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Original Contribution

A Low-Cost Stove Use Monitor to Enable Conditional Cash Transfers

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Abstract: Conditional cash transfers (CCTs)—cash payments provided to households or specific household members who meet defined conditions or fulfill certain behaviors—have been extensively used in India to encourage antenatal care, institutional delivery, and vaccination. This paper describes the social design and technical development of a low-cost, meal-counting stove use monitor (the Pink Key) that enables a CCT based on liquefied petroleum gas (LPG) usage and presents pilot data from its testing and the initial deployment. The system consists of a sensing harness attached to a two-burner LPG stove and an easily removable datalogger. For each cooking event with LPG, households receive 2 rupees—less than the cost of fuel, but enough to partially defray LPG refill costs. The system could enable innovative "self-monitoring" at a large scale—participants initiate the CCT by bringing their Pink Key to antenatal clinic visits, where care providers download data and initiate payments, and participants return the sensor to their stove at home. The system aligns with existing Indian programs to improve health among poor, pregnant women, and contributes a new method to encourage the use of clean cooking technologies.

Keywords: Household air pollution, Biomass cooking, Liquefied petroleum gas, LPG, India, Solid fuel use, Temperature sensors

INTRODUCTION

Since 2010, clean cooking—through dissemination of clean fuels (such as liquefied petroleum gas) or advanced biomass cookstoves—has been the focus of initiatives and policies seeking to reduce the health and ecosystem consequences of biomass use for household energy needs. Some of these intervention programs have noted less than expected performance in terms of avoidance of health effects (Mortimer et al. 2017) or in reductions in exposure to pollutants (Sambandam et al. 2014; Balakrishnan et al. 2015), perhaps attributable to insufficient adoption of interventions. In the household energy realm, the mixed use of traditional and intervention stoves and fuels is referred to as "stacking" or "stove stacking" (Ruiz-Mercado et al. 2011; Ruiz-Mercado and Masera 2015).

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Understanding stacking behavior has been enhanced by stove use monitors (SUMs), a suite of time-resolved, unobtrusive, battery-operated, data-logging thermometers that provide detail on how often and for how long people use cooking, heating, and lighting appliances in their homes (Ruiz-Mercado et al. 2008, 2013; Pillarisetti et al. 2014; Lozier et al. 2016; Piedrahita et al. 2016). SUMs have been deployed on traditional stoves and interventions to assess adoption over time periods ranging from a few days to many months.

When coupled with surveys or direct observation, details of stoves and fuels used for specific tasks can be better understood (Ruiz-Mercado and Masera 2015; Piedrahita et al. 2016). In order to achieve desired health goals, stacking of traditional and intervention technologies must be minimized (Johnson and Chiang 2015)—that is, even occasional use of a polluting stove results in health-damaging exposures.

This realization has led to a growing body of research on how best to understand stove usage and long-term intervention adoption and indicates a need for new ways of encouraging the use of clean cooking technologies and discouraging the use of traditional cooking technologies. One method may be conditional cash transfers (CCTs)—payment to households in exchange for fulfilling specific behaviors. CCTs have been used in India (Lim et al. 2010), Mexico (Fernald et al. 2008, 2009), Brazil (Lindert et al. 2007), and beyond (Powell-Jackson et al. 2009; Lagarde et al. 2009) to promote maternal and child health and educational outcomes. CCTs address key clean cooking implementation science domains, including diffusion of innovation, concerns about financial viability of interventions at the household level, and alignment with the existing policy paradigms in countries evaluating clean cooking rollouts (Rosenthal et al. 2017).

This paper describes a novel stove use monitoring sensor system designed to enable a CCT to promote liquefied petroleum gas (LPG) use among pregnant women in Junnar, India, as part of ongoing pilot work. The study takes advantage of innovative national policies in India (Smith and Sagar 2015; Tripathi et al. 2015) that extend the availability of LPG in rural areas through targeted social investments to poor families. The goal of our work is to provide policy-relevant suggestions for how to encourage clean fuel use throughout and after pregnancy, beginning soon after conception to maximize benefits to mothers and unborn children during a period of high vulnerability to smoke exposure (Amegah et al. 2014).

India’s efforts to increase access to LPG (Smith 2017) and its history with CCTs targeted at pregnant women (Lim et al. 2010; Paul 2010) provide a supportive environment to explore how to implement a CCT to encourage sustained adoption of LPG—the first of its kind, to the best of our knowledge, applied to household fuels. In subsequent sections, we describe the elements required to implement the CCT: a class of new conditional cash transfer sensors (COCATS), the first of which is a meal-counting SUM, which we call the Pink Key (PK); their deployment in Junnar; and preliminary findings on their performance relative to thermocouple-based SUMs.

METHODS

Study Location

Our pilot takes place ~ 60 km north of Pune and ~ 60 km east of Mumbai in Junnar (block), Pune (district), Maharashtra (state), India (Fig. 1). Junnar has a population of ~ 374,000 (Commissioner OOTRGC 2011). 55 percent of households use solid fuels (wood, dung, and crop residues) for cooking in Junnar. KEM Hospital Research Centre (KEMHRC) works in rural Pune district through its Vadu Rural Health Program (VRHP), where it conducts nationally and internationally funded public health studies. Villages for this study were selected based on proximity to the VRHP Junnar office and to local LPG distributors, their prevalence of solid fuel use, and the availability of Accredited Social Health Activists (ASHAs), who assisted throughout the study.

Intervention Package

Participants in the study receive an LPG stove, two full LPG cylinders, a regulator, and hosing to connect the stove to the regulator and cylinder. This duplicates what is available in the national LPG dissemination program (*Pradhan Mantri Ujjwalla Yojana* or PMUY) for poor families (not all states provide a stove) (Mittal et al. 2017) and adds a second LPG cylinder to decrease opportunity for breaks in supply, an issue in rural areas where refilling an LPG cylinder can take many days, during which time households likely return to the use of traditional stoves and fuels. The provision of a second cylinder provides a buffer between when a request for a refill is made and when it is received.

The cylinder and stove were delivered and installed by service providers from local LPG distributors, who pro-

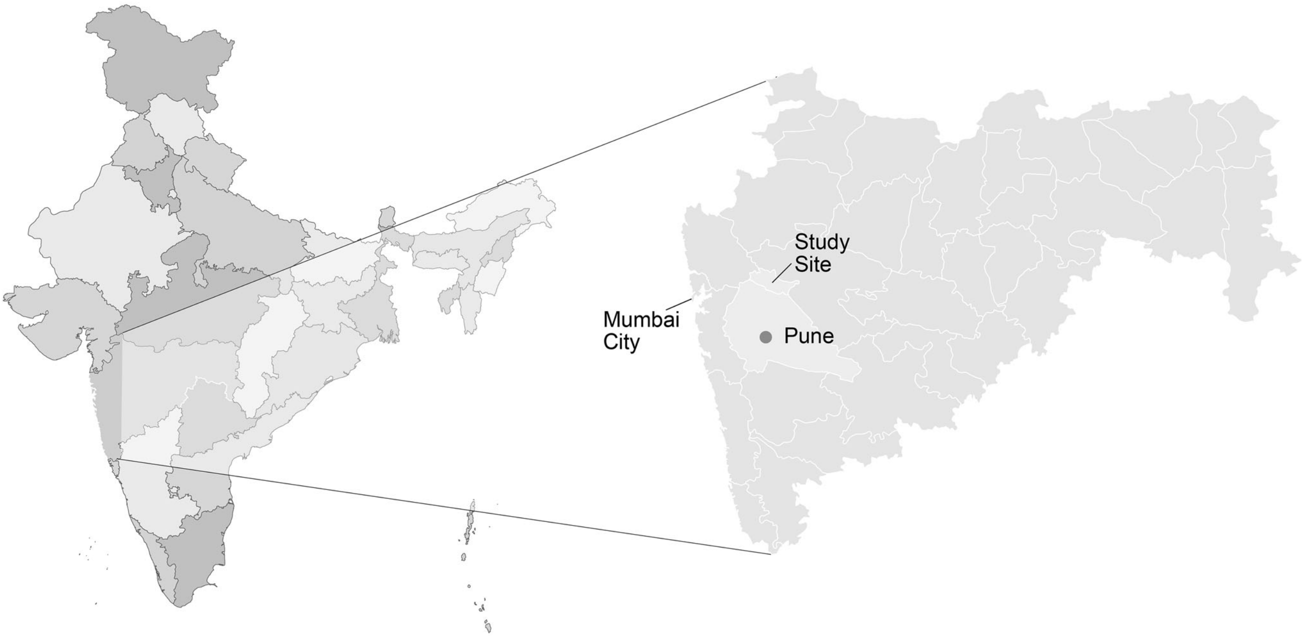

Figure 1. Study location in Junnar block, Pune district, Maharashtra, India.

vided guidance on usage and safety. This safety messaging was supplemented by our local field staff, who provided additional information on benefits for pregnant women, unborn children, and other household members of clean fuel use. Additionally, households received a table ∼ 1 m high with a surface area large enough to hold the stove and to provide a work surface for the cook. Because LPG is heavier than air, the cooking appliance should be placed above the top of the gas supply tank to reduce the chance of accidents in case of a leak. Households participating in the CCT arm of this study received a stove modified to accommodate the PK sensing system, described below.

Pink Key Sensing System

To enable a CCT, we created an inexpensive sensing system that consists of two components—a pink, cylindrical meal-counting data logger (Fig. 2a) that connects to an LPG Stove (Fig. 2b) and a sensing harness installed underneath the operating surface of the stove (Fig. 2c). The logger contains a reprogrammable microcontroller (PIC12F675, Microchip Technology, Chandler, AZ, USA) powered by a CR2025 lithium coin cell and a reference temperature sensor. The battery lasts for over 1 year, and the logger can record over 16 million cooking events. The total cost of parts is ∼ 15 USD; this would decrease substantially at scale.

The Pink Key attaches to a sensing harness fixed on an LPG stove via a 3.5-mm stereo headphone jack manually installed on the front surface of the stove by drilling an appropriately sized hole in the stove, screwing the jack into the stove, and securing with locally available glue. The PK logger is visible to participants; it serves as a visual reminder of the potential cash benefit of using the stove.

The sensing harness consists of two silicon diodes (Comchip Technology, 1N4148-G, Fremont, CA, USA), which exhibit a linear response to changes in temperature and are rated up to 200°C. Their wires are color-coded to distinguish between the two burners on the stove; the cathode end of each diode is clamped under a bolt approximately 2 cm from the flame, allowing it to heat and cool fairly quickly. The return electrical path for the diodes is through the stove body and back to the stereo jack.

The PK counts meals by comparing its internal reference temperature to temperatures measured on the stove. If the measured temperature of either burner is above the reference temperature by a defined amount (the hot threshold, 20°C) for a defined period of time (hot threshold time. 5 min), a meal counter is incremented. To denote the end of a meal, the temperatures of the burners must drop a certain amount below the reference temperature (the cold threshold, 10°C) for a defined period of time (cold threshold time, 5 min) to reset the timer. If the temperatures drop below the cold threshold, but for a

Figure 2. **a-b** The Pink Key Sensing System. **a** The Pink Key meal-counting datalogger. Approximately 1.5″ diameter and 0.75″ tall with a 0.5″ 3.5-mm headphone jack for mounting on the stove. **b** The mounting location for the PK on the front of a two-burner LPG stove (shown flipped over, resting on its burners). Also visible is the location of the two diodes connected to the bolts near the burners for measuring temperature changes on the stove.

period of time shorter than defined (that is, the temperature rises again), a single meal is counted. The thresholds and times are programmable.

Data are retrieved from the PKs by removing them from the stove and plugging them into a custom downloader which interfaces with a laptop via a serial terminal over USB. When connected, the device provides a menu allowing resetting, downloading, and programming of the PK. When downloading data, a single string of characters from the Pink Key is provided, including its unique device ID, constants related to the meal-counting algorithm, the total time duration of the current deployment in units of 10 s, the total time considered cooking for each burner, and an aggregated number of meals counted during the current deployment without regard to which burner(s) were used.

Sensor Validation

Two sets of validation tests were performed. First, we evaluated the sensing ability of 43 unique PKs during controlled tests and during routine evening and morning cooking by fieldworkers on a stove at the study's field office in Junnar. The stove was set up with four sets of stereo jacks and four sets of separate probes, allowing four PKs to be evaluated simultaneously. PKs were randomly selected from the complete batch of available sensors and placed into a sampling port, also at random. During the tests in the field office, we compared sensor meal counts with written accounts of the time spent cooking on each burner logged by fieldworkers.

The second test involved deployment of PKs in households participating in the study. For these tests, we also placed continuous, time-stamped, data-logging K-type thermocouple temperature sensors (Datalogger SSN61, Wellzion, Xiamen, China) on each burner to validate meal counts recorded by the PK on the same stove. Thermocouple sensing elements were placed in a standard position on all stoves, but not in the exact location of the Pink Key sensing elements due to lack of mounting space.

To match as closely as possible the measurements made by the Pink Key, the traces from the two thermocouples were merged into a single datastream by taking the maximum temperature at each timepoint across both left and right burners. A threshold algorithm was applied to determine periods of use. Peaks less than 45 min apart were clustered into a single event.

Fieldworkers and field managers kept detailed notes of any issues with installation and steps taken to resolve them. Repairs and modifications to stoves occurred either in the field or back at the field office.

Ethical Considerations

The study and all procedures performed in the study that involved human participants were approved by the Committee for the Protection of Human Subjects of University of California, Berkeley, and by the Institutional Ethics Committees (IECs) of Sri Ramachandra Medical College & Research Institute (Deemed to be University), Chennai, India, and KEM Hospital Research Centre, Pune, India. Informed consent was obtained from all individual participants included in the study.

RESULTS

Controlled Tests

In total, 43 unique PKs were evaluated over the course of 71 controlled tests. During 59 of these tests, a pot of water was heated on the large burner to boiling and allowed to simmer for 15 min. After 15 min, the stove was turned off and the pot was removed; the next test was not started until at least 15 min had passed, allowing the stove to cool. These tests evaluated the ability of the keys to count a single cooking event on a single burner. During 90% of these tests ($n = 53$), the PK correctly identified the single cooking event on a single burner. In three cases, the PK logged no data; in the remaining three cases, it logged on average two events more than were observed.

The remaining 12 tests involved evaluating the performance of the PK to detect stove use on both burners. Water was heated to a boil and then left to simmer on the large burner for 25 min. After 10 min of simmering, a second pot of water was heated on the smaller burner for 15 min. Both burners were then turned off and pots were removed for fifteen minutes, allowing the stove to cool. Both pots were returned to the stove and reheated for 15 min and then removed, and the stove was allowed to cool for 15 min. 75% of two-burner tests ($n = 9$) resulted in values measured by PKs matching those observed; the remaining three tests overestimated by one meal.

Overall, three tests (4% of all tests) of two sensors (5% of available sensors) resulted in no data logged by the PKs. In one case, the PK was not properly mounted to the stove. For the other two cases, the sensor was not functioning properly. For 61 tests (82%), the values measured by the PK matched those observed. Six PKs overestimated cooking by an average of 1.5 events (SD = 0.84, range = 1–3) and three PKs underestimated events by 1 (SD = 0). Figure 3 shows a Bland–Altman (BA) plot with the mean measurement between the two methods on the X axis and the difference between the measurements on the Y axis. BA plots show the limits of agreement between two measurement methods (in this case, the PK event counts vs the actual event counts).

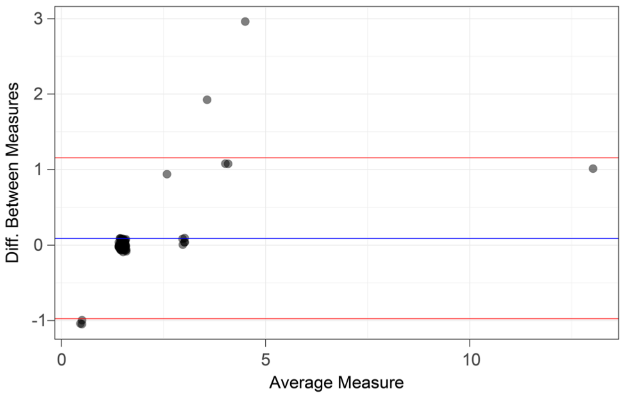

Figure 3. A Bland–Altman plot showing the limits of agreement between the Pink Key event counts and the actual event accounts (as logged by the stove user). The middle line is the mean difference between measurements. The upper and lowers lines are the upper and lower limits of agreement (defined as the mean ± 1.96SD). Points are jittered off their exact location to make them visible. As noted, however, the stove user data cannot be considered perfectly accurate.

Field Tests

Field tests were initially attempted in 28 households. During installation and preliminary sensor checks, over half of the PKs recorded no data or logged no cooking events when compared to findings from thermocouples. The following failure modes were identified in these households:

1. Improperly seated PK. For the PK to function, it must be fully seated in the stereo jack in the stove. In 11 households, the holes drilled in the stove were too large or were not appropriately sanded, preventing the logger from sitting flush in the jack against the stove body. As such, no data were recorded on the PK. Fieldworkers returned to homes and drilled a new hole and reinstalled jacks or used sandpaper to smooth existing holes.
2. PK electrical signal not grounded. In three households, the jack into which the Pink Key is plugged was not properly grounded to the stove body, leading to an incomplete electrical circuit. This was a result of error during installation of the harness and/or due to movement of the stove from the field office to the participant's home, during which the sensing elements may have been jostled loose. Fieldworkers rewired sensing harnesses as needed to repair this issue in or near homes.
3. Probes disconnected. In four households, sensing probes were not fixed to stoves. This occurred because households cleaned and/or moved the stove or removed the probes. Fieldworkers reattached probes and spoke with household members about care when moving or cleaning the stove.

Invalid sampling periods ($n = 13$) either had missing or nonexistent thermocouple data ($n = 5$), no PK data

(n = 3), or had malfunctioning PKs (n = 6) where many meals were recorded by TCs, but none were recorded by PKs. After resolving the above issues, another round of field data collection occurred. The final dataset consisted of valid thermocouple and PK data from 21 households across 31 unique sampling periods.

Measurements in the final dataset were made for on average 6.1 days (SD 2.9, range 3–16) between downloads. PK meal counts exhibited a moderate linear relationship with counts determined from the thermocouple ($R^2 = 0.35$), but were lower on average by 3.5 meals (Fig. 4). PK measurements had a mean absolute error of 8.4 and a root mean square error of 10.9.

DISCUSSION

For clean cooking interventions, as for many others in the health realm, behavior change remains a significant challenge even after a new technology is introduced. One method to address these challenges in other realms, such as prenatal care, has been to provide cash transfers conditioned on specific behaviors. One of the largest and most successful of these types of programs is Janani Suraksha Yojana (JSY) in India (Lim et al. 2010), which provides cash transfers to pregnant women upon completion of a series of antenatal care visits and delivery in an institution.

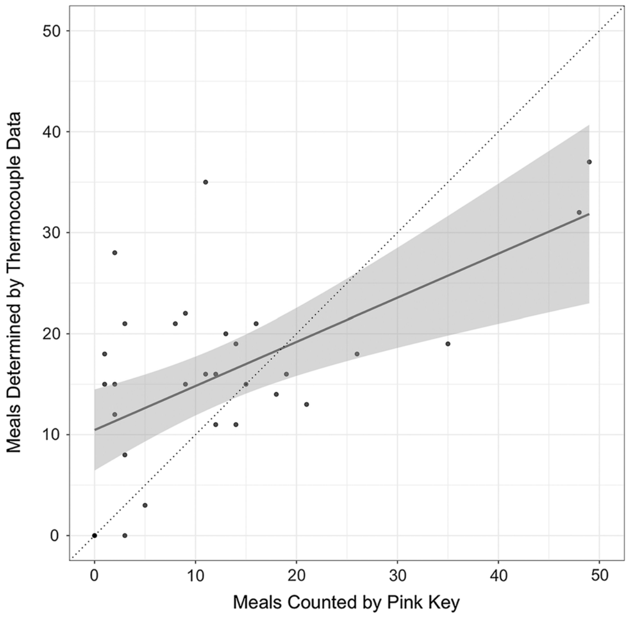

Figure 4. Relationship between thermocouple-derived meal counts and Pink Key-derived meal counts. The dotted line is a 1:1 line. The solid line is a linear model (Thermocouple counts ~ Pink Key counts); the shading is the standard error. The bias model fit may be due to differences in the placement of sensing elements and differences in the ways meal-counting algorithms are implemented between the TC and PK.

The application of this type of methodology to environmental health issues, such as clean cooking, is challenging. Unlike JSY or CCTs for clinic visits, which require interaction with and observation by a healthcare worker to verify behaviors, payments for clean cooking rely on monitoring stove use. Some solutions, like tracking fuel use solely through self-reported LPG sales or refill requests, may lead to a perverse incentive—participants may use more fuel in order to access more money. Another option, asking about stove use via questionnaire, has in many contexts been a poor predictor of actual use and could lead to poorly targeted cash transfers (Wilson et al. 2016; Ramanathan et al. 2016). Finally, using standard stove use monitoring techniques—which rely on sensors that must be carefully placed, regular downloads using laptops or mobile phones, and intensive data processing—would most likely prove too expensive to be a scalable and sustainable solution.

Our proposed solution—a low-cost, meal-counting sensor system to encourage the use of a clean fuel among pregnant women—seeks to avoid some of these pitfalls. By providing an objective measure of stove use, it eliminates the need for questionnaire-based recall and simplifies analysis related to stove use monitoring data by outputting a simple and understandable metric—the number of meals cooked. Furthermore, in being portable and small, it enables a woman to monitor herself—decreasing the costliness and intrusiveness of household visits to download data. Like other targeted CCTs in India, it only provides subsidized fuel for the period of time between detection of a pregnancy and delivery and thus avoids pitfalls of non-conditioned cash transfers without a clearly defined end. Finally, its upfront cost is lower than for other stove use monitoring technologies, indicating that it could be brought to scale. Other stove use monitoring technologies, like iButtons or thermocouples, cost between 25 and 80 USD per sensing element (between 50 and 160 USD per two-burner LPG stove). Further, it is unlikely that these monitors would be able to be removed and replaced by a participant reliably or easily. However, while our system enabling CCTs shows promise, it has been challenging to implement efficiently and effectively to date.

Strengths and Limitations

Our laboratory sensor validation provided substantial evidence that the PK system (1) could detect cooking events that included the use of one or two burners and that it clustered events properly, i.e., treated many short heating events separated by 1 or 2 min as a single event; (2) did not count very short heating events—under 10 min—as cooking; and (3) could detect multiple events when left attached for more than 1 day. We characterized events, not duration of cooking, because they are discrete occurrences that are easily explained to participants and to avoid perverse incentives for burning fuel to get a cash incentive.

Results from the field validation were mixed, beginning with significant challenges in ensuring proper functioning in village homes. Much of this initial trouble—including nonfunctioning sensors and poorly mounted sensing TRS jacks—was due to human error during the setup and deployment of the stoves. Nonetheless, while solvable, these errors indicate that a more robust mounting solution and an easier to install and deploy sensor harness may be needed before using this type of sensor in a larger project. It is worth noting, however, that a large-scale program could take advantage of economies of scale and centralized manufacturing to more professionally and permanently install sensors into stoves, rather than the retrofits performed during this project.

The relationship between use events counted using thermocouples and those counted using Pink Keys was moderate. A number of factors may have impacted the strength of that relationship. First, the algorithm utilized on the PK could not be implemented for analysis of the thermocouple data; the PK uses the difference between an internal measure of ambient temperature and a measurement at each burner to determine whether cooking is occurring. Analysis of the thermocouples, meanwhile, required aggregating two data streams and then using a fairly simple thresholding algorithm to determine cooking events. The algorithm utilized on the TC data was manually verified (not shown) by counting and clustering peaks chosen at random from daily data and comparing to the algorithmically derived data. This does not preclude, however, a fundamental difference in how the two algorithms detect events. Second, the PK and TC sensing elements were differently positioned under the stove and in different proximity to the heat source, potentially explaining some of the discrepancy between the measurements. Future evaluations should place the sensors in similar positions, where they experience similar thermal profiles on stove components that heat and cool consistently, likely leading to more similar identification of events by the two types of sensors. Finally, the two measurement devices utilize different types of sensing technologies, which may heat and cool differently. We believe that this would have only a small impact on our findings.

A cash transfer conditioned on clean fuel use may not decrease the use of the traditional stove. As part of ongoing work, we are performing a larger (albeit still small) pilot in 50 homes to see how the CCT influences the use of the chula and the LPG intervention stove. We are tracking the use of both traditional and LPG stoves using sensors and keeping detailed logs of fuel refill patterns in these homes. In these homes, we additional ask participants to disable their chula—either by removing it from the home, disassembling it, or by filling it with rocks as an added disincentive for the use of biomass fuels. Findings from this ongoing study will inform the design of the CCT and help decide if it is indeed worth pursuing at a larger scale. Additional CCT modes could also be explored—like paying people to stop using their traditional stove or paying people only when a certain small fraction of cooking is done with biomass. Such modes would require relatively inexpensive and simple ways to monitor traditional stove use, which is challenging due to the wide heterogeneity in traditional stove construction and fuel quality.

Our future work will couple fieldworker observation with thermocouple and Pink Key measurements to better characterize how the PKs are counting LPG stove usage, including refining the time and temperature thresholds that define a meal. A comparison between direct observation and PK counts may be more robust than relying on thermocouple data. Future tests will also better characterize each sensing element's rate of temperature increase and decrease and minimize differences in placement of sensing elements relative to the heat source. Finally, although this project addresses some implementation science domains, future research using implementation science methods may be useful for contextualizing the CCT system by focusing on the suitability of the technology and the incentive and incorporating feedback from participants, including household LPG users, distributors, and policymakers.

Social Design Considerations

Assuming, with further iteration, that technical challenges with the sensing system can be overcome, we think there is a significant opportunity for this type of sensor to enable a CCT complementary to JSY and other pregnancy-associated schemes in India. Under this scenario, pregnant women could carry the PK with them to an antenatal care center, where data could be downloaded from the sensor and a cash transfer—preferably directly to the women's bank account as is done with JSY, the PMUY programs, and other successful CCT programs—would be initiated. As such, a participant could "monitor herself" and reduce intrusive, time-intensive, and costly visits from fieldworkers, while working within a paradigm—cash transfers conditional on clinic visits—that she already understands and utilizes. The additional download time is minimal (approximately 30 s); we are investigating methods to use standalone devices that would be faster.

An issue related to any CCT is how much to pay for the desired behavior. For this study, we decided on approximately half the cost of fuel required to cook a meal, or approximately 2 Indian rupees (0.03 USD). At a higher price—and perhaps even at our chosen price—it is possible that households may use more LPG than is needed for tasks previously performed with biomass. While our per-meal CCT is low, if a cook used the stove twice a day for a month, the resulting CCT payment could meaningfully help defray costs of a refill or provide for other household needs. Future studies could explore optimal values for and methods to deliver this reimbursement.

CONCLUSIONS

Encouraging sustained behavior change around specific health-related goals remains challenging. While much progress has been made in recent years in understanding the dynamics and needs of rural households where clean cooking programs are targeted, less is understood about how best to encourage the consistent use of new technologies over time. CCTs provide one proven method on how to do so across a variety of policy domains and settings, but require careful thought and considerable reframing when applied to environmental health issues to ensure they are properly conditioned and targeted.

Using relatively low-cost sensors, such as the Pink Key described here, to enable CCTs offers a potential way forward. Any sensor-based CCT will require considerable evaluation and testing prior to significant implementation. Vitally, for our ongoing study and any other sensor-based CCT, at least two conditions must be met: (1) the sensor must accurately and unobtrusively monitor the behavior of interest and easily provide reliable summary metrics to those administering financial incentives and (2) the process of using the sensor and initiating cash transfers based on desired behaviors must be frictionless—that is, the sensor and CCT should impose only minimal burden on participants and field staff administering the program.

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COMPLIANCE WITH ETHICAL STANDARDS

CONFLICT OF INTEREST The authors declare that they have no conflict of interest.

REFERENCES

Alderman J (2017) *Envirofit announces groundbreaking Smart-Gas^{TM} program offering pay-as-you-cook LPG service for emerging markets [Internet]*. Retrieved from: https://envirofit.org/envirofit-announces-groundbreaking-smartgas-program/

Amegah AK, Quansah R, Jaakkola JJK (2014) Household air pollution from solid fuel use and risk of adverse pregnancy outcomes: a systematic review and meta-analysis of the empirical evidence. *PLoS ONE* 9:e113920–e113923. https://doi.org/10.1371/journal.pone.0113920

Balakrishnan K, Sambandam S, Ghosh S, Mukhopadhyay K, Vaswani M, Arora NK, et al. (2015) Household air pollution exposures of pregnant women receiving advanced combustion cookstoves in India: implications for intervention. *Ann Glob Health.* 81(3):375–385

Commissioner OOTRGC (2011) *India Population and Housing Census 2011*, New Delhi, India: Office of the Registrar General & Census Commissioner

Fernald LC, Gertler PJ, Neufeld LM (2008) Role of cash in conditional cash transfer programmes for child health, growth, and development: an analysis of Mexico's Oportunidades. *The Lancet.* 371(9615):828–837

Fernald LC, Gertler PJ, Neufeld LM (2009) 10-year effect of Oportunidades, Mexico's conditional cash transfer programme, on child growth, cognition, language, and behaviour: a longitudinal follow-up study. *The Lancet.* 374(9706):1997–2005

Johnson MA, Chiang RA (2015) Quantitative guidance for stove usage and performance to achieve health and environmental targets. *Environ Health Perspect*

Lagarde M, Haines A, Library NPTC (2009) The impact of conditional cash transfers on health outcomes and use of health services in low and middle income countries. Wiley Online Library

Lim SS, Dandona L, Hoisington JA, James SL, Hogan MC, Gakidou E (2010) India's Janani Suraksha Yojana, a conditional cash transfer programme to increase births in health facilities: an impact evaluation. *The Lancet.* 375(9730):2009–2023

Lindert K, Linder A, Hobbs J, la Brière De B (2007) The nuts and bolts of Brazil's Bolsa Família Program: implementing conditional cash transfers in a decentralized context

Lozier MJ, Sircar K, Christensen B, Pillarisetti A, Pennise D, Bruce N, et al. (2016) Use of temperature sensors to determine exclusivity of improved stove use and associated household air pollution reductions in Kenya. *Environ. Sci. Technol.* 50(8):4564–4571

Mittal N, Mukherjee A, Gelb A (2017) *Fuel Subsidy Reform in Developing Countries: Direct Benefit Transfer of LPG Cooking Gas Subsidy in India*. CGD Policy Paper. Washington, DC: Center for Global Development. https://www.cgdev.org/publication/fuel-subsidy-reform-developing-countries-india

Mortimer K, Ndamala CB, Naunje AW, Malava J, Katundu C, Weston W, et al. (2017) A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial. *Lancet.* 389(10065):167–175

Paul VK (2010) India: conditional cash transfers for in-facility deliveries. *The Lancet.* 375(9730):1943–1944

Piedrahita R, Dickinson KL, Kanyomse E, Coffey E, Alirigia R, Hagar Y, et al. (2016) Assessment of cookstove stacking in Northern Ghana using surveys and stove use monitors. *Energy for Sustainable Development.* 1(34):67–76

Pillarisetti A, Vaswani M, Jack D, Balakrishnan K, Bates MN, Arora NK, et al. (2014) Patterns of stove usage after introduction of an advanced cookstove: the long-term application of household sensors. *Environ. Sci. Technol.* 48(24):14525–14533

Powell-Jackson T, Morrison J, Tiwari S, Neupane BD, Costello AM (2009) The experiences of districts in implementing a national incentive programme to promote safe delivery in Nepal. *BMC Health Services Research* 9(1):97

Ramanathan T, Ramanathan N, Mohanty J, Rehman IH, Graham E, Ramanathan V (2016) Wireless sensors linked to climate financing for globally affordable clean cooking. *Nature Clim Change.* 7(1):44–47

Rosenthal J, Balakrishnan K, Bruce N, Chambers D, Graham J, Jack D, et al. (2017) Implementation science to accelerate clean cooking for public health. *Environmental Health Perspectives* 125(1):A3–A7

Ruiz-Mercado I, Canuz E, Walker JL, Smith KR (2013) Quantitative metrics of stove adoption using Stove Use Monitors (SUMs). *Biomass and Bioenergy.* 57:136–148

Ruiz-Mercado I, Lam NL, Canuz E, Davila G, Smith KR (2008) Low-cost temperature loggers as stove use monitors (SUMs). *Boiling Point* (55)

Ruiz-Mercado I, Masera O (2015) Patterns of stove use in the context of fuel–device stacking: rationale and implications. *Ecohealth* 1–15

Ruiz-Mercado I, Masera O, Zamora H, Smith KR (2011) Adoption and sustained use of improved cookstoves. *Energy Policy.* 39(12):7557–7566

Sambandam S, Balakrishnan K, Ghosh S, Sadasivam A, Madhav S, Ramasamy R, et al. (2014) Can currently available advanced combustion biomass cook-stoves provide health relevant exposure reductions? Results from Initial Assessment of Select Commercial Models in India *Ecohealth.* 12(1):1–17

Smith KR (2017) Why both gas and biomass are needed today to address the solid fuel cooking problem in India: A challenge to the biomass stove community. *Energy for Sustainable Development.* 1(38):102–103

Smith KR, Sagar AD (2015) Making the Clean Available: Escaping India's Chula Trap. *Energy Policy.* 75:410–414

Tripathi A, Sagar AD, Smith KR (2015) Promoting clean and affordable cooking. *Economic Political Weekly* 50(48):81–84

Wilson DL, Coyle J, Kirk A, Rosa J, Abbas O, Adam MI, et al. (2016) Measuring and increasing adoption rates of cookstoves in a humanitarian crisis. *Environmental Science and Technology* 50(15):8393–8399