstove adoption and use. However, the benefits of pairing awareness campaigns with complementary initiatives or policies that address other dimensions of fuel choice - like costs and accessibility - to affect meaningful change in decision-making around the adoption of environmental health technologies like clean cookstoves have been observed in other cases (Thurber et al., 2013; Mobarak et al., 2012; Johnson, Lambe, and Ochieng, 2016). Formal education could help people understand what their options are and how to use LPG. Education may also facilitate financial decisions and encourage long-term considerations

such as health. Thus, general educational attainment might be a more powerful way to promote LPG adoption in India than specific, tailored awareness campaigns that focus only on attitudes.

The study of HAP reduction is a growing area of research, and our contribution focuses on understanding the role of education in the process. We encourage scholars to deepen their understanding of not only the education-adoption linkage, but also develop research programs that explore the role of education in LPG use, cooking behaviors, and ultimately HAP reduction. Only such a multidimensional understanding of the problem can result in lasting improvements in public health - the real goal of this research and practice.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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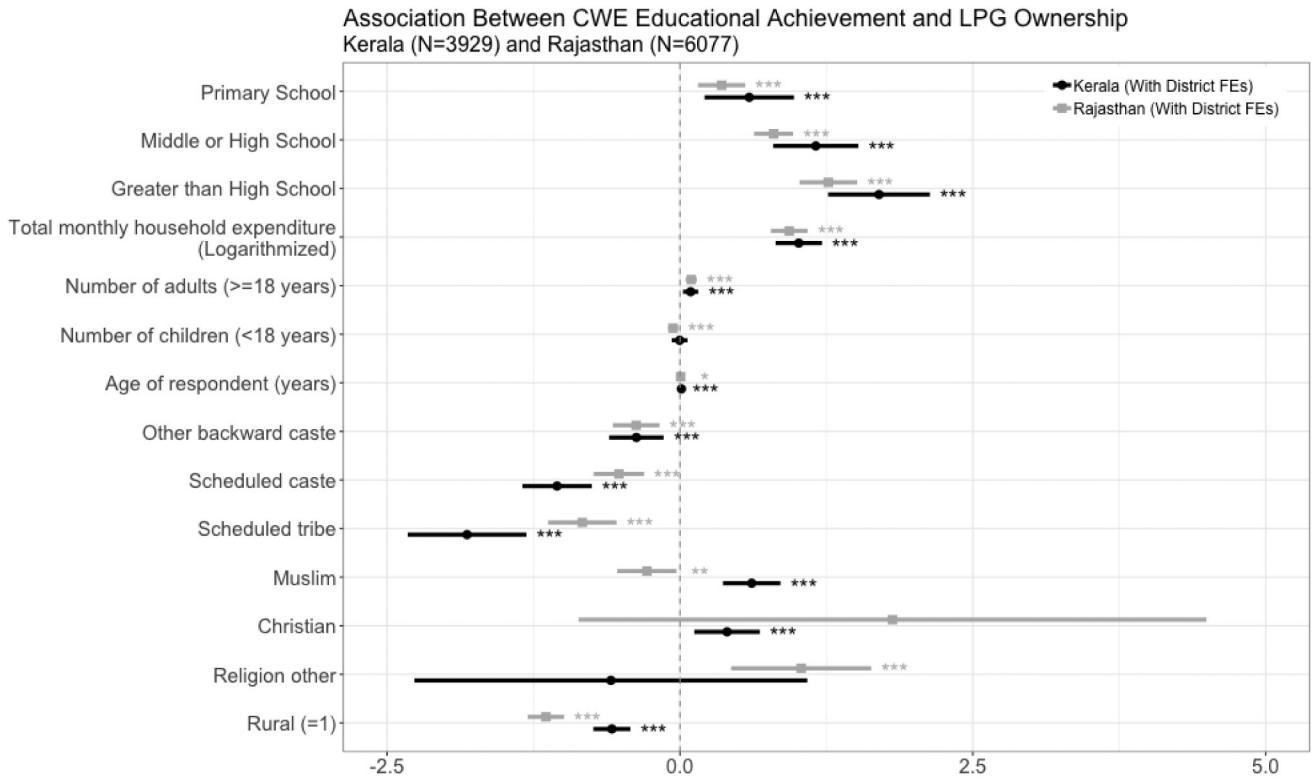

Figure 1:

Coefficient plot for logistic regressions showing the association between CWE education and LPG ownership in Kerala and Rajasthan. Regressions control for covariates and respective district fixed effects. Coefficients are not exponentiated. Whiskers show 95% confidence intervals. Stars show statistical significance after Benjamini-Hochberg method for controlling for false discovery rate: * P<0.10, ** P<0.05, *** P<0.01.

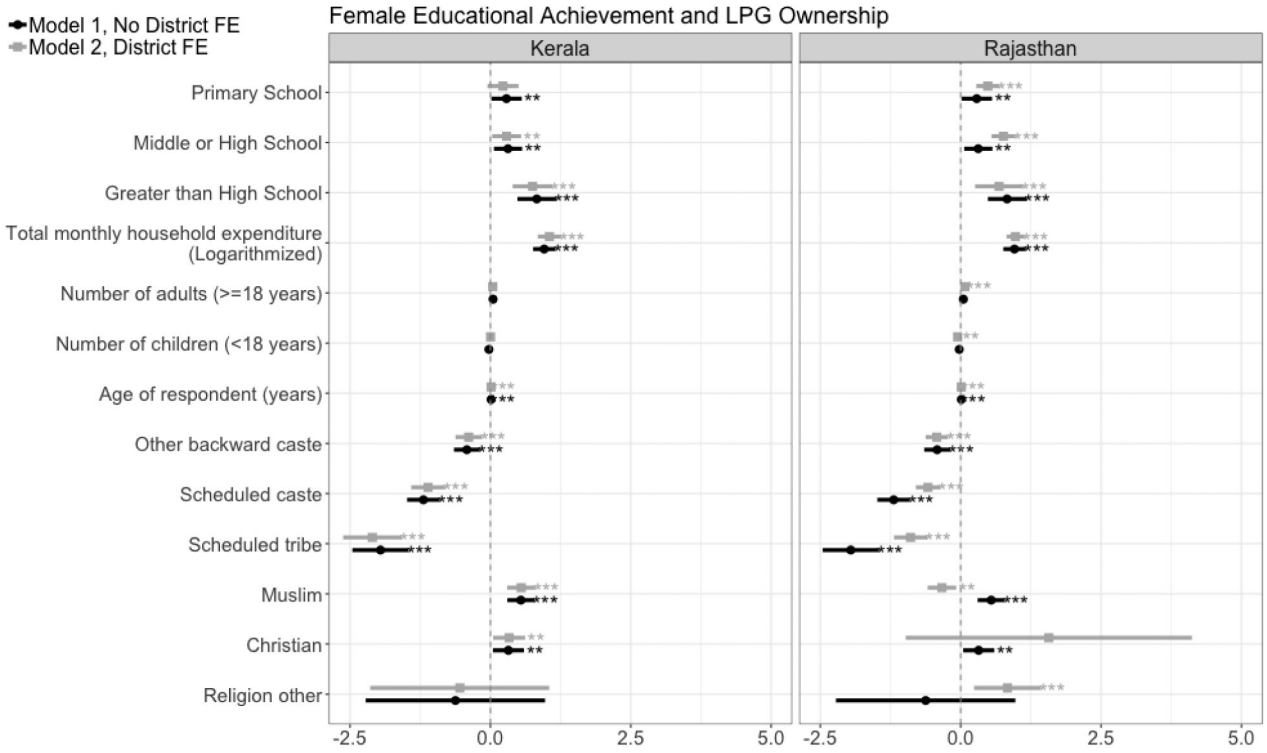

Figure 2:

Coefficient plot for logistic regressions showing the association between the highest education level achieved by a female in the household and LPG ownership, controlling for covariates. Models 1 and 2 also include the caste category ”Don’t know / Can’t say” (not shown on plot) and model 2 accounts for district fixed effects (not shown on plot). Coefficients are not exponentiated. Whiskers show 95% confidence intervals. Stars show statistical significance after Benjamini-Hochberg method for controlling for false discovery rate: * P<0.10, ** P<0.05, *** P<0.01.

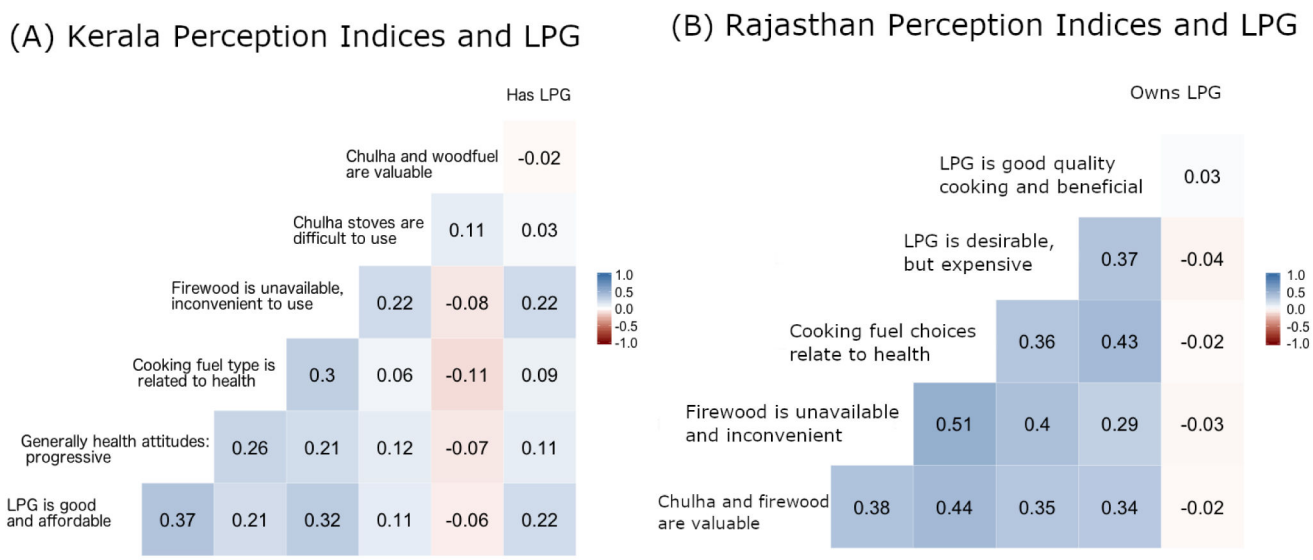

Figure 3:

Correlation matrix of Perception Indices and LPG ownership in (A) Kerala and (B) Rajasthan households using the Pearson's product-moment correlation.

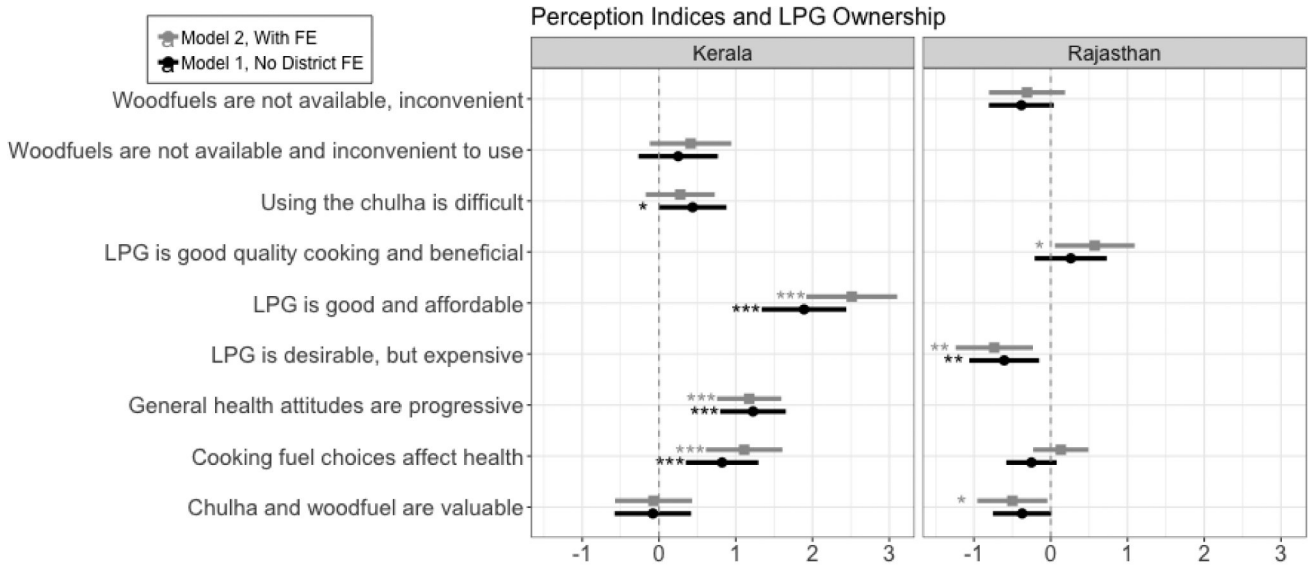

Figure 4:

Coefficient plot for logistic regressions showing the association between perception indices and LPG ownership, controlling for covariates. Model 2 accounts for district fixed effects (not shown on plot). Coefficients are not exponentiated. Whiskers show 95% confidence intervals. Stars show statistical significance after Benjamini-Hochberg method for controlling for false discovery rate: * P<0.10, ** P<0.05, *** P<0.01.

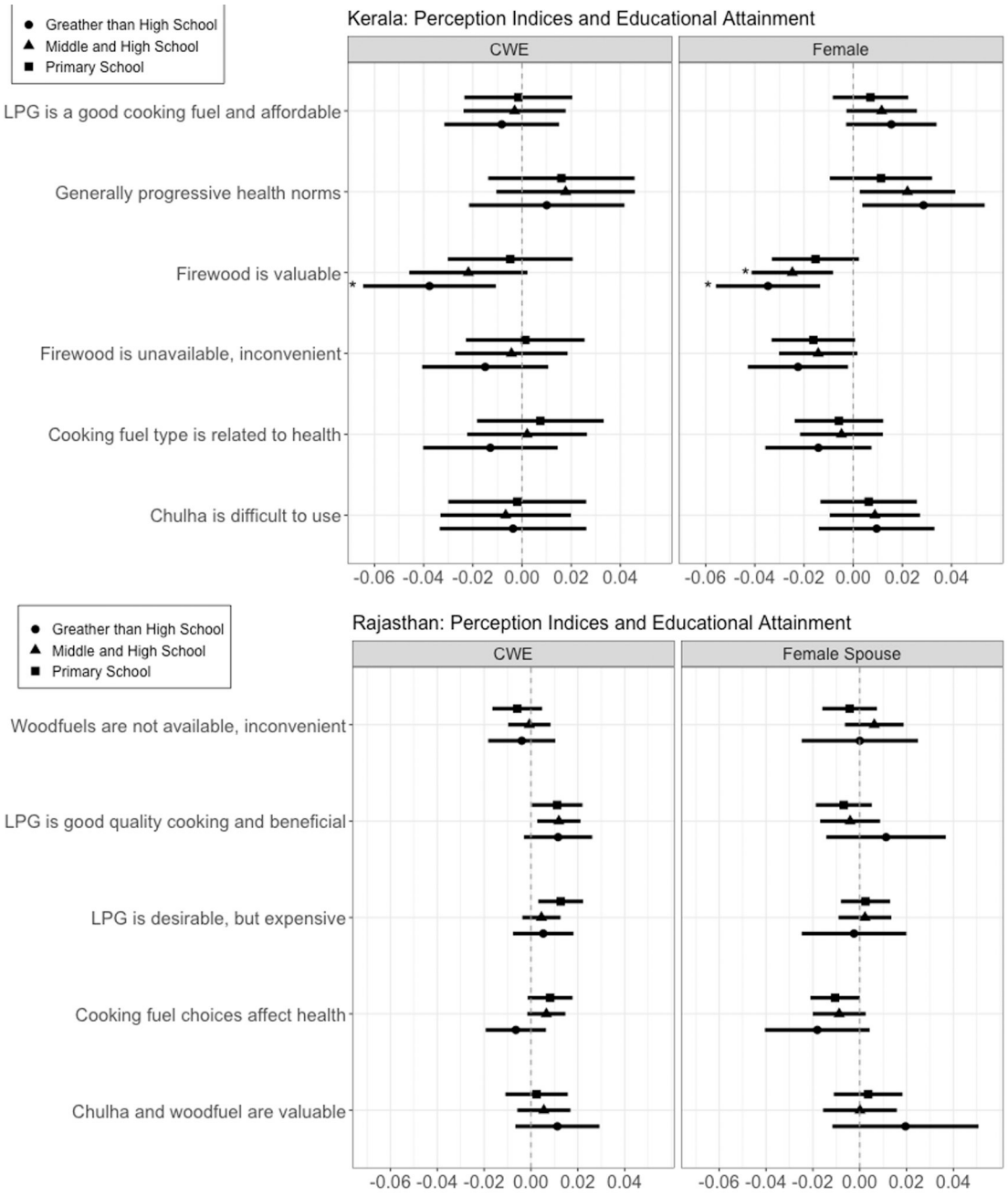

Figure 5:

Coefficient plot for linear regressions showing the association between CWE education and perception indices in Kerala households. Baseline CWE education is illiterate / no formal education. Regressions control for all covariates (not shown). Coefficients are not exponentiated. Whiskers show 95% confidence intervals. Stars show statistical significance after Benjamini-Hochberg method for controlling for false discovery rate: * P<0.10, ** P<0.05, *** P<0.01.

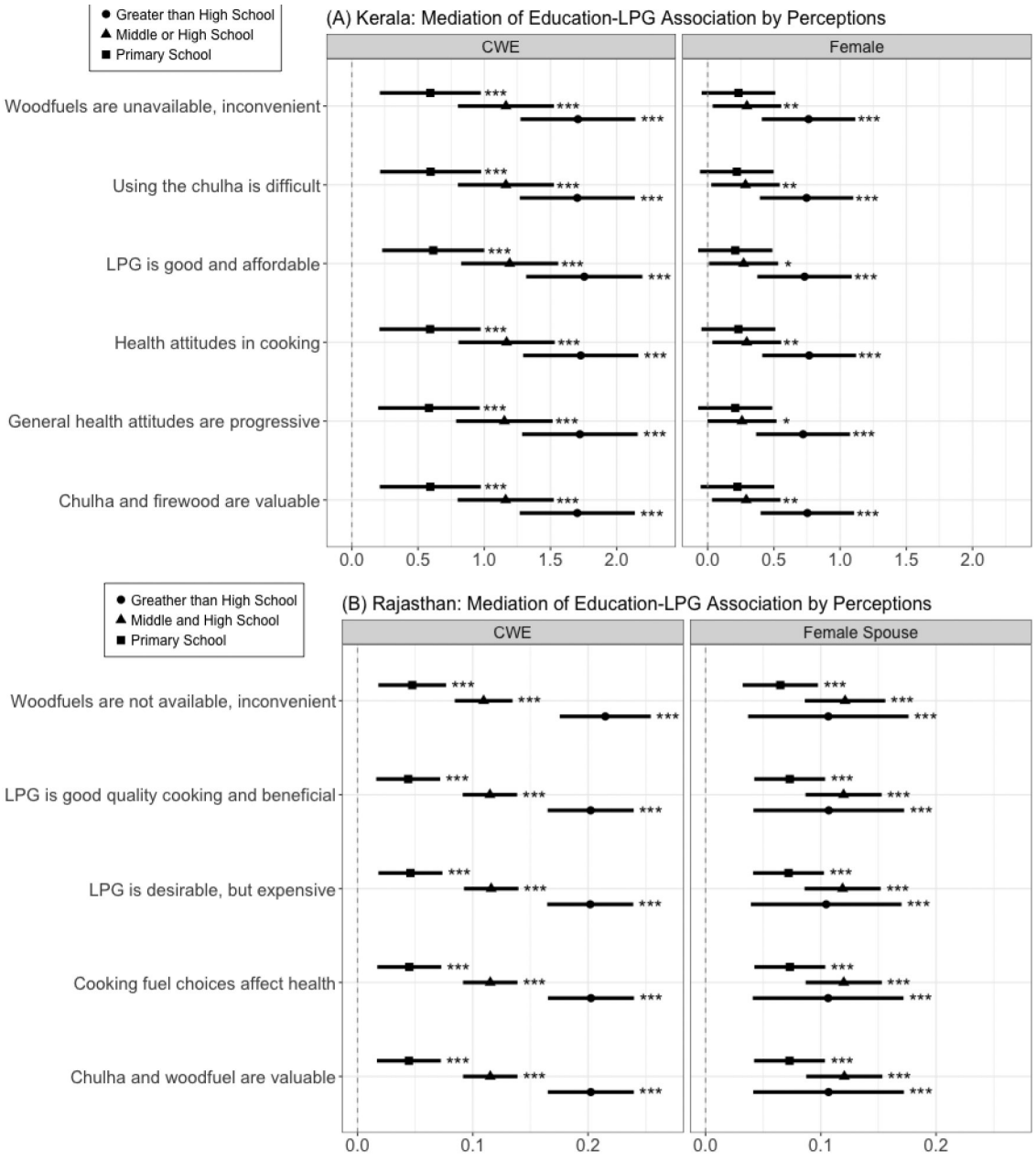

Figure 6:

Coefficient plot for linear regressions showing the associations between CWE and female education and LPG ownership, with and without including perception indices, in Kerala and Rajasthan households. Regressions also control for covariates and district fixed effects (not shown). Coefficients are not exponentiated. Whiskers show 95% confidence intervals. Stars show statistical significance after Benjamini-Hochberg method for controlling for false discovery rate: * P<0.10, ** P<0.05, *** P<0.01.

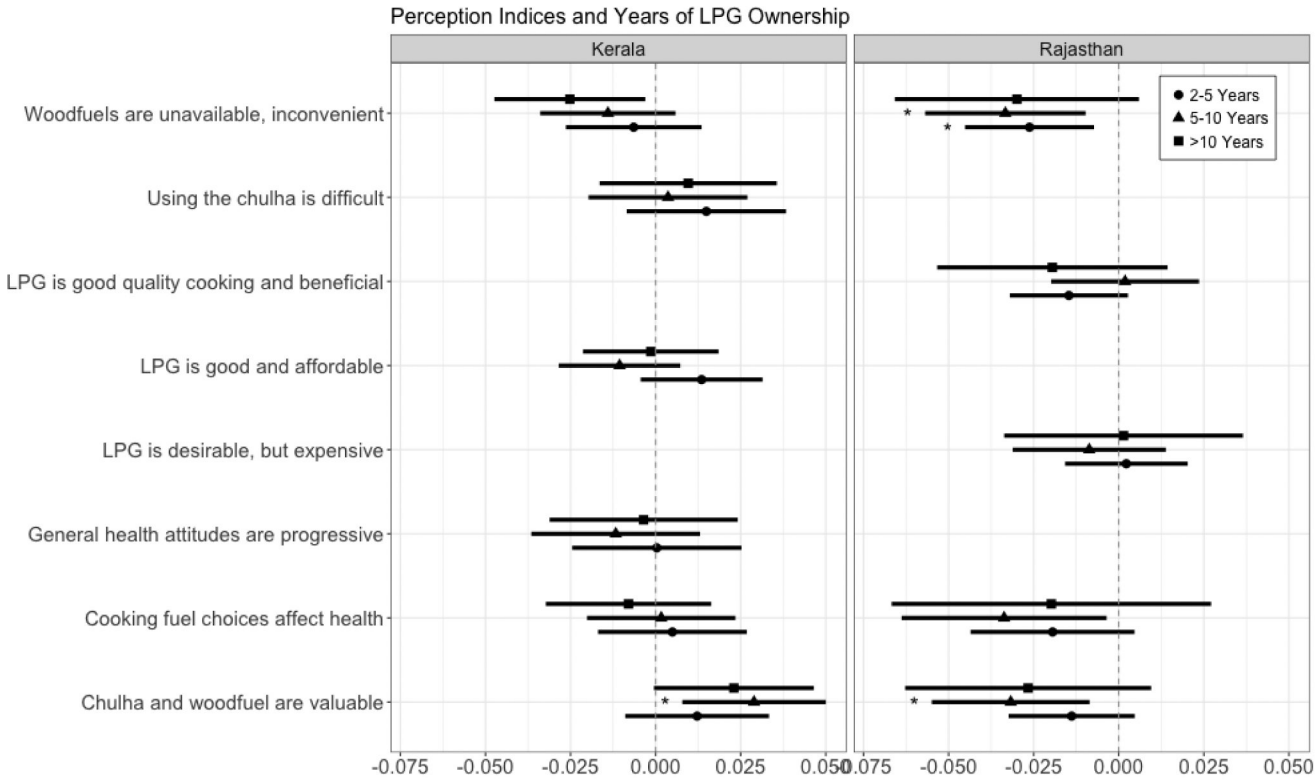

Figure 7:

Coefficient plot for linear regressions showing the associations between perception indices and yeas of LPG ownership in Kerala and Rajasthan households. Baseline level is “1–2 Years.” Regressions also control for covariates and district fixed effects (not shown). Coefficients are not exponentiated. Whiskers show 95% confidence intervals. Stars show statistical significance after Benjamini-Hochberg method for controlling for false discovery rate: * P<0.10, ** P<0.05, *** P<0.01.

Table 1:

Summary statistics of dependent, explanatory, and control variables for Kerala and Rajasthan households. At the time of data collection in October 2015, 1 USD = 65.15 INR.

	Kerala	Rajasthan
Households (N)	3929	6077
Has LPG	0.73	0.24
Fraction Rural	0.52	0.75
Age Respondent	43.80	36.37
Male Chief Wage Earner	0.91	0.97
Relationship of Respondent to CWE:		
CWE herself	0.07	0.02
Wife	0.78	0.89
Daughter/DIL	0.04	0.05
Other	0.12	0.04
CWE Education Level:		
Illiterate / No Formal Schooling	0.11	0.48
Primary School	0.25	0.16
Middle / High School	0.52	0.28
Greater than High School	0.12	0.08
Religion:		
Hindu	0.71	0.90
Muslim	0.17	0.09
Head of Household Caste:		
General	0.19	0.14
OBC	0.62	0.43
Scheduled Caste	0.12	0.28
Scheduled Tribe	0.03	0.15
Mean # Adults	3.19	3.04
Mean # Children (<18 yrs old)	1.05	2.23
Median Total Monthly Expenditure	5657	5500
Median Monthly Fuel Expenditures	500	300