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Article

Incentivizing Elimination of Biomass Cooking Fuels with a Reversible Commitment and a Spare LPG Cylinder

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ABSTRACT: In India, approximately 480,000 deaths occur annually from exposure to household air pollution from the use of biomass cooking fuels. Displacing biomass use with clean fuels, such as liquefied petroleum gas (LPG), can help reduce these deaths. Through government initiatives, most Indian households now own an LPG stove and one LPG cylinder. Many households, however, continue to regularly use indoor biomass-fueled mud stoves (chulhas) alongside LPG. Focusing on this population in rural Maharashtra, India, this study (N = 186) tests the effects of conditioning a sales offer for a spare LPG cylinder on a reversible commitment requiring initially disabling indoor chulhas. We find that almost all relevant households (>98%) were willing to accept this commitment. Indoor chulha use decreased by 90% (95% CI = 80% to 101%) when the sales offer included the commitment, compared to a 23% decrease (95% CI = 14% to 32%) without it. For both treatment groups, we find that 80% purchased the spare cylinder at the end of the study.

1. INTRODUCTION

In India, it is estimated that 480,000 deaths and 16 million lost DALYs (disability-adjusted life years) occur per year due to exposure to household air pollution (HAP) from use of biomass as a cooking fuel.[1] The Indian government is addressing this problem through distribution of liquefied petroleum gas (LPG) two-burner stoves and initial fuel cylinders at a reduced price to poorer households through the Pradhan Mantri Ujjwala Yojana (Ujjwala or PMUY) program.[2] PMUY largely solves the problem of access to clean fuels. Yet, due to the nonlinear exposure-response relationship between HAP and health outcomes, most health benefits may not be realized until households nearly completely abandon biomass use.[3,4] Unfortunately, there is a significant portion of households that use both LPG and indoor biomass-fueled mud stoves (i.e., chulhas) on a regular basis.[5,6] Jain et al.[7] found that approximately 50% of rural households across six large and poor states still use both LPG and biomass for cooking. Given that continued use of old stoves is pervasive around the globe,[8] it is likely that at least a significant portion of this generalizes throughout India. If so, then tens of millions of rural households in India use both stoves regularly.[9] Despite some households expressing dissatisfaction with their chulha,[7] as long as the indoor chulha is still present and functional, it is likely that many households will continue to use it.

Within this population, the primary suggested reasons for using both LPG and biomass for cooking include: (1) supply issues—there is a gap in time between when a household's LPG cylinder becomes empty and when they receive a refill, (2) information problems—respondents were unaware of the harms of biomass use,[10−12] (3) cultural practices and behavioral barriers—households have the habit, routine, and preference for using a chulha,[7,13] and (4) cost.[5,14]

The supply issue—of lacking constant access to LPG—results in a return to biomass use for cooking while the household waits for a refill. Middle- and upper-income households have solved this problem by owning a second, or spare, cylinder. That is, when the first cylinder runs out, they have a second cylinder to use while they wait for the refill of their empty cylinder. To acquire a second cylinder, households must pay approximately $20 (1450 INR) as a security deposit.[15] Some households that can afford to use LPG may find this upfront cost an important barrier to owning a second cylinder.

Furthermore, despite the increase in LPG use in India, there is low awareness of the negative health effects of burning biomass for cooking.[7] Understanding how burning biomass harms health may decrease biomass use and increase safe cooking (i.e., LPG).

Behavior change issues are well known in the public health and technology adoption literature, as well as in development economics.[16] Commitments have been used as one strategy to encourage behavior change.[16] In this literature, past research

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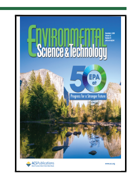

has focused on the effects of both hard commitments, those that have economic penalties or rewards, and soft commitments, those that have largely psychological consequences.[17] Hard commitments have found large effects among a variety of outcomes including worker performance, savings, and exercise.[18−20] Soft commitments have also found significant effects in areas such as savings and educational progress where participants make nonbinding commitments for future behaviors (e.g., allocating a portion of future earnings for retirement savings or staying on track for graduation).[21,22] One study compared a hard and soft commitment savings account and found that the soft commitment savings account caused larger increases in savings for educational supplies.[23]

Our study targets a population of rural users who use LPG and also continue to use an indoor chulha. To identify households who us\e LPG on a fairly consistent basis, we required participants to have purchased at least three LPG refills in the past 9 months (which is consistent with about 3/4 the usage we would expect from a household of median size that exclusively uses LPG).

Our basic intervention addresses supply and information problems through a sales offer of a free trial (followed by installment payments) of a second, or spare, cylinder coupled with health educational messages on the harms of using biomass for cooking with chulhas. The combination of a free trial and installment payments is used because a previous study[24] found that it increased fuel-efficient biomass cookstove sales by a factor of ten. We also evaluated the effects of conditioning our sales offer on a reversible commitment—requiring the initial disabling of the indoor chulha by either dismantling it or filling it with mud or pebbles (with the option of moving it outdoors). Our reversible intervention is largely a soft commitment, with large elements of moral suasion. At the same time, there is a modest time requirement to re-enable an indoor chulha (as in a hard commitment): less than an hour if the chulha was filled with pebbles, or a half day if it was dismantled. Also, households still received the sales offer if they rebuilt the chulha during the study as long as they initially disabled it. Given the ease of reversing the commitment, the effectiveness of the strategy is uncertain.

2. MATERIALS AND METHODS

2.1. Study Site and Participant Selection. Our study was conducted in seven rural villages in a subset of the Junnar block of the Pune district in the state of Maharashtra. These seven villages are within a 15 kilometer radius and include a population of approximately 6000 individuals living in 1200 households. This area has similar literacy rates to the rest of Maharashtra and has a substantial Scheduled Tribe population.[25] The study was conducted by KEMHRC Pune, which has worked extensively in the area for decades conducting health-related research. This location was chosen due to KEMHRC's experience with the study area and the high percentage of households that use biomass for cooking. According to the two LPG distributors in the area, approximately 70% of households (i.e., 840 households) owned only one LPG cylinder at the time of the study and hence were potentially eligible for participation (other households either owned two LPG cylinders or did not own any LPG).

Working with Accredited Social Health Activists (ASHAs), local women who act as village health workers, we identified all households in a subset of the study area (371 in total) that own one LPG cylinder, have purchased at least three refills in the past 9 months, and own an indoor chulha. We then approached a random subset of 189 of the eligible households, explained the study design (while verifying that they satisfy the eligibility criteria), and invited them to participate in the study. Of the 189 households, three did not agree to participate (before treatment status was known) because they did not want to be assigned to the study arm that is required to disable the indoor chulha in order to receive the sales offer. After obtaining written informed consent, each household was randomly assigned to one of three study arms (while stratifying at the village level), described below. At the end of the study, each household was given 500 INR as compensation for participation.

2.2. Study Design. All households that agreed to participate in the study (N = 186) were randomly assigned to one of the following three intervention arms:

1. Treatment 1 (N = 62): receive a six week free trial of a second LPG cylinder (i.e., what in India is called "a second LPG connection"), with the right to return it during the free trial followed by four equal installment payments collected every 2−3 weeks over 10 additional weeks. This offer was strictly an interest free loan for the cost of the cylinder deposit, which was 1450 INR. This offer also included a detailed set of health educational messages to explain the harms of using biomass for cooking;
2. Treatment 2 (N = 62): same offer as Treatment 1, but with a requirement to disable or move their indoor chulha in order to receive the sales offer;
3. Control group (N = 62): no special sales offer or health messages but provides access to purchase a second cylinder, as is commonly available in the area.

The study included a 4 week baseline period in addition to the 16 week follow-up endline period. During the baseline period, a baseline survey was conducted to gather household characteristics and participant demographics. At the beginning of the endline period, the field team assisted treatment group households in submitting documents to the distributor to obtain a second cylinder as a loan. Additionally, the research study covered the cost of the deposit. After the first 6 weeks of endline, installment payments began with households paying approximately one-fourth of the cost (i.e., 400 INR) of the cylinder deposit every 2−3 weeks. Households were visited every 2 −4 weeks to monitor stove usage and to deliver health messages (although the control group did not receive health messages). Due to a misunderstanding with a portion of the field team, some of the originally recruited households did not satisfy the eligibility criteria of owning an indoor chulha. This resulted in approximately half of the households beginning the study in December 2018 and the other half beginning in March 2019. The study concluded in July 2019.

Two sets of health messages were used in the study. The first is a flipchart (see Figure S1) that focuses on the harms to health of using biomass with related images. The second is a video that focuses on different scenarios in which households may be inclined to use biomass (e.g., during festivals, when they run out of LPG, or taste preferences) and then suggests potential solutions.[26]

2.3. Outcomes. As the primary goal of our intervention was to eliminate indoor use of biomass fuel, our primary outcome is indoor chulha use. LPG use is also measured as a secondary outcome. For chulha and LPG stove use, outcomes include time spent using each stove per day, cooking events per day on each stove, and a binary indicator for whether or not each stove was used each day. We also measure uptake rates of the sales offer for each treatment group and rates of purchasing the second cylinder at the end of the study.

2.4. Measurements. Thermocouple-based stove use monitors (SUMs) manufactured by Wellzion (model number SSN-61, Xiamen, Fujian, China) were used on both chulhas and LPG stoves to measure stove usage in all households in the study. Due to budget constraints and prioritizing chulha use measurement, we were only able to monitor LPG use on the burner primarily used in most households. Although we do not account for the effects of the presence of SUMs on behavior as is done in some other studies,[27] we assume these effects are equal across each study group and thus they do not bias the comparison of study groups. In treatment group 2 (in which indoor chulhas were disabled), we placed SUMs on all filled in chulhas to monitor if households used them. In cases where households completely destroyed the indoor chulha, we monitored if they rebuilt the chulha at each household visit (without any associated penalty). If they did rebuild the indoor chulha, we placed SUMs on it. For households that completely destroy their indoor chulha, indoor chulha use is assigned zero for all relevant days and then weighted proportional to rates for households in which we have valid SUMs data.

SUMs record temperature readings every 10 min and can stay powered for more than a month at a time. In order to analyze stove use, we first need to convert SUM data—in the form of temperature time series data—into metrics of stove use. For this analysis, we used a slightly modified version of the FireFinder algorithm, part of the open-source SUMSarizer R package maintained by Geocene.[28] Firefinder builds upon previous SUM detection algorithms to determine approximate time spent cooking on each stove (in minutes), number of cooking events per day (count), and days of any stove use (binary).[29−31] Note, interpreting time spent cooking between stove types should be done with caution as there is a much slower decay in heat on a chulha compared to that of an LPG stove.

2.5. Specification. The following ordinary least squares regression is used to determine the effects of each treatment on traditional biomass and LPG stove use:

$$Y_{it} = \boldsymbol{\alpha}_{\mathbf{i}} + \mathrm{b}_3\mathrm{post}_t + \beta_1\, T_{1i}{*}\mathrm{post}_t + \beta_2\, T_{2i}{*}\mathrm{post}_t + \varepsilon_{it}.$$

where Y_{it} is the stove use outcome (i.e., minutes per day, cooking events per day, or binary indicator for any use per day) for household i at time t (t = 0 if pretreatment, t = 1 if post-treatment), $\boldsymbol{\alpha}_{\mathbf{i}}$ are household fixed effects (which are necessary due to the autocorrelative nature of daily measurements from the same household), T_{1i} is a dummy variable equal to one if in treatment group 1, T_{2i} is a dummy equal to one if in treatment group 2, post_t is a dummy variable equal to one if occurring after treatment, and ε_{it} is the error term. The coefficients of interest are β_1 and β_2 which, due to the exogeneity of treatment status, are the causal effect of being in treatment groups 1 and 2, respectively, post-treatment. As the data may be correlated at levels of stratification, which is at the village level, standard errors are clustered at the village level.

For the binary outcomes of accepting the sales offer and purchasing a second cylinder we will run a two-sample t test for equality of proportions.

3. RESULTS

3.1. Summary Statistics and Randomization Tests. Table 1 shows baseline summary statistics of households that participated in the study. The average household had 4.6 people and owned one indoor chulha. Most (64%) of households were below the poverty line. The average respondent was 40 years old and had nine years of education. On average, households used the indoor chulha for 53 min per day (averaging over all days) and used it on 44% of days. They also averaged 101 min of LPG stove use per day and used LPG on 77% of days. Approximately 24% of SUMs data was missing across all study arms and days. Details of SUMs missingness are in the Supporting Information, which is available online.

Table 1. Baseline Summary statistics[a]

statistic	mean	st. dev.	min	max	N
household size	4.63	1.73	2.00	12.00	185
respondent is primary cook (share)	0.86	0.35	0.00	1.00	185
respondent age	39.68	12.45	19.00	72.00	185
female respondent (share)	1.00	0.00	1.00	1.00	185
years of education	8.93	2.99	0.00	15.00	185
below poverty line (share)	0.64	0.48	0.00	1.00	185
electricity access (share)	0.98	0.13	0.00	1.00	185
number of mud stoves owned	1.04	0.19	1.00	2.00	185
received LPG through PMUY (share)	0.06	0.24	0.00	1.00	185
years owned LPG	7.01	5.43	0.17	24.00	185
days used mud stove (share)	0.44	0.36	0.00	1.00	171
days used LPG stove (share)	0.77	0.29	0.00	1.00	182
no. of daily mud stove uses	0.79	0.78	0.00	4.23	171
no. of daily LPG stove uses	2.55	1.36	0.00	5.88	182
mud stove daily minutes used	52.69	61.05	0.00	276.21	171
LPG stove daily minutes used	101.12	72.44	0.00	519.38	182

[a]Note: To be included in the study, households were required to own at least one mud stove and have an LPG connection with one LPG cylinder. This data includes baseline stove usage measured 4 weeks preintervention. Days used mud/LPG stove (share) refers to the share of days using the respective stove during the 4 week baseline period. PMUY refers to a government program in India that distributes LPG connections to below poverty line families.

Table 2 shows balance tests for covariates comparing the control group, Treatment 1, and Treatment 2. The 16 covariates were not jointly statistically significant in predicting the treatment arm (χ^2 = 31, P = 0.42). Of the 48 possible comparisons, four were statistically significant. Treatment 1 had almost 1 year less of education than the control group (8.37 vs 9.28). Treatment 2 had slightly fewer households with electricity access than the others (95% vs 100%), used LPG on 10% more days than Treatment 1 (83% vs 73%), and used LPG for about 25 more minutes (i.e., 25% more) per day than either Treatment 1 or the control group (119 vs 94 vs 89). Fortunately, the core baseline covariates of chulha use (daily, number of cooking events per day, and minutes per day) were balanced across the study groups. Also, note that approximately 30% of monitored days of SUMs data is missing due to overheating, malfunctioning, and a shortage of SUMs.

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Table 2. Baseline Summary Statistics and Balance of Covariates (Treatment Groups Separated)[a]

0	covariate	C mean	T1 mean	T2 mean	p-value C T1	p-value C T2	p-value T1 T2	N
1	household size	4.46	4.71	4.71	0.42	0.40	1	185
2	respondent is primary cook (share)	0.85	0.87	0.85	0.77	0.97	0.80	185
3	respondent age	39.08	40.15	39.81	0.64	0.74	0.88	185
4	female respondent (share)	1	1	1				185
5	years of education	9.28	8.37	9.15	0.09	0.79	0.18	185
6	below poverty line (share)	0.72	0.58	0.63	0.11	0.28	0.59	185
7	electricity access (share)	1	1	0.95		0.08	0.08	185
8	number of mud stoves owned	1.02	1.05	1.05	0.32	0.32	1	185
9	received LPG through PMUY (share)	0.03	0.10	0.05	0.15	0.66	0.30	185
10	years owned LPG	6.86	7.17	7.00	0.76	0.89	0.85	185
11	days used mud stove (share)	0.48	0.41	0.42	0.34	0.40	0.90	171
12	days used LPG stove (share)	0.77	0.73	0.83	0.45	0.25	0.06	182
13	no. of daily mud stove uses	0.84	0.73	0.79	0.44	0.71	0.68	171
14	no. of daily LPG stove uses	2.41	2.48	2.74	0.77	0.17	0.31	182
15	mud stove daily minutes used	51.17	52.90	54.03	0.88	0.79	0.93	171
16	LPG stove daily minutes used	89.43	94.25	119.42	0.66	0.03	0.09	182

[a]Note: C, T1, and T2 refer to control, Treatment 1, and Treatment 2 groups, respectively. Treatment 1 received a free trial of a second cylinder. Treatment 2 received the free trial contingent on disabling the indoor mud stove. PMUY refers to a government program in India that distributes LPG connections to below poverty line families. A chi-squared test for joint significance of a multinomial logit where all X variables predict T1, T2, or the control group is insignificant (χ^2 = 31, p-value = 0.42).

However, the missing data is spread evenly across each study group arm.

3.2. Initial and final sales offer uptake. Before being randomly assigned to a study group, households consented to participate in the study. Of 189 households approached, three (less than 2%) did not consent to participate. After randomization, all who consented accepted their initial sales offer. The three who declined consent are included in the analysis as one in each study group. Thus, 98% of Treatment 1 and 2 each accepted the relevant initial sales offer (Table 3). Postrandomization, all Treatment 2 households complied with their sales offer and initially disabled the indoor chulha. This implies that households did not perceive disabling their indoor chulha as a costly action compared to the benefit of receiving a free trial of a second cylinder. Of these participants, 53% destroyed their indoor chulha and 47% filled it with mud or pebbles. All 53% who destroyed their indoor chulha did not rebuild it throughout the study. Of the 47% who filled their indoor chulha with mud or pebbles, 39% subsequently used it at some point during the study. No Treatment 1 or control group household destroyed or filled their indoor chulha throughout the study. At the end of the study, roughly 80% of Treatment 1 and 2 purchased the second cylinder by paying the deposit cost (i.e., 1450 INR) after the free trial while 20% returned it. No participants from the control group purchased a second cylinder during the study.

Table 3. Initial and final offer uptake[a]

	initial offer uptake		purchased second cylinder		sample size
	%	*p*-value	%	*p*-value	*N*
control	NA		0%		63
treatment 1	98%		82%		63
treatment 2	98%		81%		63
control vs treatment 1		NA		0.000***	
control vs treatment 2		NA		0.000***	
treatment 1 vs treatment 2		1.000		1.000	

[a]Note: *p < 0.1; **p < 0.05; and ***p < 0.01. Households consented to participate in the study before being randomly assigned to a group. All who agreed to participate in the study accepted the sales offer they were assigned. They were offered 500 INR (USD $7.30) for participation. Three households did not consent to participate, so we count those declining households as one in each group. This accounts for the 98% in initial offer uptake. The control group received no special sales offer. Treatment 1 received a free trial of a second LPG cylinder. Treatment 2 received a free trial contingent on disabling the indoor mud stove: 53% destroyed it and 47% filled it with mud or pebbles. All 53% did not rebuild their mud stove throughout the study.

3.3. Effects of Sales Offer on Biomass and LPG Use. Next, we analyze our primary outcome, the causal impact of each sales offer on biomass use (Table 4). In the preintervention period, households on average use the indoor chulha for 53 min per day (our most precise measure), for 0.8 cooking events per day, and on 44% of days. After receiving the

Table 4. Regressions of Daily Indoor Mud Stove Use and Treatment Group[a]

all columns include household fixed effects			
	daily minutes used (1)	no. of daily uses (2)	any daily use (3)
endline	−6.07***	−0.26***	−0.15***
treatment1*endline	−11.92***	−0.02	−0.003 (0.02)
treatment2*endline	−47.57***	−0.48***	−0.27*** (0.02)
baseline mean	52.69	0.79	0.44
observations	16,343	16,342	16,343
no. of household FEs R^2	166 0.33	166 0.37	166 0.44

[a]Note: *p < 0.1; **p < 0.05; and ***p < 0.01. Standard errors are in parentheses. Treatment 1 received a free trial of a second LPG cylinder. Treatment 2 received the free trial contingent on disabling the indoor mud stove. The study includes approx. 4 weeks of pre-endline data and 16 weeks of endline data. There is some missing data due to monitors overheating or malfunctioning. Col (3)'s outcome variable refers to an indicator if any use occurred that day with the stove.

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sales offers, based on daily minutes used, Treatment 1 decreases indoor chulha use by 23% (−12 min, 95% CI = −17 to −7.5, $p < 0.01$) while Treatment 2 decreases indoor chulha use by 90% (−48 min, 95% CI = −53 to −42, $p < 0.01$). The difference between Treatment 1 and Treatment 2 is highly statistically significant ($p = 0.002$). Note that in addition to the causal impact we find of each sales offer on biomass use, we also find an overall decrease in chulha use during the endline period (see Table 4 row 1).

Thus, the requirement to initially disable the indoor chulha—prior to our sales offer for the second cylinder—leads to an additional 67% decrease in minutes of indoor chulha use. In regard to the number of cooking events per day and percent days of any use, we find no change for Treatment 1 households while we find a 61% decrease in both measures for Treatment 2 households (−0.48 cooking events per day, 95% CI = −0.54 to −0.42, $p < 0.01$; −27% of days, 95% CI = −30% to −24%, $p < 0.01$).

Lastly, we analyze the causal impact of each sales offer on LPG use (Table 5). In the preintervention period, households on average use the LPG stove for 100 min per day (our most precise measure), for 2.6 cooking events per day, and on 77% of days. After receiving the sales offers, we find a small, but statistically significant decrease in LPG use for Treatment 2 households of approximately 10% ($p < 0.01$).

These results of LPG use are puzzling as one would expect to see an increase in LPG use to compensate for the decrease found in chulha use. Potential reasons for this lack of reduction include: (1) households may have shifted indoor chulha use to outdoor chulha use (which we were unable to observe); (2) households may have increased their intensity of using LPG by using both burners on the LPG stove (due to budget constraints, we were only able to monitor LPG use on the burner primarily used in most households); or (3) seasonality may have caused a decrease in overall cooking needs (e.g., some may work as day laborers during the endline period and receive meals from their places of work).

Table 5. Regressions of Daily LPG Stove Use and Treatment Group[a]

all columns include household fixed effects			
	daily minutes used (1)	no. of daily uses (2)	any daily use (3)
endline	1.51	−0.08	−0.04***
treatment1*endline	−5.33*	−0.10	0.01 (0.02)
treatment2*endline	−12.61***	−0.22***	−0.05*** (0.02)
baseline mean	101.12	2.55	0.77
observations	18,032	18,031	18,032
no. of household FEs R^2	179 0.36	179 0.36	179 0.33

[a]Note: *p < 0.1; **p < 0.05; and ***p < 0.01. Standard errors are in parentheses. Treatment 1 received a free trial of a second LPG cylinder. Treatment 2 received the free trial contingent on disabling the indoor mud stove. The study includes approx. 4 weeks of pre-endline data and 16 weeks of endline data. There is some missing data due to monitors overheating or malfunctioning. Col (3)'s outcome variable refers to an indicator if any use occurred that day with the stove.

4. DISCUSSION

Household air pollution from using biomass as a cooking fuel is a significant contributor to ill-health in India, approaching five hundred thousand deaths per year.[1] The PMUY program helped enable most households to access a safe cooking fuel (LPG). However, many households regularly use indoor biomass along with LPG.

Our study finds a potential solution for many of these households—a sales offer for a spare LPG cylinder coupled with the reversible commitment to initially disable the indoor chulha. We find high demand for this sales offer (98%). We also find a huge effect, a 90% reduction, in indoor biomass stove use. Additionally, we find that the reversible commitment is vital to this very large reduction; without this commitment, the sales offer results in just a 23% reduction in indoor biomass use. These results imply a high willingness of households to agree to a reversible commitment (i.e., disabling the indoor chulha) that leads to a large decrease of 67% in indoor chulha use. Future research is needed to determine how well the effects last outside of our observed 4 month period and to measure their impacts are on household air pollution and health.

Past research has focused on government policies that add a bit of inconvenience to inhibit use of certain goods. These studies have found positive, but somewhat mixed, results. One study finds that the removal of slot machines from neighborhood bars in Alberta, Canada reduced personal bankruptcies filed by close neighbors.[32] Another study finds that consumers in relevant US states increase their liquor consumption in response to extended Sunday hours at restaurants and bars, but not in response to extended hours at liquor stores.[33]

A key distinction of this paper from past research on government policies is that in our case participants voluntarily remove the good (i.e., the indoor chulha) instead of the government imposing barriers. On the one hand, because the commitment here is voluntary, there may be a larger effect of inconvenience than when the government imposes the inconvenience. On the other hand, given the ability to easily re-enable the indoor chulha, households may choose to reuse it shortly after initially disabling it.

The current research builds upon previous findings in which we explored related issues in a nonrandomized sample of a specific population—pregnant women.[34] This study loaned 200 households in rural Maharashtra, India a second LPG cylinder for the duration of the study to ensure they have constant access to LPG. The study asked, but did not require, households to disable their indoor chulha during the study. Surprisingly, 65% disabled it. At the end of the study, households were asked to either purchase the second cylinder or return it: 85% chose to purchase it. These previous findings provide suggestive evidence that a reversible commitment to disable the indoor chulha in exchange for a second LPG cylinder loan may lead to significant effects on decreasing indoor chulha use and uptake of a second LPG cylinder. Our current work reinforces these findings with a more rigorous study design in a general population.

If the effects we note are persistent, this intervention may be one of the most cost-effective means to save lives among tens of millions of Indian households. Jain et al. (2018) found that about half of rural households across six large and poor states still use both LPG and biomass for cooking.[7] Even if only a

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portion of that share generalizes, then tens of millions of rural households in India use both stoves regularly.[9] While some homes rely on smoky stoves for heat or other purposes, it is possible our intervention could reduce household air pollution in many of these homes.

We next discuss cost-effectiveness. When the Ujjwala program began, household air pollution in India caused nearly half a million deaths per year and 16 million lost DALYs.[1] Given that roughly 180 million homes burnt biomass, each home lost an average of roughly 0.09 DALY per year. While the Ujjwala program shifted most of these homes partially to LPG, the majority of health harms remain if biomass cooking remains common.[3,4] Suppose half the harm from smoke remains after Ujjwala, and conservatively assume our intervention removes 10−50% of the remaining harm (due to continued use of biomass cooking outdoors, refusal of our offer, and rebuilding indoor chulhas). With these assumptions, our intervention averts 0.004−0.02 lost DALY per household per year. The one-time cost of this intervention is less than USD $10 per household (for transportation of LPG cylinders, hiring ASHAs to deliver health messages, ensuring households initially disable the indoor chulha, and institutional costs). If we assume the intervention speeds the transition to safe cooking by 4 years, then this intervention averts a lost DALY for $125−$625. This cost-effectiveness is comparable to such cost-effective treatments as oral rehydration solution, yellow fever, meningitis and Japanese encephalitis vaccination, or household water treatment in low-income nations.[35] A conservative approach values a DALY at GDP per capita, or roughly $2800 per year.[36] This valuation implies our $10 LPG intervention creates health benefits worth $48−$240 (= $12−$60 per year for 4 years, ignoring discounting). Thus, even with very conservative estimates, the benefits of this intervention far exceed the costs.

We have not tested this intervention widely in a national program, but doing so seems worth considering. More broadly, as noted above, households around the globe routinely use both old and new stoves.[9] Thus, any intervention that promotes a safe cooking method with a subsidy or free trial should consider requiring a commitment to disable the traditional stove. Even more generally, many environmental and health interventions related to energy efficiency, safe water, and other technologies face the dual challenge of introducing a new product and of limiting the use of old ones. It may be that a related offer with a reversible commitment can assist in disseminating safe environmental behaviors more broadly.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.0c01818.

> Details on health messaging and stove use monitoring (SUM) data completeness, which includes the English version of the health message used in this study, and details on stove use monitoring data completeness include expected versus sampled days of SUM data and missingness by stove type, study arm, and month.(PDF)

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Notes

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