LPG for Free? A Difference-in-Differences approach to analyze effect on adoption of India's PMUY LPG program

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Article

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Abstract

In 2016, India introduced the Pradhan Mantri Ujjwala Yojana (PMUY) policy, which offers below-the-poverty-line (BPL) households a free liquified petroleum gas (LPG) connection. Using a difference-in-differences approach with a non-equivalent comparison group, we provide causal evidence of the effect of the PMUY policy on the probability of obtaining an LPG connection, overall LPG consumption, and clean cooking access. Overall, the policy led to a 3.3-to-3.6 percentage point increase in the probability of obtaining an LPG connection for PMUY-eligible households. We also find that PMUY-households will consume 7.4 fewer kgs of LPG per year than the comparison group and no effect on the tier level of clean cooking access or opting for home delivery. Our work suggests the need to expand the policy to address consumption and the Clean Cooking Tier Group. Finally, this analysis advocates investigation into the size of the refill subsidy beyond simply improved targeting of BPL households.

Background

The adoption of clean stoves by the 3 billion people using traditional fuels is necessary to achieve health, climate, and gender equality goals1. Access to clean cooking fuel could help prevent 3.7 million annual deaths attributable to household air pollution1. In India, the burning of biomass for domestic cooking causes 1.24 million deaths annually2 as 750 million Indians continue to use unclean fuels3. Despite numerous clean options, the UN Sustainable Energy for All Initiative launched the Global LPG Partnership in 2012 under the premise that liquified petroleum gas (LPG) was the preferred cooking solution for the next 15-20 years4.

India has subsidized LPG since the 1970s, yet there still remain large rural-urban disparities in LPG access5. The 2015, the ‘Give it Up’ campaign successfully reduced these disparities by calling on middle class families to voluntarily give up subsidies6. This campaign, along with transitioning to direct deposit of subsidies, improved access and eased the government’s financial burden. However, the initial cost of the LPG stoves still remained a barrier to access among vulnerable groups7,8.

In May 2016, India introduced the Pradhan Mantri Ujjwala Yojana (PMUY) policy, which offered women from below-the-poverty-line (BPL) households (identified through the 2011 Socio-Economic & Caste Census) 1,600 Rs (~22USD) to purchase an LPG connection. This subsidy covered the cylinder deposit, regulator fee, and other set-up costs9. Households had to provide a LPG provider an address, bank account, and aadhaar number (India’s social security number)9. The policy targeted women and offered an optional loan of 1500 Rs (~20 USD) to cover the cost of the stove and first cylinder refill. PMUY had provided 57 million households a subsidized connection as of November 201810. India additionally has a universal subsidy for LPG of 50-350 Rs (~0.7-4.5 USD) per 14.2 kg cylinder depending on the market11. This subsidy is delivered directly to bank accounts through the Direct Benefit Transfer (DBTL)11.

Despite praise for India’s LPG program, numerous studies point to barriers beyond cost that affect the adoption of clean fuels. These barriers include lack of supply, social acceptability, education level, household socio-economic characteristics, perceived benefit, and safety issues1,12–18. Additionally, households often obtain a clean stove but continue to use unclean fuels, a practice termed fuel stacking19. However, to meet the World Health Organization (WHO) particulate matter targets, three-stone fire and charcoal stove usage

must be under three hours per week20. It is in light of these concerns that this paper evaluates the effect of the PMUY policy on LPG consumption and clean cooking access.

This paper utilizes a difference-in-differences (DiD) intent-to-treat methodology to investigate ***whether the PMUY policy led to higher LPG connection rates and higher LPG consumption compared to a non-equivalent comparison group of households immediately above the poverty line.*** This work investigates whether the policy pushed households to adopt LPG, consume LPG (measured as kgs, large cylinders, or small cylinders), to increase their level of access to clean cooking, and to opt for home delivery.

Overall, we determine that the policy led to a 3.3 or 3.6 percentage point increase in the probability of obtaining an LPG connection (measured as an increase in any positive LPG use— either in kilograms or large cylinders, respectively) for PMUY eligible households. We also find that PMUY-households will consume 7.4 fewer kgs of LPG per year than the comparison group and no effect on the tier level of clean cooking access or opting for home delivery. Our work suggests the need to expand the policy to address consumption beyond the connection and to increase Clean Cooking Tier Group. Subsidy targeting is often cited as a means to improve the policy21,22. We agree and suggest that our findings imply that increasing the size of the refill subsidy for BPL households may be a more effective strategy.

Relationship to the Literature

Our paper complements the clean cooking literature in two ways. First, we are the first to use a methodology that evaluates the causal effects of the PMUY policy. Previous evaluation of these data investigated the odds of PMUY customers using LPG as a primary or exclusive fuel23. The research found that PMUY beneficiaries have lower odds of using LPG as a primary or exclusive fuel compared to general customers. Our work builds off this important study by investigating the causal mechanism of whether the offering of the PMUY policy increased rates of LPG adoption among the policy-eligible compared to the rates of LPG adoption among those who were policy-ineligible but have only slightly higher incomes. Our study, therefore, investigates whether the PMUY policy was an effective nudge to transition households to LPG, even if used in combination with traditional fuels. Although the best health benefits result from exclusive use of LPG, even partial LPG adoption has been shown to improve health outcomes24. Additionally, India's Council for Energy, Environment, and Water (CEEW) noted in their Access to Clean Cooking Energy and Electricity Survey of States (ACCESS) that households' use of LPG increases with the age of connection25. Therefore, if the PMUY policy provides an impetus for families to even partially adopt LPG when they would otherwise be wholly reliant on unclean fuels, it can be considered an effective policy.

Second, our work addresses the core question of the effectiveness of the policy, while other research has addressed its sufficiency. Previous studies on the PMUY policy used LPG market data to investigate LPG consumption for PMUY customers as compared to general customers in Karnataka22. They found that PMUY customers refilled 2.3 cylinders per year compared to 4.7 cylinders per year for general customers. A 2019 government audit of the program found across all of India PMUY customers were purchasing 2.98 cylinders per year compared to 6.73 cylinders for general customers9; however, it is not surprising that families living below the poverty line would refill LPG cylinders less frequently than non-vulnerable group

customers. While such research shows the PMUY policy may not be sufficient, they do not address our question of whether the PMUY policy was effective at encouraging these lower income households to increase LPG connection and use.

Note that because the PMUY policy specifically focuses on the decision to obtain an LPG connection and stove and not on the post-connection decision regarding how much LPG to use, we only expect to find policy effects on the connection/stove decision. We do not expect to find that the PMUY policy impacts the decision regarding how much LPG to purchase, a decision that was already being influenced by the universal subsidy for LPG, which was implemented in earlier years21.We thus examine the effect of the PMUY on the decision to use any amount of LPG (measured as number of large cylinders, small cylinder, or total kgs of LPG) an area where we expect to find an effect, and the effect of the PMUY on the overall increase in average LPG use, an area where we do not expect to find an effect.

Empirical Framework

We utilize the DiD method on repeated cross-sectional survey data from 2015 and 201825. This general causal approach has been used in other environmental policy research26. Our treatment group consists of households eligible for a free LPG connection per PMUY policy. The comparison group is composed of households slightly above the poverty line that are in a similar income bracket but were not PMUY eligible. Based on the 131 (1.75 USD) Rs cut off, we include families with incomes of up to 300 Rs (4 USD) per day in the comparison group but conducted sensitivity analyses using incomes up to 500 Rs (6.63 USD) and all observations (max 35 USD).

The DiD regression controls for age, gender, education, religion, caste, household size, and daily expenditure. To ensure comparable treatment and comparison groups, we also used propensity score matching38. We address exposure to the PMUY policy on the following outcomes: obtaining an LPG connection, number of large LPG cylinders used, number of small LPG cylinders used, kilograms of LPG used, home delivery of LPG, and whether the policy increased the Clean Cooking Tier Group. All sensitivity analysis and additional tables can be found in Supplemental Materials.

The Clean Cooking Tier Groups were defined by the CEEW as a measure of access and are described in the Data Collection and Variables section. All regression analyses were performed using STATA 16.1.

Results

Decision to Obtain a Connection or Refill

We begin the analysis by exploring the effect of PMUY eligibility on obtaining an LPG connection. Our analysis suggests that the PMUY policy causally results in eligible households being 3.3 percentage points more likely to obtain an LPG connection (Table 1, Panel A, Figure 1, Panel A). At expenditures of 500 Rs per day and all observations, the magnitude of the effect (Tables 6 and 8) increases to 4.2 percentage points and

4.5 respectively. Adding in the quadratic of age, decreases the effect to 3.28 percentage points (See Table 10).

TABLE 1. USE OF ANY AMOUNT OF LPG (BY WEIGHT OR CYLINDER SIZE)

	(1)	(2)	(3)
Panel A: VARIABLES	Any LPG Use (kg) (binary)	Any Large Cylinder Use (binary)	Any Small Cylinder Use (binary)
Post-Period	0.306***	0.302***	0.00454*
	(0.0142)	(0.0141)	(0.00235)
PMUY Eligible	-0.0546***	-0.0538***	-0.00356**
	(0.00963)	(0.00966)	(0.00157)
Policy Effect (Post-Period x PMUY Eligible)	0.0332**	0.0358**	0.00158
	(0.0163)	(0.0163)	(0.00281)
Constant	0.157***	0.156***	0.00587***
	(0.00880)	(0.00880)	(0.00123)
Observations	14,106	14,106	14,106
R-squared	0.122	0.120	0.001

Comparison group: 300Rs cut-off.

Cluster-robust standard errors in parentheses. Clustering is by village.

*** p<0.01, ** p<0.05, * p<0.1

Decision to Refill Large Cylinders. — Our analysis suggests that the PMUY policy causally results in eligible households being 3.6 percentage points more likely to obtain any large cylinder (Table 1, Panel A). This result is somewhat sensitive to the comparison group definition. At expenditures of 500 Rs per day and all observations, the magnitude of the effect (Tables 6 and 8) increases to 4.5 and 4.7 percentage points, respectively. Adding in the quadratic of age, decreases the effect to 3.5 percentage points (See Table 10).

Decision to Refill a Small Cylinder. — Our analysis suggests that eligibility for the policy does not have a statistically detectable effect on the decision to refill a small cylinder (See Table 1, Panel A). Sensitivity analysis did not change this result (see Tables 6, 8, and 10).

Overall Consumption of LPG in kgs, Large, or Small Cylinders

Consumption of LPG. — We found no detectable effect on LPG consumption in kilograms, large cylinder, or small cylinders (see Table 2). Sensitivity analysis did not change this result (see Tables 7, 9, and 11) Previous work has suggested that poorer households are more equipped to purchase smaller refills27–29 and therefore, LPG should be offered in different quantities. In India, large and small cylinders contain 14.2 kg and 5 kg of LPG, respectively. Although smaller quantities of LPG is often cited as a means to increase consumption as they are less expensive30,31, very few surveyed households reported purchasing small cylinders. These results suggest that PMUY is not affecting overall consumption of either size.

Note that Figure 1, which illustrates the raw data, shows that both the treatment and comparison groups are increasing their connections and consumption. Our findings show that those that those exposed to the PMUY have increased their LPG connections and consumption slightly more than the non-equivalent comparison group. This is especially important considering that the PMUY beneficiaries now are likely to have a loan to repay and have lower incomes than the non-equivalent control group. It is notable that the policy is not affecting consumption, yet the LPG consumption in both groups has increased dramatically in three years. This is often anecdotally attributed to the PMUY policy17; however, the causal models reveal that the policy is only having a slight effect on obtaining connections and no effect on consumption. Therefore, there must be other socioeconomic policies or simply India's rapid economic development driving LPG consumption.

TABLE 2. USE OF LPG (BY WEIGHT IN KG, LARGE CYLINDERS, AND SMALL CYLINDERS)

	(1)	(2)	(3)
Panel A: VARIABLES	LPG Use (kg) (continuous)	Large Cylinder (continuous)	Small Cylinders (continuous)
Post-Period	25.19***	1.751***	0.0670**
	(1.518)	(0.107)	(0.0268)
PMUY Eligible	-6.074***	-0.429***	0.00389
	(1.098)	(0.0773)	(0.0133)
Policy Effect (Post-Period x PMUY Eligible)	-0.476	-0.0174	-0.0458
	(1.715)	(0.121)	(0.0313)
Constant	16.15***	1.129***	0.0232***
	(1.015)	(0.0713)	(0.00532)
Observations	14,106	14,106	14,106
R-squared	0.071	0.071	0.001

Comparison group: 300Rs cut-off.

Cluster-robust standard errors in parentheses. Clustering is by village.

*** p<0.01, ** p<0.05, * p<0.1

Consumption of LPG if a connection was obtained. In contrast to our results above, these analyses suggest that, given an LPG connection is in place, the PMUY policy causally results in PMUY-eligible households using 7.37 kgs less than non-PMUY households (Table 3. Panel A). This is not a paradoxical finding, but merely implies that the great increase in the number of overall LPG connections across all groups (Figure 1, Panel A) is being accompanied by diminishing average use among users of LPG as new connections are added, and that this diminishing use is larger among households with the lowest incomes. This is to be expected.

As the income cutoff of the comparison group rose and then age squared was included, the measured effect increased to 7.58 kgs, 7.40 kgs, and 7.49 kgs respectively (Table 3).

TABLE 3. USE OF LPG (GIVEN AN LPG CONNECTION IN PLACE)

	(1)	(2)	(3)	(4)
Panel A: VARIABLES	LPG Use (kg) (continuous) 300Rs Cutoff	LPG Use (kg) (continuous) 500Rs Cutoff	LPG Use (kg) (continuous) All Observations	LPG Use (kg) (continuous) 300Rs Cutoff Quadratic Age Included
Post-Period	-12.34***	-11.56***	-11.74***	-12.33***
	(2.521)	(2.248)	(2.175)	(2.504)
PMUY Eligible	-2.147	-1.803	-2.507	-2.041
	(3.343)	(2.935)	(2.840)	(3.329)
Policy Effect (Post-Period x PMUY Eligible)	-7.371**	-7.584**	-7.396**	-7.486**
	(3.718)	(3.290)	(3.196)	(3.704)
Constant	100.6***	102.8***	103.9***	100.6***
	(2.258)	(2.068)	(1.991)	(2.243)
Observations	4,785	5,928	6,211	4,786
R-squared	0.025	0.022	0.023	0.025

Cluster-robust standard errors in parentheses. Clustering is by village.

*** p<0.01, ** p<0.05, * p<0.1

Tier Group and Home Delivery

Next, we investigate the relationship between benefiting from the PMUY policy and moving up a clean cooking tier group and opting for home delivery. We find no detectable effect of the PMUY policy on either of these dependent variables (see Tables 12 and 13 in the supplemental material).

Discussion

This study evaluated whether households in the comparison group which are slightly above the poverty line would go out and purchase the initial LPG connection (i.e. was the PMUY policy was necessary?). We asked if comparison group households were “waiting and watching” as proposed in Kar et al.’s work22. Our findings that the treatment (BPL) group was only 3.3 and 3.6 percentage points more likely to obtain any LPG (kg and large LPG cylinders, respectively), show that the comparison group is not waiting and watching but is obtaining LPG connections at only a slightly lower rate than the treatment group.

Our results suggest that the PMUY policy is an effective nudge for households to adopt LPG, but is not large enough to increase their consumption of clean fuel or their tier group. We found that PMUY beneficiaries consume 7.4 fewer kgs of LPG than the comparison group. Even against wealthier income groups, this is roughly 50% of a large cylinder of LPG a year. Typically, 10-12 large cylinders are required for annual exclusive use. Therefore, our analysis shows that PMUY consumers are two weeks of fuel behind their counterparts on the other side of the poverty line.

Finally, other studies have suggested that the decision and effort to obtain an LPG connection implied greater preparedness to consume LPG23. Despite bed net and improved cookstove studies that suggest otherwise 7, there is also a general notion that individuals are more likely to use and maintain a technology if they have paid for it. Our work suggests that the PMUY customers who have not paid for the connection only consume half a cylinder less than the paying customers. It should be noted that BPL households had to apply for the connection and therefore, did have to make a decision and put in effort. Sunk cost effects may play a role, but it is more likely that the income difference between the treatment and comparison group led to this cylinder difference.

Since the 2018 ACCESS survey was conducted, the PMUY policy has been expanded to 7 additional categories and as of 2020, it is for “all other poor households irrespective of Caste, Religion, Sects.” By 2020, India hopes to reach every single kitchen and PMUY has been hailed as the “Blue Flame of Hope.” People are taking advantage of the government policy and obtaining the LPG connection. From an average base of roughly 10.2% (Table 1, sum of coefficients for Constant + PMUY Eligible), the policy thus leads to a 3.3 percentage point change or a 32.3% change (3.3/10.2) in obtaining the connection for PMUY households. However, this is not translating into consumption of LPG at a rate similar to their counterparts. Consistent consumption of clean fuels is necessary to see the health benefits and the improvement of their tier group with respect to access to clean cooking20. Our results suggest that the policy is not broad enough and should be expanded to help BPL households refill. Numerous evaluations of PMUY have advocated for targeted subsidies6,22; however, this analysis suggests that the size of the subsidy and the particular decisions targeted are equally important. For every Indian household to have LPG by the end of 2020 is a

very ambitious and meaningful goal; however, it may be more worthwhile to increase the level of subsidy for poorer families to not only gain the connection but also consume LPG.

Conclusions And Implications

Our analysis shows that the policy is an effective nudge for poor households to obtain LPG but is not a large enough nudge to consume. Therefore, we suggest that there be further research into the level of subsidy that would increase LPG consumption for BPL households. A case study of two states in India argued that the capital cost subsidy leads to some dropouts because some households cannot afford the fuel costs despite the free connection, which results in dead investment32. Our analysis shows that the capital cost subsidy is beneficial but should be coupled with an increased subsidy for fuel use for BPL customers.

We advocate for a year-long randomized controlled trial that would give households differing levels of subsidy. India's CEEW suggested 308Rs (4.1 USD) for BPL households and Ecuador subsidizes 15kg of LPG for 3.6 USD (Range 1-5USD) with transportation costs)33. Trials could offer subsidies in this range in addition to the free connection in the treatment group and then the control would have only the current PMUY policy. A factorial design of the RCT could also lead to optimizing the level of subsidy for the largest LPG adoption. A longer-term study could evaluate how the age of connection affects consumption at this differing subsidy levels, as a the CEEW report suggested consumption increased with time25

The universal LPG refill subsidy is much more expensive for the Indian government at 4.7 billion USD compared to the PMUY policy at 0.84 billion34. Our work suggests that despite the added cost of expanding the PMUY policy to a larger subsidy, relatively speaking, this policy is not the most financially burdensome for the Indian government. Once an effective level of subsidy is found from the RCT research suggested above, the "Give it Up Campaign" could be expanded (even to households who received PMUY and feel that they did not necessarily need the connection for free) to meet these new financial demands on the government.

Our analysis concludes that the PMUY policy does not go far enough to increase consumption substantially or move BPL families up a tier group. In order to use the 0.84 billion USD effectively and achieve the health benefits of clean fuel use, we advocate for policy adjustment and future research particularly into the size of the refill subsidy for India's BPL households. Researchers should continue to pursue causal models to isolate and evaluate policies to ensure the provision of clean cooking fuel for the Indian poor.

Methods

Empirical Model

LPG Regressions. —The first three DiD regressions compare the effect of exposure to the PMUY policy for the treatment group relative to the comparison group with regard to obtaining an LPG connection (any kgs of LPG, any large cylinders of LPG, and any small cylinders LPG) and then overall LPG consumption (kgs of LPG, number of large cylinders, or number of small cylinders). The equation describing these regressions is as follows:

(1) $$y_i = \beta_0 + \beta_1 TRT_i + \beta_2 AFT_i + \beta_3 TRT_i * AFT_i + \beta_4 X + \varepsilon_i$$

where y_i is a binary variable for obtaining any LPG (kg, large cylinder, and small cylinders) and continuous variables of kg of LPG, number of large cylinders, and number of small cylinders, respectively. TRT is a dummy variable to indicate if the household was eligible for the PMUY policy, AFT is a dummy variable to indicate if this data point was before or after treatment, *X* is representative of the control variables, and ε is the error. These equations are estimated using an intent-to-treat linear regression DiD model with kernel propensity score matching on the common support using the STATA function DIFF35. We assume that both the parallel trends assumption and the common shocks assumption of DiD are satisfied. Since we do not have more than one period of data prior to PMUY implementation, we implement the standard approach to correct for any deviations from the parallel trends assumption: propensity score matching36. With respect to the common shocks assumption, we are unaware of simultaneously implemented policies that would only have affected either the treatment or comparison group.

The second regression allows us to determine if the household did take advantage of the policy (i.e. get a free connection), did this lead to an increased consumption of LPG as compared to the non-equivalent control.

(2) $$y_i = \beta_0 + \beta_1 TRT_i + \beta_2 AFT_i + \beta_3 TRT_i * AFT_i + \beta_4 X + + \varepsilon_i \; if \; y_2 > 0$$

Where y_i is the amount of LPG in kg the household purchased annually, TRT is a dummy variable to indicate if the household was eligible for the PMUY policy, AFT is a dummy variable to indicate if this data point was before or after treatment, *X* is representative of the control variables, and ε is the error.

Tier and Home Delivery Regressions. —The final two regressions compare the effect of exposure to the PMUY policy for the treatment group relative to the comparison group with regard to opting for homedelivery and moving up a tier group, and is defined as:

(3) $$y_i = \beta_0 + \beta_1 TRT_i + \beta_2 AFT_i + \beta_3 TRT_i * AFT_i + \beta_4 X + \varepsilon_i$$

Where y_i is binary dependent variable for home delivery and then moving up a tier group respectively, TRT is a dummy variable to indicate if the household was eligible for the PMUY policy, AFT is a dummy variable to indicate if this data point was before or after treatment, *X* is representative of the control variables, and ε is the error. These equations are estimated using DIFF as described above.

Data Collection and Variables

India's CEEW conducted the ACCESS survey in conjunction with the National University of Singapore in 2015, prior to the implementation of the PMUY policy, and then again in 2018, after the policy's implementation 5. Six states were surveyed: Bihar, Jhardkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal. Enumerators randomly sampled one district within each administrative division (except West Bengal where two were sampled because it was the largest administrative division). Within these administrative divisions, a district was chosen for the sampling with a probability proportional to population size. Within each district,

they selected 7 large villages (from a sample containing 50% of district population) and 7 small villages (from a sample containing 50% district population). In total, 8,568 responses were collected from 714 villages in 51 districts in 2015. In 2018, they expanded to three additional districts in Odisha to increase the sample size of that state, which added 504 observations 37.

We describe here our dependent, explanatory, and independent variables. The CEEW's questionnaire is available online25 (see Data Availability).

Dependent Variables. — For the LPG section, the dependent variables of interest are binary variables that indicate the decision to consume any amount of LPG, any amount of large cylinders, and any amount of small cylinders. Then, the continuous dependent variables indicate the amount of LPG (in kgs), the number of large cylinders of LPG, and the number of small cylinders of LPG. Finally, for equation 2, the dependent variable is LPG (in kgs) only if that value is greater than zero.

To address the issue of whether LPG is used in addition to other fuels, we also examine use as dependent variables through the following "tiers" of LPG use: exclusive LPG use, partial LPG use, and no LPG use. The CEEW defined these Tiers as a measure of access to clean cooking based on health and safety, availability, quality, affordability, and convenience. These tiers are based on self-responses. Households are classified as Tier 3 if they only use BLEN (Biogas, LPG, Ethanol, or Natural Gas), if they are satisfied with availability, if the quality of cooking is adequate, if cooking fuel is affordable, and if it is neither difficult nor time consuming. These classifications were self-reported directly from survey questions. Households are Tier 2 if they use a mix of traditional fuel and BLEN is used, if they are neutral to availability, if the quality of cooking is adequate, and if it is either difficult to use or time consuming. Households are Tier 1 if they use a mix of traditional fuel and BLEN is used, if they are unsatisfied to availability, if the quality of cooking is not adequate, and if it is both difficult to use or time consuming. Finally, Tier 0 households only use traditional fuels (firewood, dung cakes, or agricultural residues), if they are cooking less because of lack of availability, quality of cooking is not adequate, cooking fuel is not affordable, and cooking is both difficult to use and time consuming 5. Our dependent variable was a binary variable indicating if the household moved up at least one tier group.

The final dependent variable we used was home delivery. Home delivery increased from roughly 19% to 39% in 2019. It is unclear how PMUY customers are obtaining LPG (home delivery or procuring it themselves). Kar et al. found that the worst performing LPG provider (India has 3 LPG companies) provided home delivery to all villages, while the other two do not. Therefore, we include this as a dependent variable to investigate if the policy leads to connection, but not to convenient access.

Explanatory Variable. — Our explanatory variable is eligibility for the PMUY policy. Starting in 2016, the PMUY policy offered free connections to all households that had the ration card distinguishing them as BPL. Previous work found that PMUY LPG consumers purchased fewer refills than general customers 22. These households are at a lower income than typical general customers who could afford the high upfront cost of the initial connection.

Independent Variables. — We included the following independent variables in our models based on existing literature on LPG adoption. The descriptive statistic table (Table 4) outlines the summaries of the variables; however, here we discuss the hypothesized direction of effect on the dependent variables. Our model included socio-economic factors that have been studied in relation to adoption of LPG.

State: We included binary indicators of each state surveyed (Bihar, Jhardkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal (base case). This controls for differing levels of improvement in clean cooking access 5. Jhardkhand and Odisha had the highest percentage increase in clean cooking access index 5.

Age: We included the age of the respondent, which was either the head of household or the primary cook as a continuous variable. Studies have found that the age of the head of household is negatively associated with clean fuel adoption 38.

Religion: We included binary indicators of three religion categories (Hindu, Muslim, and Other Religion). Studies such as 38–40; found that adhering to the major religion, Hindu, in India was positively correlated with LPG use.

Education: Previous studies have found that level of education has been positively correlated with clean cooking use 12,14,15,41. The survey grouped categories of education into: no education (the base category), up to the 5th Standard, up to the 10th standard, up to the 12th standard, and then graduate education.

Household Daily Expenditure: We used daily expenditure as a proxy for economic status because although BPL status was calculated from a number of socio-economic variables, the PMUY policy was not offered to anyone with an income over 131 Rs per day 42. Household expenditure has been shown to be positively correlated with use of clean cooking fuels 41.

Caste: The survey collected data on each household's social stratification, or caste within Indian society. We included binary indicators of four caste categories: Scheduled Caste, Scheduled Tribe, Other Backward Class, and General. Households within Scheduled Caste and Scheduled Tribe have been negatively correlated with clean cooking adoption 43,44.

Household Size: There is an unclear association between household size and clean fuel adoption. Previous studies have found negative 14,15 correlation between household size and clean fuel adoption 16,43.

Female Decision Maker: Our model controlled for households with females as the only decision maker or as an equal joint decision maker. In an analysis of the 2015 ACCESS data, female decision-making families had higher odds of owning LPG 17. Female led households have been shown to be positively correlated with clean cooking fuel 18,45 and male heads of households are less likely to adopt clean cooking fuel. However, other studies found that female led households were less likely to adopt clean cooking fuel due to the social and economic disadvantages of women 46. Typically, women are the primary cook and are more likely to allocate household funds for expenditures that ease their work 47.

Descriptive Statistics

Table 4 provides information on household-level demographic characteristics from the baseline year of 2015 that were mentioned as control, key interest, and outcome variables. The majority of respondents were from Uttar Pradesh at 35%. In 2018, households from Odisha increased from 6% to 11% which is expected based on the addition of 3 districts and 504 observations from the state in the second round. The average age of the respondent was 42 years and then 43 years respectively in 2015 and 2018. Eighty five percent of respondents were male in 2015, but only 72% in 2018. Education levels were similar across the 2015 and 2018 panels with roughly a third having no education and a third having up to the 5th standard. The majority of respondents are Hindu at 87% and 88%, respectively. For caste, 48% of respondents were classified as "Other Backwards Class." Household size shrunk slightly from 6.7 to 6.2 between 2015 and 2018. Average daily expenditure also increased from 177 to 208 Rs per day (2.33 to 2.74 USD per day), but the standard deviation on both years implies a large spread among respondents. For context, no one over 131 Rs a day (1.75 USD per day) was considered below the poverty line 42. In 2018, there was a slight increase of female decision makers (31%) from 19% in 2015, but households are still largely led by male decision makers. Average price for all the alternative fuels were relatively stable, except for agricultural residues, which decreased from 4.5 Rs to 1.8 Rs. The average age of LPG connection decreased from 5 years to 3.5 years, likely due to the addition of all the new LPG users from the PMUY policy. Home delivery also doubled in this time period (from 18% to 39%). Additionally, both large and small annual LPG refills declined from 7.5 and 0.2 in 2015 to 6.2 to 0.1 in 2018 respectively. This is also likely due to the addition of poorer families into the LPG market. Use of LPG increased from 22% to 55% from 2015 to 2018. We also evaluated the demographic characteristics of the treatment and control groups, which are outlined in Table 5.

TABLE 4—DESCRIPTIVE STATISTICS

	Mean	Sample Size	Frequency	Proportion	Minimum	Maximum
Panel A. Independent Variables 2015 State						
Bihar		8563	1511	0.18		
Jhardkhand		8563	840	0.10		
Madhya Pradesh		8563	1680	0.20		
Odisha		8563	504	0.06		
Uttar Pradesh		8563	3023	0.35		
West Bengal		8563	1005	0.12		
Age	42 (14)	8563			18	95
Gender (Male) Education		8563	7306	0.85		
Up to 5th Standard		8563	2648	0.31		
Up to 10th Standard		8563	1713	0.20		
Up to 12th Standard		8563	817	0.10		
Graduate Education		8563	649	0.08		
Religion Hindu		8563	7463	0.87		
Muslim		8563	1051	0.12		
Other Caste		8563	49	0.01		
Scheduled Caste		8563	1569	0.18		
Scheduled Tribe		8563	860	0.10		
Other Backwards Class		8563	4082	0.48		
General		8563	2052	0.24		
Household Size	6.7 (3.5)	8563			1	46
Daily Expenditure	177 (130)	8563			17	2000
Female Decision Maker		7558	1457	0.19		

Panel B: Dependent Variables 2015				
Home Delivery LPG	1851	341	0.18	

# of Large LPG Refills per Year	1.58(3.5)	8563			0	32
Binary Large Cylinder		8563	1790	0.209		
# of Small LPG Refills per Year	0.038(.623)	8563			0	25
Binary Small Cylinder		8563	60	0.007		
Kg of LPG	22.7 (49.9)	8563			0	454.4
Binary LPG		8563	1806	0.211		
Increase in Tier Group	.	8185	6978	0.853		

TABLE 5—DEMOGRAPHIC STATISTICS OF TREATMENT AND CONTROL

	Mean	Sample Size	Frequency	Proportion	Minimum	Maximum
Panel A. Comparison Descriptive Statistics						
State						
Bihar		5940	895	0.151		
Jhardkhand		5940	615	0.104		
Madhya Pradesh		5940	1106	0.186		
Odisha		5940	706	0.119		
Uttar Pradesh		5940	706	0.119		
West Bengal		5940	702	0.118		
						98
Age	43 (14.7)	5940			18	
Gender (Male)		5940	4233	0.713		
Education						
Up to 5th Standard		5940	1841	0.310		
Up to 10th Standard		5940	861	0.145		
Up to 12th Standard		5940	478	0.080		
Graduate Education		5940	349	0.059		
Religion						
Hindu	5940		5266	0.887		
Muslim	5940		648	0.109		
Other	5940		26	0.004		
Scheduled Caste	5940		1108	0.187		
Scheduled Tribe	5940		742	0.125		
Other Backwards Class	5940		4082	0.687		
General	5940		1334	0.225		

Household Size	5.7 (2.7)	5940			1	27
Daily Expenditure	160 (66.9)	5940			0	300
Female Decision Maker		5940	1948	0.328		

Panel B: Treatment Descriptive Statistics	Mean	Sample Size	Frequency	Proportion	Minimum	Maximum
State						
Bihar		1559	246	0.158		
Jhardkhand		1559	147	0.094		
Madhya Pradesh		1559	306	0.196		
Odisha		1559	245	0.157		
Uttar Pradesh		1559	453	0.291		
West Bengal		1559	162	0.104		
Age	42.6 (14.2)	1559			18	86
Gender (Male)		1559	1058	0.679		
Education						
Up to 5th Standard		1559	523	0.335		
Up to 10th Standard		1559	185	0.119		
Up to 12th Standard		1559	97	0.062		
Graduate Education		1559	58	0.037		
Religion						
Hindu		1559	1378	0.884		
Muslim		1559	173	0.111		
Other		1559	8	0.005		
Caste						
Scheduled Caste		1559	433	0.278		
Scheduled Tribe		1559	184	0.118		
Other Backwards Class		1559	670	0.430		
General		1559	272	0.174		
Household Size	5.8 (2.5)	1559			1	27
Daily Expenditure	160 (62.8)	1559			6.67	300
Female Decision Maker		1559	477	0.306		

Internal and External Validity

The largest limitation in our study is the lack of an exact control group. Instead, we use a non-equivalent comparison group. Our comparison group is households slightly above the poverty line that are in a similar income bracket to those below the line but were not offered the PMUY policy.

We reasonably assume that the parallel trends assumption holds. However, this assumption is not empirically testable due to earlier relevant data for the treatment and comparison groups being unavailable. However, Table 2 outlines the demographic statistics between the treatment and comparison groups. The only notable difference is the slightly higher proportion of Other Backward Class in the comparison (67% in control compared to 43% in the treatment) and the slightly higher proportion of treatment households from Uttar Pradesh (11.9% in control compared to 29% in treatment). Given the overwhelming similarity despite these two aspects, it is not unreasonable to assume that parallel trends hold. However, for robust analysis, we have incorporated kernel propensity score matching.

In addition, we also reasonably assume that the common shocks assumption holds. We are unaware of any simultaneous policy intervention or other event that may violate the common shocks assumption.

Reverse causation is not likely to be present in the variables of interest. Eligibility for the policy is based on a number of socio- economic characteristics that establish the household of BPL. Potential omitted variable bias may be present which would bias the parameter positively or negatively depending on its correlation with our dependent variables. However, we are confident in our engagement with the literature of factors affecting clean fuel use. Measurement bias is also likely to be present in the variables. The estimated parameter will therefore be biased towards zero and to the extent the mis-measured variable is correlated with other independent variables, the estimated parameters of those correlated variables will be biased in unknown directions.

Despite the complex survey design, we do not use probability weights in the analysis as they are not available at the household level. Solon, Haider, and Woodridge suggest weighting is only an issue when estimating causal effects in three situations: (1) correcting for endogenous sampling, (2) correcting for heteroscedasticity, and (3) identifying average partial effects in situations where effects are likely to be heterogenous by subgroup48. None of these issues applies in the current study, since sampling was not endogenous, we are able to correct for heteroscedasticity apart from weighting, and we are interested in the local average treatment effect, not in identifying heterogenous effects by subgroup. Thus, not being able to weight at the family level is of no practical significance.

This paper is externally generalizable to the Indian population as of 2018. The PMUY policy further expanded to groups beyond BPL status after this 2018 survey was taken. This could also provide valuable lessons for the evolution of the PMUY policy in India and serve as an example for other countries in the developing world (Ghana, Indonesia, South Africa, etc.) pursuing national LPG policies. However, these results should not be taken without the context of India's socio-economic environment in these particular states, the current LPG infrastructure, and other national policies that benefit BPL households.

Declarations

Data availability

The data and the CEEW's questionnaire that supports the findings of this study are available at https://doi.org/10.7910/DVN/AHFINM.

Code availability

The Stata.do files that produce the regression results are available through OPEN ICPSR at [will insert doi.org/ for publication]. To create the binary dependent variable of increasing a tier group, the data was formatted in R, exported to an .xlsx file, and imported into STATA for analysis. The R notebook is also available through OPEN ICPSR at [will insert doi.org/ for publication].

Acknowledgements

This paper is dedicated to the last author, Dr. Kirk Smith, who passed away on June 15, 2020 before this work's final publication. Dr. Smith's life's work played a vital role in creating the field of indoor air quality, cooking fuels, and health impacts. His research had a specific focus on India, and he was a vocal advocate of the PMUY policy. We honor his enormous intellectual contribution to this paper, this field, and the lives ~and lungs~ of the most vulnerable.

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Note Regarding Tables 6-13

Tables 6-13 can be found in the Supplementary Files.

Figures

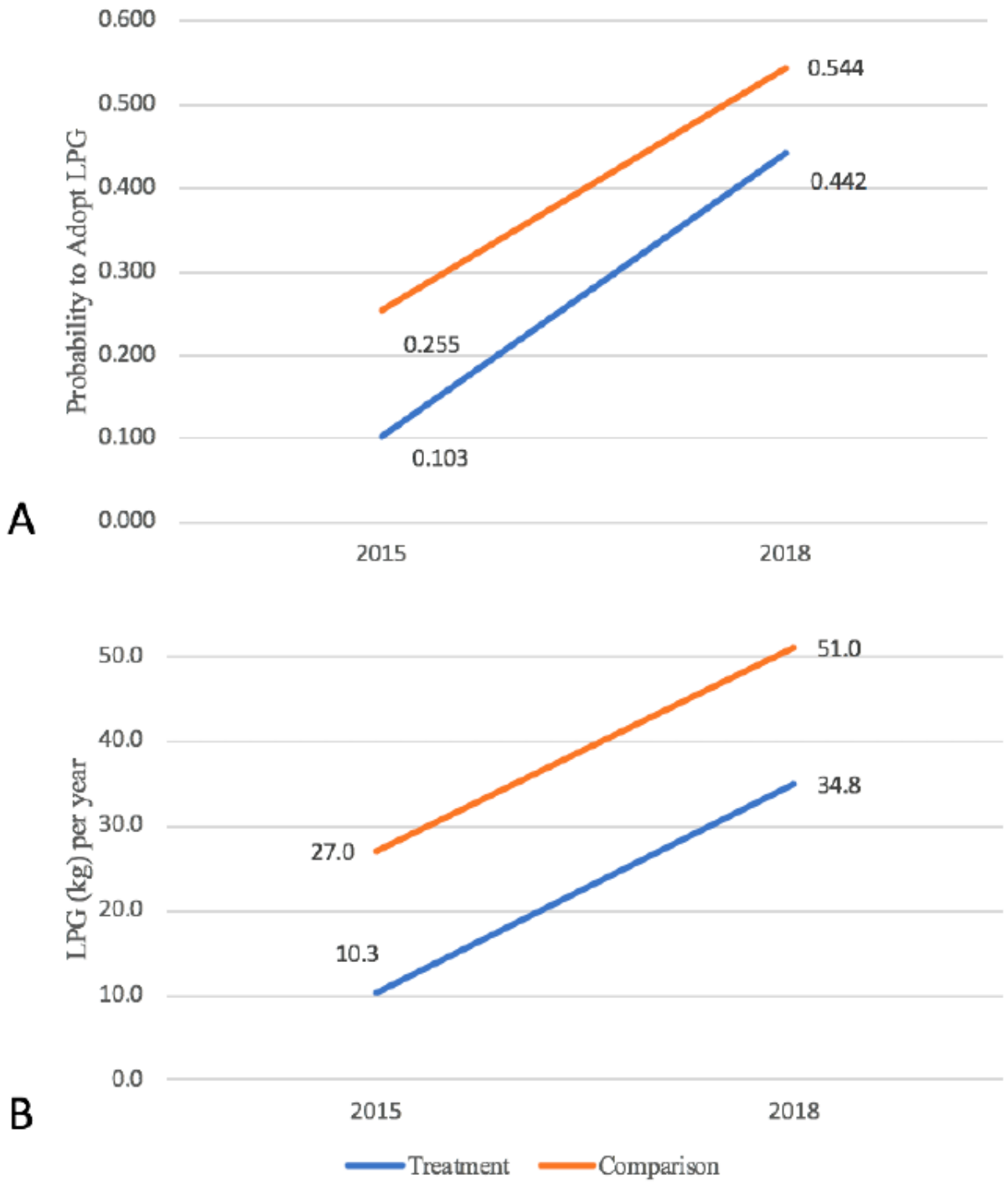

Figure 1

PANEL A DEPICTS THE DIFFERENCE IN LPG CONNECTIONS (BINARY) FOR TREATMENT AND CONTROL GROUPS. PANEL B DEPICTS THE DIFFERENCE IN LPG CONSUMPTION IN KILOGRAMS FOR TREATMENT AND CONTROL GROUPS.

Supplementary Files

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- 81220SupplementalMaterial.pdf