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Bodie Cabiyo[1], **Isha Ray**[1] and **David I Levine**[2,3]

[1] Energy and Resources Group, University of California, Berkeley, CA 94720, United States of America
[2] Haas School of Business, University of California, Berkeley, CA 94720, United States of America
[3] Author to whom any correspondence should be addressed.

E-mail: levine@berkeley.edu

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Abstract

From 2016 to 2019, the Indian *Pradhan Mantri Ujjwala Yojana* (PMUY) distributed over 80 million liquefied petroleum gas (LPG) stoves, making it the largest clean cooking program ever. Yet, evidence shows widespread continued use of the traditional *chulha*, negating the potential health benefits of LPG. Here we use semi-structured interviews with female and male adults to understand the drivers of LPG usage in Mulbagal, Karnataka, the site of a proto-PMUY program. We find that respondents perceive the main value of LPG to be saving time, rather than better health. We also find that norms of low female power in the household, in addition to costs, delay saving for and ordering LPG cylinder refills. Namely, female cooks controlled neither the money nor the mobile phone required to order a timely refill. These factors together contribute to the 'refill gap': the period of non-use between refilling cylinders, which may range from days to even months. Our work reveals how gender norms can amplify affordability challenges in low-income households.

1. Background

Of the 2.8 billion people who eat meals cooked on smoky, open biomass fires every day, up to 700 million live in India [1]. Until recent efforts by the Government of India, this number remained nearly constant over the last four decades and represented the near-complete failure to address a critical health and environmental problem [2, 3]. Smoke from cooking fires has consistently been the leading risk factor for disease in India, mostly affecting women and children [4]. Household biomass combustion also contributes to climate change, and may be the second leading contributor to near-term warming [5, 6]. Furthermore, in some regions, women may have to spend 4–10 h weekly in fuel collection and preparation, at the expense of other activities [7].

In 2016, India launched the largest global effort to spur adoption of liquefied petroleum gas (LPG) for cooking [8]. The *Pradhan Mantri Ujjwala Yojana* (PMUY, informally known as *Ujjwala*) distributed over 80 million new LPG stoves across India from 2016 to 2019. Under PMUY, consumers pay for the stove and the cylinder deposit over several gas refills to reduce the customer's upfront cost. Gas refills cost a flat subsidized rate of Rs. 450 (US$6 in 2017) per cylinder, but the customer pays the full market rate upfront and receives the subsidy later as a bank deposit. The intent of PMUY is to encourage rapid transition away from the incumbent technology—the mud *chulha*—at an unprecedented scale. As a result, for the first time in history, 95% of Indian households have access to LPG hardware and subsidized gas [8].

At the same time, a large literature documents 'stove stacking'—simultaneous use of different cooking devices—in India and throughout the world. Stove stacking is common because new stoves are imperfect substitutes for traditional ones [9, 10]. Stoves may have end uses which extend beyond cooking (e.g. for spirituality, gathering, space heating, bathing), and may be suitable for widely differing cooking tasks, depending on socio-cultural preferences [10]. Furthermore, low incomes and poor fuel availability inhibit the consistent use of modern fuels like LPG [9, 10]. Access to multiple fuels, by contrast, allows households to adjust to economic changes and fuel availability with relative ease.

Research has shown that most of the harm to health remains with even moderate *chulha* usage [11]. Thus, a nearly complete shift to cooking on LPG is necessary to realize the potential health benefits

Figure 1. Map of the study area. The blue pin indicates the Mulbagal district, where the interviews were conducted. In the inset map of India, the state of Karnataka is highlighted in blue, and the zoomed map area is indicated with a red box.

of PMUY. Initial studies suggest that low-income PMUY households use much less LPG than non-PMUY LPG households [8, 12, 13]. In some states, up to twice as many PMUY beneficiaries report using biomass *chulhas* for cooking compared to long-time LPG users [13].

Journalistic accounts [14, 15] and academic evaluations [16–20] have identified affordability as a key barrier to timely refilling of LPG cylinders. In contrast, some evaluations have found that LPG use among PMUY beneficiaries does not depend on economic status [8] and adoption is higher where women have more decision-making power [21]. Other reasons for the persistent use of traditional stoves after clean fuel adoption include space heating, the taste of food, and access to free biomass [8, 18]. Academics have called for a concerted effort to promote the health benefits of LPG in order to increase consistent use [2, 16, 22].

In this paper, we investigate perceptions and use of LPG 2 years after the 'Smokeless Villages' program was implemented near Bangalore, Karnataka in 2015 (figure 1). This program preceded and was functionally equivalent to PMUY; thus, it offers a preview of potential outcomes under PMUY. In our study villages, LPG use had become normal, the average household had modestly higher income than the average rural household in the state, and LPG delivery was reliable (Methods). While researchers typically evaluate affordability for the household as a whole, we argue that households may not function as a single unit. Deconstructing the costs and benefits of LPG stoves from the perspectives of individual actors within the household reveals a more granular understanding of why stove-stacking occurs. Specifically, we find that women's low control over money and the household mobile phone are major contributors to the 'refill gap'.

2. Research design and methods

2.1. Study area

Our study area is the Mulbagal subdistrict (*taluk*), Karnataka, located roughly 2 h by car east of Bangalore (figure 1). In 2015, under the Smokeless Villages program, distributors offered all households without an LPG stove a new cylinder and stove with an interest-free loan. Users repaid the loan incrementally with each refill, similar to PMUY. Many of the Smokeless Villages were selected for ease of access to an existing LPG distributor. At the time of study (late 2017), most households had paid off their loan. Project participants had been using LPG for 2 years, while pre-Smokeless Village LPG users had been using it for up to 6 years. The program acted as a prototype for the larger 2016 launch of PMUY.

Urban proximity grants Mulbagal access to markets, increased options for economic mobility (e.g. through education and labor), and direct and indirect social influence. Additionally, Mulbagal is close to the city of Kolar, which is a marketplace for the distribution of wholesale agricultural goods. Mulbagal farmers grow crops like rice, fruits and vegetables, sugar cane, and eucalyptus. They also produce specialty and high-value goods, including silk. Our study respondents typically reported earning between Rs. 200 and 500 ($3–8) per day, varying mostly because of access to land or working capital. In contrast, the day-labor rates for rural Karnataka, according to the 2013 Census, varied from Rs. 150 to 200 ($2.50–3).

2.2. Sample design and data collection

We conducted 50 semi-structured interviews in the late summer and fall of 2017. We selected five villages based on the factorial combination of two binary criteria: predominant household wealth status (poor or middle class) and distance from major highways (from 5 to 10 km or greater than 10 km from a major highway). We determined wealth status by observation according to the criteria used in Karnataka; that is, a poor (below-poverty line, or BPL) household should not own more than three hectares of land, possess a four-wheeled vehicle, or have any member employed by the government or a tax-paying institution.

All sampled villages were 'Smokeless Villages', which had been offered heavily discounted LPG stoves with no upfront costs for BPL households without an LPG stove. Within each village, the field team chose ten respondents (one per household) as follows:

(a) Seventy percent of the participants had received an LPG stove through the Smokeless Villages program. The remaining 30% were legacy customers from before the program.
(b) Our target was to have 20% of households be female-headed, although some villages did not

have enough such households to meet this criterion.

(c) Half the households were poor, as defined by BPL criteria.

(d) Households were sampled to be representative of caste and religion in each village, based on local knowledge of the villages.

(e) Participants were selected based on their status in the household as either the primary cook (80%) or the primary earning member (20%). In nearly all cases, our interviewees were not in the presence of other senior family members.

We found that, by the end of these 50 interviews, our data collection began to reach saturation. Further interviews were no longer yielding substantively new information. The interviews were conducted by a field team trained in qualitative interview methods, fluent in the local languages, and familiar with the ethnographic context. Their skills ensured that they not only understood the words spoken but could interpret the significance of and interactions between verbal and non-verbal expressions [23]. The interviews focused on the interviewee's experience with LPG and the household's cooking patterns. Interviewers followed up, where appropriate, with clarifying and probing questions. The field team transcribed, translated, and annotated the interviews in the weeks immediately following the interviews. Translation from the local language is a natural limitation of this work. Multiple authors were present for several of the interviews, and we are confident in the interview and contextual expertise of our field team. Still, qualitative research is best conducted by a speaker of the local language. Our research protocol was approved for ethical practices by UC Berkeley's Office for the Protection of Human Subjects (Protocol#2016-08-9086).

We analyzed interview data in three steps. First, after transcription and translation, we coded interviews for emergent themes. Codes were grouped into families as their relationships became apparent; examples of code families include 'ease of cooking', 'saving for refills', and 'health'. Second, after the first round of coding we re-analyzed all interviews to ensure consistency. Finally, the data were further analyzed using the online qualitative data analysis software Dedoose for code co-occurrence, code frequency by descriptor, and code frequency by participant, among others [24]. This analysis allowed us to understand the frequency and importance of codes amongst individuals and groups.

In addition to these household interviews, we conducted supplemental interviews with five LPG distributors and several Indian Oil Company (IOCL) officials. IOCL, a partially government-owned company, ran the Smokeless Villages project. These key informants discussed the motivation and evolution of the Smokeless Village program, the delivery challenges facing distributors, and refill rates for customers. These interviews were used to interpret responses in our core dataset by providing additional context with respect to the history and distribution of LPG in the region. In addition to the semi-structured interviews, during site visits in 2016, 2017, and 2018 the U.S.-based research team (with members of the local research team) met with small groups of villagers and informally discussed issues that overlapped with the semi-structured interviews. These discussions were not used in formal analysis but aided in the construction of the interview questions and the interpretation of results. The findings from these discussions were consistent with findings from the semi-structured interviews.

3. Results

3.1. The value of time

Saving time was the most-mentioned benefit of LPG, although this benefit took many different forms. The benefits of time saving fell into four emergent categories: speed, flexibility, time for leisure, and time for work. Non-time-related benefits, such as taste preferences, were less emphasized as reasons for using a particular stove, even if they were mentioned frequently across respondents (figure 2). No respondents mentioned the health benefits associated with LPG (figure 2), consistent with previous studies [13].

3.2. Speed and flexibility

Speed in cooking was a ubiquitous theme in these households where most meals were cooked fresh every day. Respondents extolled the fast-cooking benefits of LPG in the morning when children or workers left the home early. Without LPG, the main cook would have to start cooking early in the morning—sometimes 3 h before serving breakfast and packing lunch:

> While cooking on the chulha my wife had to wake up at 5.30 am in the morning to start cooking and food would be ready only by 9.00 am. The children had to go to school without breakfast and I also was often late for work and being scolded by my employer. Now, I have 3 school-going children who leave home at 7.30 am and the LPG has made it easy to cook. My wife wakes up at 6.00 am and even then, children have breakfast and then go to school. We like it [LPG] because it saves time.

Furthermore, this multi-hour process excludes the time required to collect fuelwood and scrub sooty pots, a process that cooks frequently described as 'drudgery'. For respondents with school-going children, the long preparation time without LPG often resulted in either skipping meals or sending children

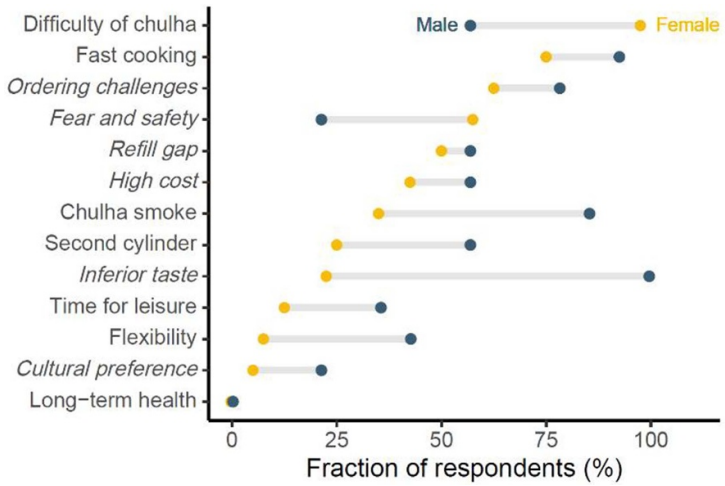

Figure 2. Frequency of selected codes by gender of respondent. Italicized codes represent factors that limit the continuous use of LPG. Conversely, non-italics represent factors that support continuous use. Interviews were coded for emergent themes in multiple rounds. Values represent the fraction of female ($n = 40$) and male ($n = 10$) interviews that were marked at least once for a given code. Some codes, like Inferior taste, were frequently mentioned but not emphasized as an important reason for using LPG/the *chulha*.

off late; fast cooking was the major driver of LPG usage in these households. Even respondents without children observed this benefit amongst neighbors or relatives who did have children.

Many respondents also described how LPG made it possible to cook quickly without planning, and that it served them well during 'urgency' or 'emergencies'. In rural India, the culturally important task of preparing tea, coffee, or a hot snack for an unexpected guest poses a significant challenge if the only cooking option is a *chulha*. Preparing a single cup of *chai* could require up to a half-hour if the stove was not already warm. In contrast, on an LPG stove the same cup of *chai* takes minutes. Stated simply: '*We can serve coffee or tea to the guests who visit our home. It is not possible to cook quickly on the chulha in times of emergencies.*'

3.3. The value of saved time

Improved livelihoods, by using saved time for income generation, are often cited as a core benefit of clean stoves [3, 18]. Of our sample of 50, about half mentioned more time for work as a benefit of the LPG, but only four referenced wage-earning work. Most respondents specified that time saved would be used for other housework. Very few women in our sample engaged in wage-earning work. The four who did mention LPG freeing up time for income generation owned productive assets such as livestock or a small shop. One male respondent said that his wife had more free hours in the day now that she used LPG, but then explained that the family was poor because he was the only earning member. He never mentioned the possibility that his wife might work for pay in her newly found free time.

Besides household work, women described the use of saved time to relax, or to bathe and change at the end of the day: '*[…] time can be saved that can be used for getting fresh after coming from the field.*' Other respondents talked about how the new free time could be used for playing with children, relaxing, sleeping, or watching TV. These activities do not translate saved time to increased income, but they do suggest significant derived value associated with LPG usage.

3.4. Refilling empty cylinders

Our interviews revealed that, though cooks used LPG consistently while it was available, the refilling process presented a substantial barrier to sustained use. We disaggregate the refilling process into four phases: running out of gas, acquisition of funds, ordering a refill, and waiting for delivery. Delays at any stage would often require cooking on an alternative stove (in our sample, almost always the *chulha*).

The first phase of refilling is the recognition that the cylinder in use is depleted or nearly depleted. Most frequently, cooks in our sample would simply wait for the LPG to run out completely, rather than try to predict running out. This delayed recognition set cooks up for an interval of multiple days, or more, when they would have to use an alternative stove.

The second phase, acquiring funds for refilling, was a major barrier in the study villages. In India, the out-of-pocket price of an LPG refill fluctuates with the market price of gas. A few days or weeks after purchase, a subsidy arrives in the bank account of the LPG account holder (under PMUY, usually the cook; here, it was varied). The subsidy fluctuates with the market price, so the post-subsidy price is stable at Rs. 450 ($6 in 2017). However, customers must bear the short-term brunt of market price fluctuations. In the study villages, the initial cost of a refill was equivalent to more than 2 d wages. Respondents reported the upfront price as a meaningful barrier: '*Recently*

the price went up to 800 rupees (US $11) and now it has gone down to 600 rupees (US $8). […] we feel it is difficult to pay the money.' As a result, most respondents used some form of saving or took out a small, informal loan from a neighbor or relative (a 'hand loan') to pay for a refill.

Respondents generally stated that they either 'save some from work' or do not save for the cylinder refills. The latter was much more common, and one male respondent expressed it this way: '*If we don't have money, then we'll wait until the money is adjusted to order the cylinder.*' How respondents decided to 'adjust' money was unclear from our interviews. In almost all cases, the male primary earner made the decision to save or borrow funds and purchase the LPG refill. Most women did not have their own cash, consistent with findings in state- and nation-wide surveys. For example, amongst adult women in rural Karnataka surveyed for the 2015–16 National Family Health Survey, only 20% agreed she 'has money that [she] alone can decide how to use [25].'

Despite generally terse responses to questions of money, nearly every respondent noted that heating bath water on the LPG (instead of on an outdoor *chulha*) was far too expensive. Some said that the LPG stove was always used for breakfast, which was prepared under time pressure, but not necessarily for other meals and not during low-work days: '*Whenever we have work load we use LPG, otherwise, we use the chulha for cooking.*' These observations imply that, even when respondents did not spontaneously mention the cost of LPG, all of them were aware that it was expensive.

The third phase of refilling was placing an order. Households could place their order for a refill in person at the distributor, but that process would require a costly trip. The most common approach was to order the cylinder using a mobile phone. Many of our female respondents, who were also the main cooks, did not own a working mobile phone or did not know how to order a refill. Instead, they relied on husbands, brothers, and neighbors to order. This power asymmetry was sometimes stated clearly, but only when it involved a party outside the marital household: '*[Husband]: Actually, I do not know [how to order]—my brother does it, we order through the phone. [Wife interjects]: His brother delays ordering by about 4–5 d each time. We should be ordering even before the LPG is consumed, but that does not happen.*' In most cases, the technology, and by extension the power, required to place a refill order rarely rested in the hands of the primary cook.

Overall, the person ordering a refill by mobile phone was usually male, while the primary cook was almost invariably female. One woman's words exemplify the gender imbalances around ordering: '*The cost of cylinder is paid by my father and brother—I do not know the cost. My father does the ordering through his friend, sometimes…my brother also makes orders for refilling.*' The woman has no role in the decision to order a new cylinder: she neither knows how much a refill costs nor has the autonomy to order it herself. Her autonomy in the refill process ends with pointing out the need for a refill.

The 'delivery boy', a gas agency employee who delivers full cylinders and accepts cash, is the final actor in the refill process. Most respondents in our sample described delivery as 'easy', 'timely', and 'reliable'. However, men in one of the villages did have complaints: '*The delivery boy is charging 30 rupees for delivery ($0.50, roughly one to two hour's wages), which he should not. But the alternative is taking the cylinder to town for refilling. The time and money required to fill it ourselves would be much higher.*' In the study area, the LPG distributor would typically deliver a refill within 1 week of a household ordering it. National regulations stipulate that distributors deliver refills within 48 h of an order. The distributors we interviewed, however, stated that they sought to make deliveries twice per week; they preferred to reduce costs by making multiple deliveries at once to a single village.

3.5. The refill gap

In nearly all cases, respondents reported a gap between when a cylinder became empty and when it was refilled. The stated gap was usually from 3 to 10 d. However, several interviews revealed that this was an optimistic range: it could be much longer, even months in some cases. Respondents sometimes reported only the refill gap imposed by delivery (a few days), but, when pressed, would admit that the actual gap was longer. Such cases imply a barrier in one of the preceding steps: namely, not 'adjusting' the money quickly or delayed ordering.

The mechanisms for managing this gap fell into two categories: using an alternative fuel or using a backup LPG cylinder. In our sample, the most common use of a *chulha* was to 'manage refilling shortfalls [gaps]'. Respondents valued the presence of the *chulha* in the kitchen even if they did not use it regularly because it served them when the LPG ran out. They perceived the *chulha* as a reliable cooking device. Conversely, LPG was a less reliable fuel that periodically went out of service.

A second strategy was to use a second LPG cylinder while the primary cylinder was pending refilling. Ownership of a second cylinder is prevalent in wealthy urban areas but is less common in the study area. Though only about 15% of respondents in our sample owned a second cylinder, some respondents would informally share second cylinders amongst neighbors and family. Typically, the borrower would borrow a full cylinder and return their own cylinder when it was refilled. As a result, those who were socially well-connected could rely on a nearby second cylinder during their refill gap. A full second cylinder creates a buffer of about two months

to refill the primary cylinder. These two months give the primary cook a chance to arrange for the two prerequisites to ordering that she may not control: cellphone access and the necessary funds. Some interviewees, however, seemed to hint that second cylinder ownership represented an increase in the autonomy of the primary cook:

> We are a seven-member family so will continue to use both LPG and the traditional chulha. I do not want to go for the second cylinder because the present arrangement is good according to me… But if there is a lot of pressure on me to [buy] the second cylinder then I don't know. Let's see how it goes. (Male, primary earner)

4. Discussion and conclusion

Decades of research on and promotion of improved cookstoves have shown that cleaner-burning stoves are rarely used exclusively [2, 26]. Thus, merely introducing a new stove fails to provide the intended health benefits [9]. PMUY seeks to shift cooking practice through widespread access to LPG hardware. Despite this access, evaluations have repeatedly shown inconsistent demand for LPG refills and continued use of the mud *chulha* [8, 20, 27]. Almost all evaluations of PMUY have argued that the main barrier to consistent LPG use is affordability [8, 16–20]. However, our qualitative study shows that affordability is only a partial answer, and it is partial in a way that limits our understanding of household energy transitions broadly.

In our study, the most common use of the traditional *chulha* was during the gap between cylinder refills, which could range from days to even months. This gap may be the best unit of analysis to understand inconsistent LPG adoption in India. Many respondents spoke as if the refill gap were unavoidable. In reality, women's low levels of autonomy drove the refill gap, in addition to the cost of the refill. Almost no women controlled the funds to pay for a refill or the mobile phone to order one. They all relied on a male family member for both money and ordering.

Most research on the household adoption of clean energy assumes a unitary household, in which 'the' household makes decisions about energy and affordability [9, 10, 28, 29]. This approach contrasts with the multi-adult, or collective, model, in which individuals have different priorities and negotiate spending decisions [30]. We find the collective model to be more useful for understanding LPG use and refilling in our setting. In our study, women typically had low bargaining power regarding both money and technology. These two factors converged to extend the refill gap and, thus, to reduce the use of LPG.

The relatively low autonomy of women also revealed itself in how respondents spoke of the convenience of LPG. Women respondents appreciated the time savings and reduced drudgery that LPG made possible. They almost never used their time savings to generate income (see [3, 18]). Male respondents valued cooking speed because they and their children got fresh meals on time. Nearly all the cooks in our sample were women, but respondents saw the dominant value of LPG in terms of benefits to the cook's husband, children, and guests. In a similar vein, electricity use in rural India has been shown to benefit women less than other family members [31]. Notably, no one mentioned the long-term health of the cook herself—the key benefit of LPG identified by researchers [2, 11].

In a few households, access to a second LPG cylinder buffered these factors and eliminated the refill gap. The present work informed the design of two quantitative studies in rural Maharashtra, both of which found that a second cylinder loan program successfully reduced the refill gap and *chulha* usage [22, 32]. A second strategy underway (as of 2018) in India is to sell LPG in smaller cylinders (5 kg vs. 14.2 kg) to enable households to buy fuel in lower-cost units [33, 34]. Both these strategies could encourage continuous LPG use by making second cylinders more accessible and affordable.

New policies like these could also affect the relevance of our results. However, despite the rapidly changing policy landscape around PMUY, many of the outcomes we observed in this proto-PMUY program are socio-cultural in nature. These change slowly, so our observations and explanations likely remain relevant to LPG use patterns under PMUY. While the length of the refill gap will change over time, the underlying drivers identified here may persist for some time.

Our case study was confined to one site, so we cannot say to what extent our findings are generalizable. The study villages were somewhat better off than the average village in the state (and the state is richer than average), the use of LPG was no longer novel, and LPG delivery was relatively reliable. Even in these encouraging circumstances, stove stacking was prevalent and the cost of LPG was a concern. However, we find that affordability alone is a limited explanation for inconsistent LPG use.

In our study setting, low affordability of LPG was exacerbated by the reality that female cooks controlled neither the money nor the technology required to order a timely refill. Thus, 'affordability' is a gender-laden concept as opposed to a household-level concept, which is how it is overwhelmingly treated in the energy literature. The value of saved time is also a gender-laden concept, with low valuations given to women's time or unpaid labor (see also [30]). Understanding the refill gap, and household-level energy transitions more broadly,

thus necessitates a granular account of 'the' household that goes well beyond its usual portrayal as a unitary actor.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Author contributions

B C and D L designed the project. B C conducted the analysis. All authors analyzed results and co-wrote the paper.

Conflict of interest

The authors declare no competing interests

ORCID iD

Bodie Cabiyo https://orcid.org/0000-0003-4321-7253

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