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Research Paper

Impact of targeted subsidies on access to resilient sanitation for climate-vulnerable households in rural Cambodia

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ABSTRACT

Access to safe sanitation is a basic requirement for human well-being and is critical for protecting public health and preventing environmental contamination at the community level. The increasing global risk of climate-related disasters exacerbates the likelihood of traditional sanitation solutions failing and exposing communities to harmful pathogens. This risk is ubiquitous in Cambodia's flood-prone Tonle Sap Lake region, which has some of the lowest rates of sanitation coverage in the country. This study sought to design and test a targeted mechanism in the region to deliver sanitation subsidies to households in a vulnerable position due to climate and socioeconomic characteristics. Subsidy eligibility was evaluated using the poverty probability index for Cambodia, with thresholds set according to households' individual and community-level climate vulnerability. In a randomized controlled trial, offering subsidies increased the likelihood of successful sales conversions for climate-resilient latrine products among targeted households by 32 percentage points, indicating effectiveness for increasing market-based sanitation uptake. The research did not find evidence of widespread or sustained market distortion due to the subsidy program.

Key words: climate resilience, climate smart sanitation, climate vulnerability, open defecation free, sanitation, subsidies

HIGHLIGHTS

- Being offered a subsidy increased the likelihood that a given household would purchase a latrine by 31% (over ineligible comparison households).
- The sales closing rate among eligible households in treatment areas was 38% compared to 6% among ineligible treatment households.
- When offered a subsidy, households who were climate vulnerable were most likely to purchase a latrine.
- No evidence of significant market distortion due to the subsidy was identified.

INTRODUCTION

Globally, open defecation rates have declined markedly in the last two decades. Between 2000 and 2020, the global rate of open defecation decreased from 21 to 6%, yet fully eliminating unsafe sanitation practices remains a challenge. Studies show that once a country reduces its rate of open defecation below 25%, progress slows, and access to safe sanitation solutions remains inequitable in many areas.[1]

Cambodia has made substantial progress in improving access to sanitation, experiencing one of the largest declines in open defecation worldwide (dropping from 87% in 2000 to 19% in 2020).[2] Nevertheless, significant disparities in sanitation access

[1] JMP (2021)
[2] Ibid.

between rural and urban areas persist. Only 61% of households in rural areas had access to at least basic sanitation services in 2020, in contrast to all households in urban areas.[3] The rate of open defecation – an environmental and public health hazard – in Cambodia remains the highest in the region, with 79% of the poorest rural Cambodians engaging in this practice.[4,5]

Communities around Cambodia's Tonle Sap Lake are among the country's most climate vulnerable and socioeconomically challenged with some of the lowest rates of sanitation coverage in the country.[6] Seasonal variations in water levels, heavy rainfall, and regular flooding there render basic sanitation technologies ineffective and unsafe, while affordability and access to appropriate technology and services limit these households from adopting safe sanitation. While past research has demonstrated the impact of targeted subsidies to increase household sanitation uptake within communities without distorting markets, there is a dearth of evidence on the effectiveness of subsidy mechanisms that include climate vulnerability as a key determinant of eligibility.[7,8]

iDE's Water for Women-funded WASH-SUP2 project and European Union-funded GREEN Project were designed to address these challenges in rural Cambodia, making safe, effective, and climate-appropriate sanitation solutions affordable to all households, especially those from systemically marginalized groups. As climate-resilient sanitation products are often difficult for the most economically and climate-vulnerable households to afford, the project provided subsidies to households in the form of partial discounts (50% of the product price) on durable, resilient latrines to help mitigate the cost. Products include the durable, concrete-lined 'Easy Latrine' (retail price ~USD70), suitable for non-flood-prone locations, and the 'Sky Latrine' (~USD140), with an elevated superstructure and added ventilation to allow access, functionality, and below-ground containment despite seasonal floods. To avoid market distortion, it was important to ensure that these subsidies were effectively targeted toward households in vulnerable positions. This research sought to build upon a previously used subsidy mechanism that relied upon the existing IDPoor mechanism, a Cambodian government poverty classification, for targeting. This included contextualizing the previous mechanism for use in climate-vulnerable regions by including additional measures of climate shocks and socioeconomic exclusion.[9] The new mechanism was designed to be incorporated into iDE's existing sales presentations conducted by trained sales agents.

By using a clustered randomized controlled trial (RCT), researchers piloted this novel subsidy targeting mechanism and evaluated its impact on latrine sales in target communities. In addition, by using primary qualitative data (interviews with sales agents, local authorities, and latrine business owners (LBOs)) as well as an analysis of the pilot program costs, the research team sought to evaluate the sustainability and scalability of the mechanism to assess its suitability for use in other contexts and environments by other implementers, including government. Qualitative interviews with sales agents were also designed to detect evidence of market distortion or manipulation of the subsidy mechanism by households or agents themselves.

RESEARCH OBJECTIVES

This research aims to build on existing literature by generating evidence on subsidies that also include eligibility criteria related to climate vulnerability at the household and community levels. Building upon iDE work to identify viable sanitation product/service combinations, subsidy delivery channels, and business service networks, this research first developed and validated a targeted subsidy mechanism with a two-layer identification process. The first layer identified climate-vulnerable geographies, while the second considered household factors. Eligibility criteria were finalized through an initial feasibility study that considered aspects of climate and socioeconomic vulnerability, including IDPoor[10] status, female-headed households, disability, and other relevant factors.

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[3] JMP Water and Sanitation Data for Cambodia (2020)

[4] Ibid

[5] World Health Organization and UNICEF (2019)

[6] Asian Development Bank (2014)

[7] Nicoletti *et al.* (2022)

[8] Guiteras *et al.* (2015)

[9] Birdsall (2022)

[10] ID Poor is a community-driven proxy means test that identifies and registers households living beyond the poverty line and households having problems to sustain their livelihood due to special circumstances. https://idpoor.gov.kh/en/about/

After developing and validating this subsidy mechanism through a field pilot, an RCT was conducted to verify the degree to which this targeted subsidy mechanism facilitated investment in safe sanitation among target households. In treatment areas, eligible households were offered the option to purchase a latrine with a subsidy, while households in control areas could only purchase at retail price.

To understand the impact of the sanitation subsidy within climate-vulnerable regions, this study focuses on three primary research questions:

1. *What impact did the subsidy mechanism have on the rate of latrine sales among households in a vulnerable position due to climate and socioeconomic challenges?*
2. *What was the impact of subsidy provision on those that are eligible? In what ways, if at all, do these impacts differ for households qualifying through the new mechanism (poverty probability index (PPI)) when compared to those qualifying through the previous mechanism (IDPoor)?*
3. *What, if any, market distortion occurred as a result of implementing the subsidy mechanism?*
4. *How sustainable and scalable is the intervention (from subsidy screening to product delivery)?*

METHODS[11]

Household eligibility assessment

This study sought to expand on previous iterations of iDE's subsidy mechanism, which used the government-implemented IDPoor poverty identification system. Providing subsidies to IDPoor households was found to be effective in increasing latrine sales; however, the IDPoor system does not account for households' climate vulnerability, which is tied to both their present and future socioeconomic conditions.[12]

Determining eligibility

The exact amount of the subsidy was fixed at 50% of the latrine purchase price (see Supporting Information). To assess socio-economic challenges, the research team utilized the existing PPI, a mechanism that has been validated and proven effective both globally and in the Cambodian context.[13] The PPI is a statistically sound, country-specific, and easy-to-use poverty measurement tool designed to assess the likelihood that a household is living below the poverty line. The PPI assessment produces a numeric score using 10 questions associated with the likelihood that a household is living below a certain poverty threshold.

Community climate vulnerability was determined using climate vulnerability index (CVI) scores calculated by The National Council for Sustainable Development at the commune level.[14] These scores, which take into account a commune's level of vulnerability to three main types of climate hazards (floods, droughts, and storms), correspond to four categories: 'Least Vulnerable,' 'Less Vulnerable,' 'Quite Vulnerable,' and 'Highly Vulnerable.' Villages located in a commune classified as 'Quite' or 'Highly' vulnerable were considered to be vulnerable at the community level for the purposes of this study (exact CVI score ranges and designations can be found in the Supporting Information).

Household-level climate vulnerability was assessed by asking households whether they had experienced a flood, drought, or storm that unusually disrupted their income or resulted in significant unexpected expenses in the previous year. The 1-year recall period was selected to be broad enough to capture potential climate-related events across all seasons while remaining narrow enough to only include those households most acutely at risk as well as to limit the recall bias associated with a longer timeframe.

To incorporate climate vulnerability metrics while maintaining the statistical integrity of the PPI scoring mechanism, the research team set and applied three distinct subsidy eligibility thresholds. These thresholds were validated using data from the feasibility study. Determining an individual household's eligibility to receive a subsidy required comparing their overall PPI score to the threshold that aligned with their household and community-level climate vulnerability. Of the three eligibility thresholds, the least restrictive threshold was applied to households who were determined to be climate vulnerable at

[11] IRB approval details located in supporting information.

[12] The World Bank Group & The Asian Development Bank (2021)

[13] Schreiner (2015)

[14] The National Council for Sustainable Development (2015–2021)

both the individual and community levels. The most restrictive threshold was applied to households who were not identified as being climate vulnerable at either the household or community level. Each household's individual PPI score was then benchmarked against the appropriate threshold. Households whose PPI score fell below the relevant threshold were considered to be eligible for a subsidy. Based on feasibility testing results, it was estimated that 25–35% of the total number of households in the study areas would be eligible. A detailed overview of each PPI threshold, the associated poverty probabilities, and the feasibility study methodology can be found in Supporting Information.

Sampling frame and sample size

Quantitative

Sample sizes were calculated to account for a clustered design to achieve statistical power while balancing budgetary and operational needs. The minimum required sample included 26 villages with 100 households per village (2,600 total households); the final sample included 30 villages. Villages were divided equally into treatment and control groups, stratifying across climate vulnerability status: 23 villages were designated as climate vulnerable (11 control and 12 treatment). Balance checks were conducted to avoid any statistically significant differences in means between the treatment and control group across key variables of interest.[15] All latrine sales took place within Kampong Chhnang province using iDE's standard sales approach.[16] Treatment status was randomly assigned at the village (community) level using Stata's randtreat function to limit spillover and allow for a robust analysis of potential market distortions occurring as a result of the subsidy (additional details available in Supporting Information).

Qualitative

Thirteen in-depth interviews were performed with various key stakeholders, including LBOs, local government representatives, and sales agents. This is cited to be sufficient to reach saturation, where all key themes have emerged from the data (Hennink & Kaiser 2022). The qualitative sampling frame is presented in more detail in the Supporting Information.

Data collection procedures

Field implementation lasted 7.5 months (20 January 2022–31 August 2022) and included 2,821 sales presentations across 30 villages in Kampong Chhnang province.[17] In treatment areas, target households received subsidies, while all households in control areas received sales pitches for the retail priced product.

iDE sales staff conducted eligibility assessments and collected sales data. Within each village, the sales team approached every household without a toilet (identified with the support of local authorities and neighbors, so long as a household decisionmaker was home). The sales agent secured consent, conducted the assessment, and began the sales presentation for the latrine product. If the household was eligible for a subsidy, the sales agent offered a discounted price for the product and the household then chose whether to purchase the latrine.

iDE's monitoring and evaluation officer independently visited approximately 10% of purchasing households and conducted the same assessment to verify whether sales agents correctly identified target households. Although sales agents received a standard commission on each sale (regardless of a subsidy was offered), they also received a small salary from iDE. Sales agents were informed that these spot checks would be occurring to ensure integrity and minimize the motivation to increase sales by artificially inflating the number of subsidies offered.

All four sales agents involved in this research were native Cambodians who were trained as professional sales agents by iDE. Three were women, one was a man, and all of them conducted sales presentations across all study villages (rather than being assigned a specific territory). Performance as measured by sales closing rate was relatively even across all sales agents.

A detailed overview of data collection with ethical protections can be found in the Supporting Information.

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[15] The results of these balance checks are presented in the supporting information.

[16] See supporting information for a description of how the eligibility assessment was incorporated into the standard sales approach.

[17] In some cases, sales agents visited households more than once. The survey tool included a screening question designed to assess whether the household had previously interacted with a sales agent. A total of 1,598 responses in the original dataset were duplicate visits, of which 36 resulted in a latrine sale. All of these duplicate entries were dropped from the dataset to mirror more realistic selling conditions (in which sales agents would likely only visit each household once). Latrine closing rates were calculated after dropping these entries.

Data analysis

Quantitative

To analyse sales and eligibility assessment data and answer key research questions, the research team employed ordinary least squares (OLS) regression models for continuous outcome variables, logistic regression with marginal effects for binary outcome variables, difference-in-means tests, and supporting descriptive statistics.

Village level. Aggregating the latrine sales rate at the village level was designed to reduce noise by mitigating the potential influence of outliers as well as to increase precision, especially in communities where the purchase of a latrine was expected to be a relatively rare occurrence at the household level. To understand the impact of the subsidy mechanism on the overall latrine sales rate at the village level, the research team utilized a linear regression model:

$$Y_{\text{village latrine uptake rate}} = \beta_0 + \beta_1 \text{treatment} + \beta_2 \text{community climate vul.} + \varepsilon_i$$

The primary model included the village-level latrine sales rate as the outcome variable and treatment (whether subsidies were offered) as the independent variable, with the village-level climate vulnerability status as a control. Subsequent models used the village-level rate of latrine sales among specific groups of interest (all eligible households, PPI-qualifying households, and IDPoor households) as outcome variables to isolate the efficacy of the subsidy mechanism in increasing latrine sales among the targeted households specifically.[18]

To isolate the marginal impact of offering subsidies in climate-vulnerable communities, the research team utilized the same linear regression model with village-level latrine sales rate as the dependent variable and treatment as the independent variable, but included an interaction term between treatment and climate vulnerability:

$$Y_{\text{village latrine uptake rate}} = \beta_0 + \beta_1 \text{treatment} + \beta_2 \text{climate vulnerability} + \beta_3 \text{treatment} * \text{community climate vul.} + \varepsilon_i$$

Household level. To estimate the impact of treatment on individual households' latrine purchasing decisions, the research team utilized a series of logistic regressions in which the outcome of interest was a binary variable, indicating whether a latrine was purchased. The independent variable used in these models was treatment, which was defined as a categorical variable representing the treatment and eligibility status of the household.[19] A base model with no controls was run first, followed by a model that controlled for the climate eligibility status of the community and of the household. Standard errors were clustered at the village level. To facilitate interpretation, the research team used the postestimation command 'margins' to convert regression results into the predicted probability of a household purchasing a latrine based on their treatment and climate vulnerability status (at all levels).

$$\log\left(\frac{P(y_{\text{latrine purchase}})}{1 - P(y_{\text{latrine purchase}})}\right) = \beta_0 + \sum(\beta_1 \text{ combined treat. and elig.}, \ \beta_2 \text{ climate vul.}) + \varepsilon_v$$

To identify the marginal impact of climate vulnerability on the predicted probability of purchase, the research team utilized the same logistic regression specification but defined treatment as a binary variable indicating whether a household was offered a subsidy. Standard errors were again clustered at the village level. This model was run twice using first community climate vulnerability and later household vulnerability. Then the postestimation command *margins* were used to evaluate the marginal impact of community-level CVI status on the predicted probability of purchase, holding subsidy status constant at both 0 and 1.

$$log\left(\frac{P(y_{\text{latrine purchase}})}{1 - P(y_{\text{latrine purchase}})}\right) = \beta_0 + \sum(\beta_1 \text{ offered subsidy}, \ \beta_2 \text{ community climate vul.}) + \varepsilon_v$$

[18] Three subsequent models were run using the rate of latrine uptake among all vulnerable households, IDPoor households, and PPI-qualifying households as outcome variables.

[19] This variable indicated if a household was (1) treated, eligible; (2) treated, ineligible; (3) control, eligible; and (4) control, ineligible.

Qualitative

All interview transcripts were analysed using ATLAS.ti Software, using a qualitative thematic content analysis approach. Coding was both deductive and inductive, whereby an initial codebook was drafted based on research questions and known key themes, with further codes and subcodes added as they emerged from the data. The finalized codebook, at the point of saturation with no more codes to be added, was applied to the whole dataset. After coding all data, analysts used ATLAS.ti's analytical capacities[20] to identify findings.

RESULTS

Overall, subsidy eligibility was higher than the 25–35% originally predicted, with 51% of households in treatment villages and 45% of households in control villages qualifying for a subsidy. This is attributed to the small sample size and limited geographic scope of the feasibility study, which was used to predict eligibility rates. Of the households who were eligible for a subsidy, the majority qualified as a result of their IDPoor status.

The percentage of qualifying households who were eligible as a result of their IDPoor status – as opposed to their PPI score – was slightly higher among the treatment group (56%) than the comparison group (54%). Through qualitative interviews, sales agents revealed that village authorities were much more inclined to support them in identifying poor households and households without an existing latrine in villages where subsidies were offered. An increased ability to identify poor households along with the heightened incentive to do so in treatment villages likely explains at least some of this difference in support from village authorities.

Impact of subsidy mechanism on latrine uptake

Subsidies were found to have a substantial and statistically significant impact on the latrine purchase rate among targeted households. At the household level, being offered a subsidy increased the likelihood that an eligible household would purchase a latrine by 31 percentage points ($p = 0.00$) (Table 1).

In treatment areas where subsidies were offered, close to a quarter of all sales presentations (22%) led to a sale, compared to 7% in control areas where no subsidies were offered ($p = 0.00$). At the village level, offering subsidies resulted in a 23 percentage point higher village-level sales closing rate when compared to the closing rate in control villages where no subsidies were offered ($p = 0.00$) (see Table 8 in the Supporting Information).

This difference was driven almost entirely by households in a vulnerable position based on key socioeconomic traits, either through their IDPoor status or their PPI scores. In treatment areas, the sales closing rate among households who were offered a subsidy was 38%, compared to 6% among ineligible households ($p = 0.00$). In control areas, where all households were offered the latrine at full price regardless of their eligibility, the fraction of households who purchased was comparable between those who were eligible and those who were not (8 versus 6%), and this difference was not statistically significant ($p = 0.32$).

Among subsidy-qualifying households, offering subsidies increased the village-level latrine purchase rate by 32% ($p = 0.00$). The biggest difference in sales closing rate was observed among households who qualified through the PPI, among whom receiving a subsidy offer increased the village-level sales closing rate by 37 percentage points ($p = 0.00$), in contrast to a 26% increase for those that qualified via IDPoor status ($p = 0.03$).[21]

Direct household climate vulnerability, defined as whether a household reported experiencing a climate-related event in the past year that severely disrupted their income or resulted in unexpected expenses, did influence sales. Consistent with the

Table 1 | Logistic regression results: Change in predicted probability of purchase by subsidy status

Treatment area	Eligibility	Received subsidy?	Marginal probability	*p*-Value
Control	Not eligible	No	Base	Base
	Eligible	No	0.0132	0.416
Treatment	Not eligible	No	−0.0056	0.860
	Eligible	Yes	0.313***	0.00

***denotes statistical significance at the 99% level of confidence.

[20] These include code-document comparison, code distribution, and examining code-co-occurrences.

[21] As all IDPoor households automatically qualified for subsidies, none of the households who qualified via the PPI mechanism were also IDPoor.

results mentioned earlier, receiving a subsidy offer increased the likelihood of a latrine purchase among all households over the baseline (ineligible control households), but this increase was 10 percentage points larger among households who reported they were personally vulnerable to climate-related events ($p = 0.00$). Among households not offered subsidies, direct climate vulnerability did not have a statistically significant impact on the likelihood they would purchase a latrine.

The share of households who purchased a Sky Latrine (the more expensive latrine model) was higher among subsidy-eligible households than those who were ineligible. This was true across the treatment and control groups, but the difference was greater among the treatment group (18 percentage points versus 5 percentage points). This is likely due to the fact that households who experience high degrees of flooding were more likely to be eligible, and the appropriate product for such households is the elevated Sky Latrine (rather than the standard Easy Latrine).

Although the majority (64%) of households identified as directly climate vulnerable were living in communities also identified as vulnerable, the latrine sales rate at the village level was comparable regardless of village climate vulnerability status. This was particularly true for communities designated as least or quite climate vulnerable. Lower sales closing rates were observed in communities identified as less vulnerable, but this is attributed largely to the sample size of less vulnerable communities, which was considerably smaller than either of the other two designations. Village-level regression results revealed that the impact of offering subsidies was comparable regardless of the climate vulnerability status of the community.

Analysis of market distortion due to subsidy mechanism

In addition to understanding the effectiveness of the subsidy mechanism in encouraging latrine sales among targeted households, this study was also designed to identify any distortion in the market that may have occurred as a result of the subsidies. Specifically, the research team was concerned that introducing subsidies to the market may encourage households who were not eligible to wait to purchase a latrine until they were also offered a subsidy, limiting sanitation uptake. Conversely, evidence from other contexts globally suggests that subsidies can have a positive impact on latrine uptake among noneligible households due to the social multiplier effect (Guiteras *et al.* 2015).

A comparison of the latrine purchase rate among noneligible households, however, revealed no significant differences between the treatment and control groups. In addition, when asked by sales agents why they had not purchased a latrine, only 3 of the 2,352 households reported that they were waiting on a subsidy. This provides strong evidence that market distortion was not an issue within treatment communities. Due to the limited timeframe, however, it is worth noting that a delayed response among ineligible households is a possibility.

Through qualitative interviews, some sales agents reported anecdotal evidence that suggests some households felt that the assessment was a test that they could 'pass.' As sales agents often followed up with households who declined to purchase multiple times, it is possible that households could have begun to understand how the assessment worked and manipulated their answers to qualify. There is no evidence that this behavior was common, however. Only 26 households in the treatment group (1%) purchased a latrine with a subsidy during a follow-up visit and less than half (12 households) qualified through the PPI mechanism, indicating this behavior occurred infrequently, if at all. In addition, no clustering was observed around each of the PPI cutoff thresholds, providing further evidence that no widespread, deliberate manipulation of the mechanism was taking place.

Overall, the subsidy eligibility rate was higher in treatment areas, where close to 52% of all households were eligible (as compared to 45% of households in control areas) ($p = 0.00$). This difference is likely driven by the number of IDPoor households, which was 5% higher in treatment areas ($p = 0.00$), suggesting that sales agents may have been working with village leaders to specifically target these subsidy-eligible households to increase latrine sales. There was no significant difference between treatment and control communities in the number of households qualifying via the PPI.

Sustainability and scalability of the mechanism

Overall, the 7.5-month pilot sales period resulted in the sale of 437 latrines across 30 villages and four districts (326 in the treatment group and 111 in the control group).

The actual fixed cost of the pilot implementation was estimated to be USD 125,305.90 and consisted primarily of costs associated with labor and administration. Marginal costs were only applied to subsidized latrines and equated to the weighted average cost of the subsidy offered (USD 44.84). Unsubsidized latrines carried no marginal costs, as all costs (including sales agent commissions) were borne by either the purchasing households or the installing LBO.

The overall programmatic cost per latrine for the pilot amounted to USD 320.20. The overall per unit cost was substantially lower within the treatment group, at USD 224.22. In contrast, the cost per latrine in the control group was USD 602.07, a difference attributed to the significantly lower number of latrines sold in these areas.

To evaluate the cost of scaling up, iDE provided estimates of the staffing requirements and fixed costs associated with expanding to 90 villages in the same 7.5-month timeframe. By using figures calculated from the pilot data, the research team estimates that without subsidies, this expansion would result in the sale of 624 latrines at a cost of USD $351.32 per latrine. In contrast, offering subsidies across the entire scaled-up program was forecasted to result in 2,096 sales during the same time period, a 236% increase. This increase in sales was also predicted to reduce the cost per latrine by more than half, to USD 149.51. Although implementing the subsidy program at scale would result in a higher total cost to iDE, it would reduce the cost per latrine sold, improving the cost-effectiveness of the program on a per unit basis.

DISCUSSION

Offering targeted subsidies significantly increases the likelihood of a household purchasing a latrine. This translated to higher sales closing rates at the village level, which should result in higher rates of sanitation coverage within communities in which subsidies were offered when compared to those without subsidies.

Under iDE's previous targeted subsidies mechanism, eligibility for a subsidy was predicated on a household's IDPoor status alone. The novel eligibility assessment developed through this research incorporated the PPI assessment to evaluate households who had not qualified through the IDPoor system and added additional dimensions of household and community-level climate vulnerability. The higher sales closing rate associated with a subsidy offer among households who qualified under this mechanism suggests that incorporating the PPI assessment increases the mechanism's efficacy at reaching households who otherwise would have been unwilling or unable to purchase a latrine, thus increasing the sanitation coverage rate in the target communities. Household-level climate vulnerability was also associated with an increase in the marginal probability that a household would purchase a latrine if offered a subsidy, suggesting that the mechanism improved accessibility to safe sanitation solutions for households most affected by climate-related weather events.

Village-level regression results revealed that the impact of offering targeted subsidies was comparable regardless of the climate vulnerability status of the community. Nevertheless, it is clear that offering subsidies increased the sales closing rate overall across all treatment communities. By extension, it is presumed that scaling the subsidy mechanism will increase the coverage rate of climate-appropriate sanitation solutions within target communities. Sanitation coverage is believed to have disproportionately positive benefits for villages determined to be more vulnerable to climate-related events, for whom the health and environmental risks of no or unsafe sanitation are also higher. Further research is required to confirm this assumption, however.

Despite the relatively high subsidy eligibility rate overall, the research team did not identify any evidence of widespread market distortion occurring either as a result of ineligible households waiting on a subsidy or manipulation of the mechanism by households. The difference in the latrine purchase rate among ineligible households in the treatment and control groups was negligible and not statistically significant, suggesting that the majority of ineligible households in treatment areas were not waiting on a subsidy to purchase a latrine. In addition, when asked to provide a reason why they had not purchased a latrine, almost no households selected the 'waiting for subsidy' option, suggesting that this was not a significant factor in their decision-making.

LIMITATIONS

The results of this study are subject to some important limitations related to the design of assessment toolkits, accounting for all canceled orders, the generalizability of the research, and differences in targeting. The research team took appropriate measures to minimize the impact of each limitation.

Cancelled and noninstalled orders

The latrine sales described here refer to orders, not installations. A percentage of all orders typically are not installed due to customer cancellations. The cancellation rate of sales was not taken into account in this research because the limited duration of the RCT did not allow the team to wait a sufficient amount of time to account for all cancellations occurring after the sales period. As such, it can be assumed that the actual rate of latrines that would be installed through a mechanism like this would

be lower, but to an unknown extent. Average cancellation rates of 10–20% of all orders are typical in iDE's experience but vary by location and other variables including the time of year.

Limited geographical area

Due to supply chain challenges occurring during this pilot sales period, the research was limited to a single province (Kampong Chhnang) in Cambodia's Tonle Sap Lake region. This limits the generalizability of the research, particularly to other regions of the country that may experience climate vulnerability differently. Similar studies in more diverse regions to increase the generalizability of the results to other rural Cambodian communities and beyond are recommended.

Differences in targeting between treatment areas

Statistically significant differences in the proportion of IDPoor households within treatment and control groups suggest deliberate targeting. Commissions offered to sales agents and village authorities may have encouraged selection bias. This is understandable in a real-world research context, and the difference in the share of IDPoor households between groups is small and unlikely to substantially impact results.

Subjectivity of household-level climate assessment

Household-level climate vulnerability was assessed using a single survey question which asked whether extreme weather events had severely disrupted the household's income or resulted in additional expenditures in the past year. This question is subjective and may be interpreted differently by different households. It is also possible that some households manipulated this question to increase their likelihood of receiving a subsidy due to the fact that it is not easily verifiable, although an analysis of market distortion suggests that this behavior, if it was occurring, was not widespread.

RECOMMENDATIONS

Ensure that sales agents and village authorities have a thorough understanding of how the eligibility survey works prior to roll-out: Qualitative interviews with sales agents and village leaders revealed persistent misunderstandings about how the tool worked even after training. Many sales agents believed qualification was predicated on one factor (namely, the number of household members or ownership of a cell phone) and that this was unfairly excluding certain households. In reality, the PPI is a 10-question assessment that is designed to serve as a proxy means test to assess the *likely* poverty status of the household. A single question does not automatically guarantee or preclude qualification. There also appeared to be a lack of understanding of how climate vulnerability impacted the thresholds applied to determine eligibility. This confusion at times made it difficult for sales agents to clearly explain eligibility selection to users and households. It is crucial for all parties to comprehend eligibility to prevent perceptions of unfairness in the assessment process.

Update the assessment to better capture the quality of certain assets: Through qualitative interviews, most sales agents reported frustration with the fact that the PPI assessment asks whether a household has a phone or motorbike, but does not take into account the quality of these items (i.e., smartphone versus button-press phone). Future iterations of the assessment could explore possible ways to incorporate the quality of assets to improve accuracy.

Explore and test options for externally determined or observable characteristics of household-level climate vulnerability: While the study found no evidence of widespread manipulation of the eligibility survey, the research team acknowledges the possibility. Difficulty verifying reported assets or household size introduces vulnerabilities to a survey-driven subsidy system, especially if means for possible manipulation become well known in a community. Although only 29 households (2% of the treatment population) purchased subsidized latrines on repeat visits, this represents 11% of the total subsidized population, making it a large enough number to warrant consideration under a scaled-up scenario.

In addition, a survey-based subsidy eligibility system might incentivize sales agents to misreport eligibility. In this study, this risk was mitigated by ensuring that sales agents were aware that iDE's M&E officer would be verifying eligibility by re-visiting a random selection of households. No instances of willful manipulation were identified; however, finding alternatives to self-reported surveys, including externally pre-determined designations (e.g., IDPoor, CVI score) or clearly observable characteristics (e.g., flood high water marks on household structures) could reduce manipulation risk and monitoring burden on staff.

More research is needed on the connection between climate vulnerability and sanitation coverage: CVI, the main geographical measure of climate vulnerability, was determined at the commune level. Climate vulnerability can vary greatly within villages, with the lack of evidence of differences in sanitation uptake by community CVI demonstrating a need for more research on the link between climate vulnerability and sanitation uptake. Specifically, practical, verifiable measures to assess and monitor climate vulnerability at the village and household level will be needed to more deeply understand this linkage.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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