Impact of clean cooking fuel adoption on women's welfare in India: the mediating role of women's autonomy

Sonia Akter¹ · Chitra Pratap¹

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Abstract

While the health and environmental benefits of adopting clean cooking fuel are widely documented in the literature, the immediate and direct benefit—women's time-saving for fuel collection/preparation and cooking—has received little or no attention. Using panel data from 6 energy-poor Indian states involving about 9000 households, we test whether liquefied petroleum gas (LPG) adoption enhances women's welfare by reducing fuel collection/preparation and cooking time and improving the overall cooking experience through a convenient and efficient cooking arrangement. We also explore the association between women's participation in decision-making and the likelihood of LPG adoption and refill. The findings reveal that LPG adopters save time by collecting firewood less frequently and preparing fewer pieces of dung cake than non-adopters. Additionally, LPG adopters save 15 min of cooking time per day than non-adopters. Finally, LPG adoption makes the cooking experience more convenient and simpler than traditional cooking fuel. Women's sole or joint decision-making power is positively correlated with LPG adoption and refilling LPG cylinders. These findings imply that the true social benefit of clean cooking fuel adoption is much greater than the welfare gain accrued through greenhouse gas mitigation and health benefits from cleaner air. However, these positive externalities are less likely to be internalized in fuel choice decisions in households where women do not participate in important household decision-making.

Keywords Clean cooking fuel · Unpaid work burden · Gender equity · Energy poverty · Modern cookstove

Introduction

Traditional cooking fuels, such as firewood, crop residues, or cow dung, and traditional cookstoves emit carbon dioxide (CO₂), respirable particles, carbon monoxide (CO), nitrogen oxides (NO; N₂O), and sulfur (S) that cause air pollution (Bruce et al. 2015; Cameron et al. 2016; Kandpal et al. 1995; Smith and Sagar 2014). Air pollution is harmful to the environment (Singh et al. 2017) and has adverse health effects for children and adults, such as respiratory illnesses (Duflo et al. 2008) and even infant mortality (Imelda 2020). Owing to these concerns, fuel conversion programs that seek

to convert traditional cooking fuels to cleaner fuels, such as liquefied petroleum gas (LPG), have been launched in many developing countries.

In India, the adoption of LPG as a cooking fuel has increased since 2015 (Kapsalyamova et al. 2021). Programs that promote LPG usage are brought forth by the central government on the premise of the environmental and long-term health benefits of clean cooking fuel adoption (Goldemberg et al. 2018). Research shows that nearly 7.2 million tons of fuelwood was replaced by increased LPG access in the country, which reduced the pressure on forests and achieved modest climate benefits (Singh et al. 2017). Imelda (2020) finds that a nationwide fuel-switching program in Indonesia that sought to replace a traditional fuel (paraffin) with LPG has reduced infant mortality and incidence of low birth weight.

In addition to switching from traditional to clean fuel, LPG adoption involves changing the cookstove from traditional to modern to accommodate the change in cooking fuel. Modern cookstoves make cooking more efficient and convenient (Baquié and Urpelainen 2017) because they get hot faster than traditional cookstoves and have multiple

Handled by Dominik Möst, Technische Universität Dresden, Germany.

✉ Sonia Akter
Sonia.akter@nus.edu.sg

¹ Lee Kuan Yew School of Public Policy, National University of Singapore, 469c Bukit Timah Road, Singapore 259772, Singapore

burners allowing the preparation of multiple items simultaneously (Jagoe et al. 2020). Modern cookstoves also take less time to start after ignition and have higher heating values than traditional cookstoves. Optimal heat management for modern cookstoves is achieved by moving burner knobs, whereas heat management for traditional cookstoves requires considerable time and effort (e.g., adding or removing fuel). As a result, using LPG to prepare food takes less time than traditional cooking fuels.

As women and girls are commonly responsible for cooking in rural societies (Akter 2021), LPG adoption can deliver important co-benefits by reducing women's disproportionately heavy unpaid work burden while achieving the sustainable development goal of delivering clean energy for all. Studies examining the benefits of clean cooking fuel have focused predominantly on its health benefits, which are accrued in the long term and not directly observable. The immediate and most directly observable benefit of LPG adoption is its positive effect on women's welfare due to: (a) reduced fuel collection/preparation time, (b) reduced cooking time and (c) convenient cooking arrangement. These benefits of LPG adoption have received little attention in the literature. The only study that investigates the correlation between LPG adoption and women's well-being is conducted by Malakar and Day (2020). The authors used a qualitative method to compare various well-being domains between LPG adopters and firewood users. The study revealed that LPG adoption improves women's well-being by improving their social status and health, freeing up time from cooking and offering them more fuel choices. The literature on modern cookstove adoption documents the significant time benefit for women in terms of time-saving from firewood collection (Guzmán et al. 2020; Jagoe et al. 2020). Other studies have identified factors involved in the adoption of clean cooking fuel; for example, affordability (Bansal et al. 2013; Pundo and Fraser 2006; Gould and Urpelainen 2018) and household expenditure, size, and education (Rao and Reddy 2007).

This study makes three contributions to the literature. First, it develops a conceptual framework that incorporates the immediate benefits along with long-term benefits of clean cooking fuel adoption. We argue that the most immediate and direct benefits of clean cooking fuel adoption are women's time-saving for fuel collection/preparation and cooking and convenient cooking experience. Given the disproportionately high time-use burden on women for unpaid domestic work and widespread undervaluation of women's contribution to household production (Akter 2021; Njenga et al. 2021), the time-use and cooking convenience benefits of LPG adoption and reuse are likely to remain unaccounted for in the household cooking fuel investment decision. Building on previous empirical work on women's empowerment and clean cooking fuel access (Krishnapriya et al.

2021; Das et al. 2020), the conceptual framework highlights the bidirectional nature of women's autonomy and LPG use and theorizes women's autonomy both as a mediator and a potential long-term outcome of clean cooking fuel adoption and reuse.

Our second and third contributions to the literature come from empirically testing a part of the proposed theoretical framework that concerns the immediate and direct benefit of LPG adoption and use. Our study is the first to test the impact of LPG adoption on fuel collection/preparation time, cooking time and cooking convenience using a quantitative method. The use of panel data regression model eliminates a large number of validity threats to causal inference. We also test the relationship between women's participation in decision-making (indicator of women's autonomy) and the likelihood of LPG adoption and reuse.

The data for this study was sourced from the Access to Clean Cooking Energy and Electricity—Survey of States (ACCESS). The survey collected data from 54 rural districts in 6 states—Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh and West Bengal—in 2 waves, in 2015 and 2018. The Council on Energy, Environment, and Water (CEEW) in collaboration with Columbia University collected the first wave of data. The CEEW in collaboration with the Initiative for Sustainable Energy Policy at the National University of Singapore collected the second wave of data. The survey is the largest panel data on energy access in India, with about 8568 households surveyed in Wave 1 and 9072 households surveyed in Wave 2.

Background discusses the background and context of the study. **Conceptual framework** presents the conceptual framework and **Empirical Models** details the measurement of key constructs of interest and empirical specifications. **Descriptive Statistics** presents the descriptive statistics of the key variables. **Results** presents the results of a series of panel data and ordinary least square (OLS) regression models.

Discussion discusses the results and **Conclusions and policy implications** provides concluding remarks and policy implications.

Background

This study was conducted in the context of the Pradhan Mantri Ujjwala Yojana (PMUY), a flagship energy policy of the federal government of India introduced in 2016. All six states covered by the ACCESS survey were among the priority states under the PMUY program due to a lower pre-program LPG usage than the national average (Ministry of Petroleum and Natural Gas 2016). Rural residents in these states relied predominantly on firewood, crop residue and dung cake for cooking fuel before the rollout of the program while the use of LPG as a cooking fuel was limited

among middle-high income urban residents (Aggarwal et al. 2018). However, penetration of LPG has still remained limited majorly to urban areas and middle-high income groups. The program offered subsidized LPG connections for rural households below the poverty line (BPL). The main objective of the PMUY was to provide poor, rural households access to clean cooking fuel, and encourage a transition from traditional cooking fuels such as firewood, coal, cow-dung cakes (Government of India 2021). The scheme provided rural BPL households, represented by a female applicant, with a subsidy (\$22) for the LPG connection, cylinder, pressure regulator and booklet, which was transferred to the bank account of the women in the households. Households were provided the option of an interest-free loan to cover the installation costs. As of July 2019, 72 million connections had been provided under this scheme (Ministry of Petroleum and Natural Gas 2019).

The program has been hugely successful in reaching its target beneficiaries within the intended timeline. LPG adoption in rural India has increased from 61.90% (May 2016) to 94.30% (April 2019) (Comptroller and Auditor General of India 2019). In 2015, the rural areas of Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal had less than 35% LPG adoption, ranging from 6% in Jharkhand to 35% in Uttar Pradesh (Alexander and Padmanabhan 2019). By 2018, LPG adoption in Jharkhand had increased to 34%, and Uttar Pradesh had increased to 47% (Alexander and Padmanabhan 2019). This growth can be largely attributed to the PMUY program. The ACCESS survey reported that 43% of all new LPG connections in these six states resulted from the PMUY program. Although a number of programs were introduced to expedite rural households' transition to clean cooking fuel in India prior to the introduction of the PMUY (e.g., the Rajiv Gandhi Gramin LPG Vitaran Yojana), none of them was as effective as the PMUY in boosting LPG adoption, particularly for low-income households.

While the PMUY program only targeted BPL households, LPG adoption among non-eligible households substantially increased from 2015 to 2018 due to two main reasons. First, the availability of LPG stoves and cylinders increased in the rural markets, making LPG easily accessible for both PMUY eligible and non-eligible rural residents. About 9000 new LPG distributors emerged between 2014 and 2019 (Alexander and Padmanabhan 2019). Second, LPG adoption increased through social influence. Households transitioned to LPG when their neighbors, friends, and family made the same transition (Kuo and Azam 2019; Srinivasan and Carattini 2020).

The PMUY rollout varied across states and districts, and was prioritized in the north-eastern and hilly states, as well as those states that had a lower percentage of usage than the national average. The variation in the PMUY rollout within

and across states was also attributed to population size, percentage of BPL households in a village, and the extent of program penetration (Srinivasan and Carattini 2020). Each state determined its district- and village-level rollout based on discretionary rules. District Nodal Officers of the Oil Marketing Company were appointed in each district to execute the program (Mhamia 2016). Some states prioritized villages with fewer LPG connections, while other states selected villages based on their LPG adoption potential.

While initial take-up of LPG through the program was encouraging, sustained use of LPG remained a challenge due to difficulty in accessing refills in remote rural villages that are characterized by fewer LPG refill options in close proximity. The number of LPG refills among PMUY beneficiaries was less than half that of non-PMUY LPG users (Kar et al. 2019). Mani et al. (2020) found that PMUY beneficiaries were much less likely to use LPG as their primary cooking fuel than non-PMUY LPG users. Ease of access to free biomass and fuelwood and irregular income are key factors affecting the sustained use of LPG (Mani et al. 2020). Low adoption and the lack of sustained LPG use were also influenced by the misperception that food cooked using LPG is bad for health (Vyas et al. 2020). Some people also feel that the food taste deteriorates when not cooked on traditional stoves (Vyas et al. 2020).

Conceptual framework

This section develops a conceptual framework (Fig. 1) of LPG adoption and reuse and their bidirectional linkage with women's autonomy.

LPG adoption benefits women most directly and immediately, because it results in faster cooking in a convenient and hassle-free environment. LPG adoption and use can also save time for fuel collection and preparation, however, this facet is conditional on the delivery option (doorstep delivery versus collection from distributors) and distance to the refill point from the household location. If a LPG refill is not delivered to the doorstep and the refill point is far from the household location, then the net time spent for LPG use at the household level can be higher than the time taken to collect traditional fuel.

Other benefits (environmental and health) of LPG adoption materialize gradually over time and are not directly observable. These benefits are less likely to influence household decisions to invest in clean cooking fuel than directly observable benefits. The adoption and sustained use of LPG can also enhance women's autonomy. The freed-up time from cooking and fuel collection can be used for leisure, education, income-generating activities, other chores, further cooking, or childcare. Most importantly, LPG adoption can improve gender equality in unpaid household work by

Fig. 1 Conceptual framework of LPG adoption benefits and their links with women's autonomy

reducing women's workload and changing gender roles (e.g., fuel collection responsibility is shared by men and women).

The literature presents evidence regarding the mediating effect of women's autonomy on LPG adoption and use. Using Wave 1 of the ACCESS survey data, Gould and Urpelainen (2020) show that the LPG adoption decision is highly gendered. Households where women participate in decision-making are more likely to adopt LPG for cooking than households where major purchase decisions are made by men alone. Choudhuri and Desai (2020) show that women's labor force participation and control over money are positively related to clean cooking fuel in India. Since household work is done mostly by women and women's contribution is highly undervalued, women's autonomy plays an important role in LPG use decision (Cabiyo et al. 2020). Ordering LPG refills requires women to have decision-making power, access to a mobile phone, and in instances where the refill point is located far from home, reliance on a male household member to help carry the heavy LPG cylinder. The PMUY program recognizes women's role in LPG adoption by directly targeting women as beneficiaries. However, the sustained use of LPG can be challenging in societies where women lack autonomy on major expenditure decisions (Akter and Francis-Tan

2021; Akter and Chindarkar 2020). In addition to women's autonomy, other important socio-economic and structural factors that influence LPG adoption and reuse in rural areas are income and education, access to a paved road, and social spillovers (Kuo and Azam 2019).

Empirical models

Measurement of key variables

LPG adoption

The key treatment variable in our study is LPG adoption. The most straightforward way to measure LPG adoption is to use a dummy variable by coding LPG adopters as 1 and the others as 0. This measure does not capture the extent of LPG use across households. As fuel stacking is common in rural areas, some households use multiple cooking fuels. Hence, we used the extent of LPG use to differentiate households by their level of usage, coded as 0 (LPG not used at all), 1 (LPG used for some cooking), and 2 (LPG used for all cooking).

Fuel collection and preparation

We used two indicators to measure time spent on fuel collection and preparation. First, we used firewood collection frequency¹ for households that used firewood as a source of fuel in 2015 and 2018. Second, we used the amount of firewood collected by household members and dung cake prepared at home as indicators of fuel collection/preparation time. It is reasonable to assume that the number of trips and volume of fuel are strongly positively correlated with the time spent on fuel collection and preparation. More specifically, a higher number of firewood collection trips mean that households spent more time on firewood collection compared to households who made fewer trips. Likewise, a higher volume of firewood collection (or dung cake preparation) means households spent more time on fuel collection (or preparation) relative to households who collected less firewood per trip (or prepared less dung cakes). To understand whether the changes in fuel collection and preparation are driven by LPG adoption and not because of a shift from home-based production/collection to market procurement, we also used the quantity of firewood and dung cake purchased from the market as outcome variables.

Cooking time

Cooking time was measured in hours per day. Households were asked to report the amount of time they spent cooking on a regular day. A qualitative measure of cooking time was used to safeguard against potential measurement or reporting errors in the quantitative cooking time. Respondents were asked to report their perceptions of cooking time by answering the following question: ‘Cooking is too time consuming (Yes = 1, No = 0)’. Additionally, we used the number of meals cooked per day as an outcome variable to understand whether the reduction in cooking time and convenience led to more cooking.

Cooking convenience

Cooking convenience was measured using respondent agreement (= 1) or disagreement (= 0) with three statements: *Smoke* (cooking creates excessive smoke), *Dangerous* (cooking is too dangerous), and *Difficulty* (cooking is too difficult).

¹ Although data on firewood collection time was collected by the ACCESS survey, a large number of missing observations makes the data unusable.

Women’s autonomy

Autonomy is a complex and multi-dimensional concept. Previous studies have used women’s participation in decision-making as an indicator of autonomy (Akter and Francis-Tan 2021; Akter et al. 2017; Alkire et al. 2013; Malapit et al. 2020). We used two types of decision-making power as indicators of women’s autonomy. The first was women’s participation in decision-making for LPG adoption, and the second was women’s participation in decision-making for LPG refill. Women’s participation in decision-making for LPG adoption was measured using a response to the question “Who in your household makes decisions on the purchase of durable goods?”. The response options were: (a) male head of household, (b) female head of household, (c) jointly, and (d) other. The variable was coded 1 if the response to this question was (b) or (c), which implies that women had either sole or joint decision-making power to purchase durable goods. Women’s participation in decision-making for LPG refill was measured using the response to the question “Who decides whether to order a refill?”. The response options were: (a) head of household, (b) spouse of head of household, (c) both, (d) son, and (e) daughter/daughter-in-law. The variable was coded 1 if the gender of the decision-maker was female and 0 otherwise.

Empirical models

We used the following fixed-effects panel regression model to estimate the impact of LPG adoption on fuel collection/preparation and cooking time and cooking convenience:

$$Y_{it} = \beta_0 + \text{LPG}_{it}\beta_1 + X_{it}\beta_2 + \lambda_{TS} + u_{it} \quad (1)$$

where Y_{it} is an indicator of fuel collection/preparation time, cooking time or convenience and LPG_{it} represents LPG adoption (or extent of use) for household i in year t . The panel fixed-effects specification outlined in Eq. 1 cancels out time-invariant unobserved characteristics at the household level. X_{it} is a vector of time-varying household-level control variables that may influence LPG adoption, such as income, assets, and standard of living. λ_{TS} represents year and state fixed-effects. This component of the equation controls for time-varying state-level unobserved factors (e.g., state policy, tax, fuel subsidy, funding for PMUY, institutional characteristics, and so on) that may influence LPG adoption. u_{it} is the robust error term clustered at the household level to account for autocorrelation and heteroscedasticity.

The regression model outlined in Eq. 1 does not account for household-level unobserved characteristics that varies over time. The most important time-varying factors with a known link to LPG adoption are income, education, cooking intensity (e.g., number of meals cooked) which are observed

and controlled for. Other household-level factors that may influence LPG adoption but not observed by the model are willingness to embrace new technology, access to information, political capital, and so on. These factors are unlikely to change over a relatively short period of time.

We used a panel fixed-effects regression model to estimate the correlation between women's participation in decision-making and LPG adoption:

$$\text{LPG}_{it} = \beta_0 + \text{WomenDecision}_{it}\beta_1 + X_{it}\beta_2 + \lambda_{TS} + u_{it} \quad (2)$$

where LPG_{it} is LPG adoption for household i in year t . *WomenDecision* equals 1 if women had sole or joint decision-making power in the purchase of durable goods. X_{it} is a vector of household-level characteristics: income, castes, measures of living standard, kitchen location (indoor, outdoor, or both), assets, and education level of household head. λ_{TS} represents year and district fixed-effects. u_{it} is the robust error term clustered at the household level.

We used the following OLS regression model to estimate the correlation between women's participation in decision-making for LPG refill:

$$\text{Refill}_i = \beta_0 + \text{WomenDecision}_i\beta_1 + X_i\beta_2 + Z_i\beta_3 + T + \lambda_s + u_i, \text{ if } \text{LPG}_i = 1 \quad (3)$$

where *Refill* is a dummy variable that equals 1 if household i refilled their LPG cylinder within the last month² and 0 otherwise. This question was asked only to the LPG adopters in Wave 2. Hence, the analysis sample for Eq. 3 was limited to LPG adopters in Wave 2. X_i is a vector of household-level control variables: caste, poverty status, occupation, and measures of living standard. Z_i is a vector of characteristics that captures accessibility to LPG refills: average village-level price of a large LPG cylinder, LPG refill delivered to the doorstep and LPG refill delivered on the same day the order was placed.

Descriptive statistics

Table 1 presents an overview of the sample characteristics. In 2015, the percentage of households that used LPG was 21.6%, increasing to 54.6% in 2018. The number of people who used LPG as their main cooking fuel increased from 12.7% in 2015 to 33.5% in 2018. The sharp increase is partly attributed to the PMUY scheme and its spillover effect. The percentage of households that used dung cakes as the main cooking fuel dropped slightly from 20% in 2015 to 17% in 2018. Likewise, the percentage of households who used

firewood and chips as their main source of cooking fuel dropped from 63% in 2015 to 47% in 2018.

Over 60% of the LPG adopters refilled their LPG cylinders within the last one month of the survey. For the rest of the households, refill frequency varied between two and 48 months. Doorstep delivery of cylinders increased substantially between 2015 and 2018. In 2015, only 18% of the households procured refill through doorstep delivery. In 2018, 39% of the household procured their LPG refills through doorstep delivery. In about a quarter of the cases, refill was received on the same day the order was placed. For the rest of the cases, the delivery time varied between 1 and to 30 days after placing an order. When it comes to decision-making about whether to refill a LPG cylinder, women made the decision in 42% cases. The refill was ordered by a woman in only 14% of the cases. In cases where doorstep delivery of LPG cylinder was not an option, households travelled 7 km on average, to collect the LPG refill. In about a quarter of the cases, the collection point (a retail or distributor shop) was located within 2.5 km. For another quarter of the households, the nearest collection point was located within 5 km. For the rest of the cases, the collection point was located within 6 and 30 km of sampled household locations. In only a handful of cases (3%), LPG refill was collected by a female household member.

As expected, households' firewood collection frequency, the amount (kg/week) of firewood collected by household members as well as the amount (kg/week) purchased from the market declined considerably in 2018 relative to 2015. A similar pattern was observed for households who used dung cake as a cooking fuel. The average amount (pieces/week) of dung cake prepared at home and purchased from the market declined considerably in 2018 relative to 2015.

Results

Impact of LPG on fuel collection and preparation

The results obtained from Eq. 1 are presented in Table 2. The samples used for these regression models were restricted to households who used the corresponding fuel type in Waves 1 and/or 2. The results obtained using dummy coding of LPG adoption are presented in Panel A. To test the robustness of these findings, we estimated an alternative model where the extent of LPG usage replaced dummy coding of LPG adoption. These results are presented in Panel B.³

² Our findings remain robust when refill was treated as a continuous variable.

³ The analysis had fewer observations than that in Panel A because the question on the extent of LPG use was not asked in Wave 1. Therefore, households who used LPG in 2015 were excluded from the analysis.

Table 1 Summary statistics of key variables

Variables	2015					2018				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Cooking time (h/day)	8563	3.29	1.11	1	7	9072	3.10	1.15	0.5	8
Cooking is time consuming (yes = 1)	8563	0.76	0.43	0	1	9072	0.66	0.48	0	1
Cooking is dangerous (yes = 1)	8563	0.56	0.50	0	1	9072	0.53	0.50	0	1
Cooking creates excessive smoke (yes = 1)	8563	0.83	0.37	0	1	9072	0.69	0.46	0	1
Cooking is too difficult (yes = 1)	8563	0.50	0.50	0	1	9072	0.47	0.50	0	1
Households use LPG for cooking	8563	0.22	0.41	0	1	9072	0.55	0.50	0	1
Extent of LPG use										
None	6712	1	0	1	1	9072	0.45	0.50	0	1
For some cooking	–	–	–	–	–	9072	0.21	0.41	0	1
For all cooking	–	–	–	–	–	9072	0.34	0.47	0	1
LPG refill within the pastmonth	–	–	–	–	–	4960	0.61	0.49	0	1
Doorstep delivery	1851	0.18	0.39	0	1	4960	0.39	0.49	0	1
Same day delivery	–	–	–	–	–	4960	0.32	0.47	0	1
Price of a large cylinder refill (US\$)	–	–	–	–	–	7524	11.77	1.86	5.78	17
LPG refill decision made by a woman	–	–	–	–	–	4960	0.42	0.49	0	1
LPG refill is ordered by a woman	–	–	–	–	–	4960	0.14	0.34	0	1
LPG refill is collected by a woman	–	–	–	–	–	3029	0.03	0.17	0	1
Main cooking fuel										
Firewood and chips	8563	0.63	0.48	0	1	9072	0.47	0.50	0	1
Dung cakes	8563	0.20	0.40	0	1	9072	0.17	0.37	0	1
LPG	8563	0.13	0.33	0	1	9072	0.34	0.47	0	1
Other	8563	0.04	0.20	0	1	9072	0.02	0.15	0	1
Firewood collection frequency	7155	2.03	1.17	0	4	8356	1.60	1.29	0	4
Firewood collected by household members (kg/week)	7155	36.58	31.35	0	280	8341	28.83	30.95	0	300
Firewood purchased from market (kg/week)	7155	10.03	21.71	0	250	8345	6.28	7.68	0	280
Dung cake made by households (pieces/week)	5835	44.43	68.72	0	1000	6664	54.73	98.48	0	5000
Dung cake purchased from market (pieces/week)	5832	42.02	77.38	0	700	6666	7.31	32.59	0	0
Caste										
Scheduled caste	8563	0.20	0.40	0	1	9072	0.20	0.40	0	1
Scheduled tribes	8563	0.10	0.30	0	1	9072	0.10	0.30	0	1
Other backward class	8563	0.50	0.50	0	1	9072	0.50	0.50	0	1
General	8563	0.20	0.40	0	1	9072	0.20	0.40	0	1
Ration card/poverty status										
No ration card	8563	0.10	0.30	0	1	9072	0.20	0.40	0	1
Above poverty line	8563	0.40	0.50	0	1	9072	0.30	0.50	0	1
Below poverty line	8563	0.40	0.50	0	1	9072	0.50	0.50	0	1
Antyodaya	8563	0.10	0.30	0	1	9072	0.10	0.30	0	1
Primary source of income										
Agriculture on own land	8563	0.50	0.50	0	1	9072	0.40	0.50	0	1
Cultivation on leased land	8563	0.10	0.20	0	1	9072	0.03	0.20	0	1
Casual agricultural labor	8563	0.03	0.20	0	1	9072	0.03	0.20	0	1
Salaried job	8563	0.10	0.20	0	1	9072	0.10	0.30	0	1
Cattle rearing	8563	0.01	0.10	0	1	9072	0.01	0.10	0	1
Own business	8563	0.10	0.30	0	1	9072	0.10	0.30	0	1
Daily laborer	8563	0.30	0.50	0	1	9072	0.40	0.50	0	1
Other	8563	0.02	0.10	0	1	9072	0.02	0.10	0	1
Household composition and cooking characteristics										
No. adults	8563	4.30	2.30	1	35	9072	4.00	2.10	1	25

Table 1 (continued)

Variables	2015					2018				
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
No. children	8563	2.50	2.00	0	22	9072	2.10	1.90	0	19
No. children currently studying	8563	1.80	1.70	0	22	9072	1.50	1.60	1	16
Cook present during the survey	8563	0.61	0.48	0	1	9072	0.69	0.46	0	1
Decision maker is a female	7558	0.21	0.41	0	1	9072	0.33	0.47	0	1
No. traditional cookstoves	8563	1.48	0.77	0	9	9072	1.30	0.77	0	6
No. improved cookstoves	8563	0.03	0.23	0	4	9072	0	0	0	0
No. meals cooked	8563	2.11	0.36	1	4	9072	2.13	0.39	1	5
Cooking location										
Indoor	8563	0.50	0.50	0	1	9072	0.60	0.49	0	1
Outdoor	8563	0.36	0.48	0	1	9072	0.25	0.43	0	1
Mixed	8563	0.14	0.35	0	1	9072	0.15	0.36	0	1
Household wealth										
House ownership	8563	1.00	0.10	0	1	9072	1.00	0.10	0	1
No. rooms	8563	2.70	1.70	1	15	9072	2.80	1.70	0	25
Monthly household expenditure (US\$) ^a	8563	72.10	53.10	6.80	816	9072	85.0	59.30	0	1088
Standard of living										
Toilets in house	8563	0.30	0.50	0	1	9072	0.60	0.50	0	1
Piped water	8563	0.10	0.20	0	1	9072	0.10	0.20	0	1
Access to grid-electricity	8563	0.70	0.50	0	1	9072	0.80	0.40	0	1

^a1 \$US=INR 73.53

The coefficients of LPG are negative and significant at the one percent level in Columns 1–4 of Panel A. In Panel A Column 1, the coefficient of LPG implies that the LPG adopters collected firewood, on average, 0.309 point less frequently (on a scale of 0 to 4) compared to non-adopters. The coefficient of LPG in Panel B Column 1 suggests that the gain in fuel collection frequency is significant only for households who used LPG for all cooking as opposed to those who used it for some cooking. The coefficients of LPG in Columns 2 and 3 of Panels A and B are negative and significant at the one percent level. These coefficients imply that the LPG adopters collected (≈ 6 kg/week) and purchased (≈ 4 kg/week) less firewood compared to the non-adopters.

We found similar results for dung cake prepared at home. The coefficients of LPG are negative and significant at the one percent level in Column 4 and Panels A and B. LPG adopters prepared, on average, 13 pieces fewer dung cake per week at home compared to non-adopters. When LPG was used for all cooking, the adopters prepared 45 pieces fewer dung cake at home compared to partial and non-adopters. No significant effect of LPG adoption on the quantity of dung cake purchased from market was observed.

Impact of LPG on cooking time

The results obtained from using the cooking time outcome indicators are presented in Table 3. Columns 1 and 2 show the results from using quantitative and qualitative measures of cooking time, respectively. The coefficients of LPG adoption in Columns 1 and 2 of Panel A are negative and significant at the one percent level. In Column 1, the coefficient of LPG adoption (-0.278) implies that LPG adopters spent, on average, more than a quarter of an hour (approximately 15 min) less time to cook food than non-adopters. In Column 2, the coefficient of LPG (-0.354) implies that LPG adopters were 35 percentage points less likely to believe that “Cooking is too time-consuming” than non-adopters. In Column 3, the coefficient of LPG is positive but not significant at the ten percent level. This means that the adoption of LPG did not lead to cooking more meals by the adopters relative to the non-adopters.

The findings presented in Panel B of Table 3 are obtained by using the extent of LPG use as the treatment variable instead of dummy coding of LPG adoption. The findings are consistent with those presented in Panel A. In Column 1 (Panel B), both coefficients of LPG extent are negative and significant at the one percent level. The base level for this

Table 2 LPG adoption and traditional fuel use (fixed-effects panel regression model)

	(1) Firewood collec- tion frequency ^a	(2) Qnt of firewood collected (kg/week)	(3) Qnt of firewood purchased (kg/ week)	(4) Qnt of home prepared dung cake (pieces/week)	(5) Qnt of dung cake purchased (pieces/ week)
Panel A					
LPG adoption ^b	− 0.309*** (0.037)	− 5.945*** (0.944)	− 3.902*** (0.685)	− 13.710*** (2.805)	− 2.260 (2.007)
Number of observations ^c	14,640	14,626	14,630	12,204	12,206
Number of households ^c	8357	8356	8355	6679	6681
R-squared	0.119	0.112	0.059	0.039	0.208
Panel B					
LPG used for some cooking ^d	− 0.056 (0.054)	1.657 (1.495)	− 1.960* (1.015)	− 2.599 (4.427)	0.098 (3.243)
LPG used for all cooking ^d	− 0.575*** (0.0558)	− 14.360*** (1.353)	− 10.420*** (0.996)	− 45.89*** (4.200)	− 1.193 (3.154)
No. observations ^c	13,461	13,447	13,451	11,157	11,159
No. households ^c	8357	8356	8355	6677	6678
R-squared	0.135	0.132	0.069	0.059	0.212
Household controls	Y		Y	Y	Y
District and time fixed-effects	Y		Y	Y	Y

Household controls include ration card status (none, APL, BPL, Antyodaya), gender of decision maker, cook present during the survey, number of adults and children, number of children currently enrolled in school, primary income source (agriculture on own land, cultivation on leased land, casual agricultural labor, salaried job, cattle rearing, own business, daily laborer, other), access to grid electricity, toilet and piped water, number of motorcycles, number of rooms in house, stove type (traditional, modern, both), number of meals cooked, kitchen location (indoor, outdoor or mixed). Full regression results are in SM1. Robust standard errors clustered at the household-level in parentheses. *** $p < 0.01$, ** $p < 0.10$

^a0 = none, 1 = a few times a year, 2 = a few times a month, 3 = a few times a week, 4 = daily

^bLPG adoption = 1, otherwise = 0

^cSample is restricted to households that used firewood and/or dung cake for cooking in 2015 and/or 2018

^dBaseline = LPG not used for any cooking

variable is LPG non-adopters. Households who used LPG for some but not all cooking spent about 10 min less time cooking than households who did not use LPG. A higher time-saving (approximately 25 min) was reported by households who used LPG for all cooking. Households who used LPG for some cooking were not significantly more or less likely than non-adopters to believe that ‘Cooking is too time-consuming’. This is consistent with the small gain in time-saving from low-intensity LPG use presented in Column 1. Conversely, households who used LPG for all cooking were significantly less likely than non-adopters to believe that ‘Cooking is too time-consuming’.

Cooking convenience

Here, we present the findings of the impact of LPG adoption on cooking arrangements using Smoke, Dangerous, and Difficulty as indicators of cooking convenience. A bar diagram displaying the proportion of a ‘Yes’ response to the cooking convenience question across three types of cooking fuel is presented in Fig. 2. The figure reveals a considerable gap in

the proportion of the ‘Yes’ responses to all three indicators of cooking convenience for households who used LPG as their main cooking fuel as opposed to the households who used firewood and chips and dung cake as main cooking fuel.

The results of the econometric analysis of cooking convenience across LPG adopters and non-adopters are presented in Table 4. The coefficients of LPG adoption are negative and significant at the one percent level in Columns 1, 2, and 3 (Panel A). In Table 4, Column 1 (Panel A), the coefficient of LPG adoption (− 0.388) implies that LPG adopters were approximately 40 percentage points less likely than non-adopters to report that cooking created too much smoke. In Column 2 (Table 4), the coefficient of LPG adoption (− 0.063) implies that LPG adopters were approximately six percentage points less likely than non-adopters to report that cooking was dangerous. In Column 3 (Table 4), the coefficient of LPG adoption (− 0.240) implies that LPG adopters were 24 percentage points less likely than non-adopters to report that cooking was difficult. Panel B of Table 4 presents the results from using LPG adoption as a

Table 3 LPG adoption and cooking time (fixed-effects panel regression model)

	(1) Cooking time (hours/ day)	(2) Perception of cooking time ^a	(3) Meals cooked (number/day)
Panel A			
LPG adoption ^b	−0.278*** (0.031)	−0.354*** (0.012)	0.004 (0.010)
Number of observations	16,630	16,630	16,630
Number of households	9074	9074	9074
R-squared	0.188	0.194	0.020
Panel B			
LPG used for some cooking ^c	−0.180*** (0.046)	0.001 (0.014)	−0.013 (0.015)
LPG used for all cooking ^c	−0.429*** (0.046)	−0.732*** (0.015)	0.020 (0.014)
No. observations	15,019	15,019	15,019
No. households	9074	9074	9074
R-squared	0.195	0.416	0.019
Household controls	Y	Y	Y ^d
District and time fixed-effects	Y	Y	Y

Household controls include ration card status (none, APL, BPL, Antyodaya), gender of decision maker, cook present during the survey, number of adults and children, number of children currently enrolled in school, primary income source (agriculture on own land, cultivation on leased land, casual agricultural labor, salaried job, cattle rearing, own business, daily laborer, other), access to grid electricity, toilet and piped water, number of motorcycles, number of rooms in house, stove type (traditional, modern, both), number of meals cooked, kitchen location (indoor, outdoor or mixed). Full regression results are in SM2. Robust standard errors clustered at the household-level in parentheses. *** $p < 0.01$, * $p < 0.10$

^aPrimary cooking arrangement is too time consuming = 1, otherwise = 0

^bLPG adoption = 1, otherwise = 0

^cBaseline = LPG not used for any cooking

^dNumber of meals cooked per day is not included in the control variables

Fig. 2 Cooking convenience indicators by main cooking fuel type

Table 4 Impact of LPG adoption on cooking convenience (fixed-effects panel regression model)

	Cooking produces too much smoke ^a	Cooking is too dangerous ^a	Cooking is too difficult ^a
Panel A			
LPG adoption ^b	− 0.388*** (0.011)	− 0.063*** (0.016)	− 0.240*** (0.015)
No. observations	16,630	16,630	16,630
No. households	9074	9074	9074
R-squared	0.292	0.048	0.079
Panel B			
LPG used for some cooking ^c	− 0.005 (0.008)	0.007 (0.023)	− 0.041* (0.022)
LPG used for all cooking ^c	− 0.762*** (0.013)	− 0.301*** (0.023)	− 0.498*** (0.021)
R-squared	0.607	0.085	0.141
No. observations	15,019	15,019	15,019
No. households	9074	9074	9074
Household controls	Y	Y	Y
District and time fixed-effects	Y	Y	Y

Household controls include ration card status (none, APL, BPL, Antyodaya); gender of decision maker on the purchase of durable goods; number of adults and children; number of children currently enrolled in school; primary income source (agriculture on own land, cultivation on leased land, casual agricultural labor, salaried job, cattle rearing, own business, daily laborer, other); whether grid electricity is used for lighting; whether the household has a toilet and piped water; number of motorcycles owned; number of rooms in the house; whether the household uses a traditional stove or an improved stove; number of meals cooked; where cooking takes place (indoor, outdoor or mixed). Full regression results are in SM3. Robust standard errors clustered at the household-level in parentheses. *** $p < 0.01$

^aYes = 1, No = 0

^bLPG adoption = 1, otherwise = 0

^cBaseline = LPG not used for any cooking

categorical variable. The results reveal that households who used LPG for all cooking were significantly more likely than non-adopters to report that cooking created smoke, cooking was dangerous, and cooking was too difficult. The average perception of cooking convenience indicators did not significantly differ between non-adopters and households that used LPG for some cooking.

Women's participation in decision-making and LPG adoption and reuse

The key findings from the estimations of Eqs. 2 and 3 are presented in Figs. 3 and 4. As hypothesized, women's participation in decision-making had a significant and positive correlation with LPG adoption. Additionally, a noteworthy mediator of adoption is kitchen location. Households with an outdoor kitchen were significantly less likely to adopt LPG than households with an indoor kitchen. Poverty status was a significant correlate of LPG adoption. This is because the target beneficiaries of the PMUY program were BPL and Antyodaya households who were significantly more likely to adopt LPG than households without a ration card. The LPG adoption rate in 2018 was significantly higher than

that in 2015, which was expected since the PMUY program was rolled out in 2015.

Caste was negatively correlated with LPG adoption. Scheduled castes/tribes and other backward caste households were significantly less likely to adopt LPG than general castes. Consistent with previous studies, the household head's education and occupation were significantly and positively correlated with LPG adoption, as were living standard measures (access to grid electricity, piped water, toilet).

Women's participation in LPG refill decisions had a significant and positive effect on LPG refill frequency (Fig. 4). LPG refill accessibility was significantly and positively correlated with LPG refill frequency. Households were significantly more likely to refill the LPG cylinder within a month when the refill was delivered at the doorstep and delivered on the same or next day. The gender of the person who commonly ordered LPG refill was not significantly correlated with the likelihood of LPG refill within a month but in occasions where women collected LPG refill (and doorstep delivery was not an option), households were less likely to refill their LPG cylinder within the past month. The coefficient of the price of refilling a large LPG cylinder was positive but not statistically significant. Although price of refill should

Fig. 3 Socio-economic determinants of LPG adoption (Panel fixed-effects regression results)

Fig. 4 Factors correlated with LPG refill likelihoods (OLS regression results)

play an important role in LPG reuse, the coefficient is not significant in our analysis most likely due to inaccurate price data⁴ which were observed only for those who refilled their LPG cylinders.

Discussion

This study examined the impact of LPG adoption on women's welfare as a potential co-benefit. We developed a conceptual framework to explicitly account for immediate and long-term benefits of LPG adoption and use. The novelty of the conceptual framework is that it incorporates women's time use as a direct and immediate benefit of clean cooking fuel adoption and posits women's autonomy as both a mediator and a potential long-term outcome of fuel transition and its sustained use.

Consistent with the qualitative study of Malakar and Day (2020), we find that LPG adoption reduces fuel collection/preparation and cooking time. On average, LPG adopters collect firewood less frequently than non-adopters. LPG adopters also collect (and buy) significantly less firewood and prepare significantly fewer pieces of dung cake at home compared to the non-adopters. As for cooking time, we find that the LPG adopters spend around 15 min less time cooking food per day than non-adopters with no significant change in the number of meals cooked. As expected, the time-saving benefits of LPG adoption was most substantial for households who used LPG for all as opposed to some cooking.

Although LPG adoption significantly reduced the time for firewood collection and dung cake preparation, refilling LPG cylinders involved travel or waiting time for over a half of the adopters due to the paucity of distribution centers in remote areas. Therefore, while LPG adoption saved fuel collection and preparation time for women, the net effect of LPG adoption on time use at the household level is inconclusive. However, LPG adoption and reuse show some benefit in terms of shifting gender role for fuel collection. Although the responsibilities of dung cake preparation and firewood collection lied predominantly on female household members, ordering and procuring LPG cylinders were primarily male household members' responsibilities.

We find a significant and positive effect of LPG adoption on cooking experience, particularly for smoke reduction and ease of cooking. While LPG adopters were significantly less likely than non-adopters to believe that their cooking arrangement was dangerous, the magnitude of the coefficient

was rather small (6% points). This means that safety concern was unlikely to be a driver of the gain observed in cooking time. The time use gain of LPG adoption therefore were resulted from the more convenient and comfortable cooking arrangements of the modern cookstove, relative to traditional cookstoves that require more time for ignition, maintaining optimal ignition at different cooking stages, and cleaning the kitchen and utensils post-cooking.

As hypothesized, our analysis reveals a significant and positive relationship between women's participation in decision-making and LPG adoption and reuse, which is consistent with the findings of Gould and Urpelainen (2020). Although in most cases, LPG refill order and collection were done by a man, households where women made sole or joint decisions about purchasing durable goods were significantly more likely to adopt LPG than households where women did not participate in the decision to purchase durable goods. Likewise, among LPG adopters, households where women made sole or joint decisions about ordering LPG refills were significantly more likely to refill more frequently than households where the refill decision was made solely by men.

In addition to women's decision-making power, kitchen location was an important determinant of LPG adoption and reuse. Since the LPG cylinder and stove are expensive, the risk of theft might hinder adoption decisions for households with an outdoor kitchen. That is, households would not be willing to invest in LPG when the kitchen is located outdoors without adequate security measures to prevent theft. Another plausible reason for not adopting LPG or not using frequent LPG refill in households with outdoor kitchens could be low smoke exposure for household members (except the cook). When the kitchen is located outdoors, the health risk–benefit of clean cooking fuel adoption or use is perceived as low at the household level, although smoke exposure for the women in charge of cooking remains high (James et al. 2020).

Conclusions and policy implications

The study's findings reveal that the true social benefits of clean cooking fuel adoption are much greater than the social welfare effects due to reduced greenhouse gas emissions and health benefits due to the reduction of indoor air pollution. The benefit of clean cooking fuel adoption in terms of women's welfare gain is immediate and direct. However, this aspect received little attention in promotion campaigns. Given that women are time-poor and have a much higher burden of unpaid work than men, clean cooking fuel adoption has the potential for improving gender gap in unpaid household work by reducing fuel collection/preparation and cooking time and by shifting fuel collection responsibility from women to men. It thus can improve women's

⁴ Market price of LPG cylinder refill was aggregated at the village-level by averaging the price reported by the households who refilled their LPG cylinders.

opportunities for education, employment, and wellbeing by freeing up time and reducing smoke exposure.

Recognizing women's integral role in the adoption and sustained use of clean fuel, the PMUY used women as the target beneficiary for the subsidized LPG cylinder distribution program. Although this strategy increased adoption, the refill rate has been low among adopters. The paucity of distribution centers, lack of availability of doorstep deliveries, and delay in delivering refills are important drivers of the infrequent LPG refills. Therefore, to harness the full potential of LPG adoption, more investment is needed to improve access to LPG refills.

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