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Household Preferences for Rural Fecal Sludge Management Services in Cambodia: A Discrete Choice Experiment

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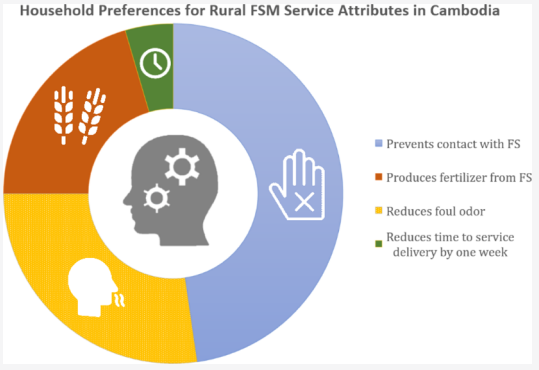
ABSTRACT: Continued access to sanitation and the improvements to public health that it provides requires safe fecal sludge management (FSM). Trained service providers offer the best path to achieve safe FSM in rural communities, but this service industry is hindered by a lack of understanding household valuation of FSM services in rural Cambodia. Using a discrete choice experiment, we characterize rural households' preferences for four different FSM-service attributes across five provinces. We find that rural households prefer preventing contact with fecal sludge (FS) most among the tested FSM-service attributes, followed by reducing foul odor and producing fertilizer from FS. Reducing time to service delivery was also preferred comparably to producing fertilizer from FS when time to service delivery increased to 4 weeks. Preferences were also analyzed by province, poverty, and education, providing regional and demographic-specific results. Based on the study's results, we recommend that Cambodia's rural sanitation sector develop an FSM-service model that focuses on preventing human contact with FS. Premium levels of service that reduce foul odor and/or provide fertilizer from FS should be offered. Development practitioners should consider the strong preference heterogeneity for FSM-service attributes of households across and within provinces and demographics. These recommendations will provide practical benefits to FSM safety and ultimately improve public health.



INTRODUCTION

To protect public health, the fecal sludge (FS) stored in billions of pit latrines used daily around the world must be managed safely.[1] While rural latrine access continues to improve globally, latrine maintenance through fecal sludge management (FSM) is typically performed using unsafe methods, thereby endangering public health by exposing pit emptiers and communities to pathogenic FS.[2] Unsafe FSM typically results from a lack of service provision, standards or regulation, which is common in rural areas.[3] When a public service of regulated pit emptying is not provided to households, a service provided by trained individuals (trained service providers) can safeguard public health. Such services can be regulated more easily and provide safe service more consistently than non-service methods, such as when households empty their own pits (self-empty) or open their pits during flooding (flooding out).[4] To support trained FSM service providers, a healthy FSM service market must be developed, which will require understanding the demand for such services and thus how households value different attributes of FSM services. Unfortunately, household valuation of FSM-service attributes is poorly understood and particularly understudied in rural areas.[5,6]

Safe FSM requires that the pathogens stored within pits be kept away from people.[7] This can be accomplished by (1) an emptying service, which typically empties, transports, treats, and reuses or disposes of FS; or (2) a new-pit service, which installs a new pit to provide increased on-site FS storage capacity and potentially on-site treatment of pathogens in FS. Each type of service can be provided using different methods, but all require personal protective equipment to be worn during service to maintain safety.[4] For emptying services, manual emptying (emptying a pit with a bucket, shovel, or other manual tool), mechanical emptying (emptying a pit with a submersible pump or other small powered mechanism), and vacuum-truck emptying (emptying a pit using a vacuum truck) are possible. For new-pit services, a new pit could be installed alone (i.e., creating a new pit latrine), in series with the existing pit, or in parallel with the existing pit (i.e., creating an alternating dual-pit system).[4] Alternating dual-pit systems

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allow FS within a pit to be left undisturbed for at least two years, during which time pathogens die-off sufficiently to allow households to empty their own pits with decreased health risks.[8]

To manage their FS and maintain latrine functionality, households must choose either a service method, which is performed by someone that does not live at the household, or a non-service method, which requires a member of the household to manage the household's FS. This decision-making process can be described using Random Utility Theory, which states that an individual will tend to select the method that provides the most utility, or subjective usefulness.[9,10] The utility of a given method is defined as the sum of the marginal utilities of the attributes of that method for a specific household.

Based on Random Utility Theory, discrete choice experiments (DCEs) provide a method to determine individuals' stated preferences for different attributes of a product or service. In a DCE question, an individual selects their most preferred option from a set of two or more presented options. Each option is described by a set of attributes, each of which has a range of values (levels). FSM-service attributes included in a DCE to determine how households value FSM services should be (1) important to households when evaluating a decision about FSM; (2) applicable to both emptying and new-pit FSM services; and (3) of practical benefit by providing FSM practitioners with knowledge that could improve rural FSM. DCEs can be useful when designing a product or service that does not yet exist by identifying and prioritizing critical traits.[11] If cost is included as an attribute in a DCE, stated willingness-to-pay (WTP) estimates can be calculated for each attribute.[11] In the case of managing household FS, stated WTP estimates how much more a household is willing to pay for a service that has a given attribute (e.g., prevents exposure to pathogens) compared to a service that does not have that attribute (e.g., does not prevent exposure to pathogens). Note that stated WTP estimates are different from revealed WTP values (what an individual actually pays for something) and are typically larger than revealed WTP values.[11]

DCEs have been used in various fields, including consumer product design, infrastructure development, economics, health policy, and planning; however, few DCEs have been applied in low-income contexts[11] or to sanitation.[6,12−14] One prior study used a DCE to describe household preferences for different cost structures for pit-emptying-service attributes in Rwanda, finding that households had strong preferences for FS treatment, formal services, and distant disposal.[13] We deviate from this study and contribute to the literature by developing a DCE that investigates (1) both emptying and new-pit services as well as non-service methods and (2) a rural context.

While existing literature provides a basis for developing a DCE to describe household preferences for FSM service attributes, behavioral theory states that decision-making is influenced by variations in context;[15] thus, attribute selection requires detailed knowledge of a specific geographical area for study. To select this area, a partnership was formed between iDE, an international development organization that works to improve rural sanitation via market development channels, and the University of Colorado Boulder's Mortenson Center in Global Engineering. Our multi-national team of researchers selected Cambodia, a lower-middle income country in Southeast Asia where 80% of the population lives in rural areas where pit latrines are common,[16] pits are typically emptied by household members via "bucketing" with little or no training (see S1),[17] and FSM services remain rare.[18,19] Despite their rarity, FSM services are known to rural households and are in demand; however, the prices charged by services tend to be markedly higher than both stated WTP estimates and revealed WTPs.[19] Previous research in rural Cambodia found that household FSM preferences vary spatially[17] and are associated with poverty and education.[20]

The research questions explored in this study of the preferences of rural Cambodian households were:

1. Which attributes of FSM services do households prefer?
2. What are households willing to pay for each of these attributes?
3. How do household preferences for FSM-service attributes and for service versus non-service options vary among provinces, with household poverty level, and with the highest education level achieved by a household member?

This study specifically presents new knowledge about what attributes of FSM services are preferred by rural Cambodian households, what households state that they are willing to pay for each attribute, and whether households prefer service or non-service options for FSM. This study also disaggregates results by province, poverty, and education, and provides practical recommendations for achieving safe FSM in rural Cambodia. The study was designed to provide results that are generalizable to the rural populations in the five studied Cambodian provinces, the other 20 Cambodian provinces, and nearby countries including Thailand, Lao PDR, and Vietnam due to similarities in culture, economy, social structure, and lifestyle.[21]

The knowledge presented in this study provides a foundation upon which to build safe FSM services in rural areas of Southeast Asia. Understanding household valuation of different attributes of FSM services provides a basis for developing an FSM-service market and associated behavior change campaigns that will improve rural FSM efficiently. FSM services can also be designed to meet the demands of households while also achieving the goals of safe sanitation: prevent human and environmental contact with pathogenic FS. Thus, this study contributes to the goal of improving public health via improved FSM.

Supporting Information that describes the typical method of latrine pit emptying in rural Cambodia and details about the study design, data collection, the DCE questions, and other topics is available online.

METHODS

Development of DCE Questions. To describe household preferences for different service attributes, we developed a DCE. A literature review was used to select five FSM-service attributes important to rural Cambodians and applicable to both emptying and new-pit services: whether a method prevents or reduces exposure to pathogens; how foul an odor a method produces; if emptied FS can be used as a fertilizer by the household; the time elapsed between when a service is requested and when it is completed; and the cost of a service.[22−25] The relative importance of these attributes to households (their marginal utilities) are not well understood and likely vary by household.

Levels for each of the five attributes were selected to describe FSM services that could be used to manage FS in rural

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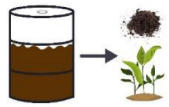
Attribute	Description and Question; Levels with Visual Aides; and FSM Services Described by Levels			
Prevents contact with FS	Different services can either prevent or not prevent people from coming into contact with FS. Does the service prevent contact with FS for everyone?			
	Yes 		No 	
	E:vac, P:par		E:man/mech, P:one/ser	
Produces fertilizer from FS	Different services allow FS to be used as fertilizer in gardens or crop fields. Can the FS fertilize crops after emptying?			
	Yes 		No 	
	E:man/mech, P:one/ser/par		E:vac[1]	
Reduces foul odor	Different services produce different amounts of foul odor that anyone nearby can smell. How disgusting is the smell produced by the service?			
	Very disgusting 	Slightly disgusting 	Not disgusting 	
	E:man	E:mech	E:vac, P:one/ser/par	
Time to service delivery	Different services may take longer before your latrine becomes functional again. How many days pass between service request and service completion?			
	1 day 	7 days 	30 days 	
	Varies			
Cost of service[2]	Different services cost different amounts of money. What is the cost of the service?			
	50,000 Riel 	100,000 Riel 	150,000 Riel 	200,000 Riel 	250,000 Riel 
	E:man	E:mech, P:one/ser/par	E:vac		

1: Vacuum-truck emptying could allow FS to be used as fertilizer depending on the household's requested disposal location. However, running a vacuum truck profitably usually requires emptying multiple pits prior to disposal at a single location.[20]
2: For comparison, the mean monthly household income in rural Cambodia is ~750,000 Riel, pit emptying costs between 60,000 and 300,000 Riel depending on the method used, and installing a new pit costs ~200,000 Riel.[20] Also, ~4000 Riel = $1 USD.[26]

Figure 1. Attributes with descriptions and questions posed to respondents, including levels with visual aids and the FSM services described by each level, where E:man = manual emptying, E:mech = mechanical emptying, E:vac = vacuum-truck emptying, P:one = install a new pit alone, P:ser = install a new pit in series, and P:par = install a new pit in parallel.

Cambodia (Figure 1). Best practices for DCEs state that the number of attributes and levels should be kept below six and three per attribute, respectively, to reduce attribute non-attendance.[11] In this DCE, the number of attributes and levels per attribute were minimized while maintaining adequate representation of existing types of FSM services. For example, manual emptying produces a very foul odor, while mechanical emptying produces a moderately foul odor, and vacuum-truck emptying produces no odor;[19] thus, the attribute reduces foul odor is appropriately described by three levels.

In each DCE question, a household was asked to select their preferred option among three presented: A, B, or C. Options A and B described service options and showed one level of each of the five attributes; these options were not intended to describe specific FSM services. Option C was a non-service option and was included to determine if FSM services were preferred by rural Cambodian households over non-service options. Option C was selected by each household prior to the start of the DCE by answering the question "what would you do if your latrine pit filled up and you could not hire someone to empty it or install a new pit for you?". Possible answers to this question were "a household member would empty the pit (self-empty)", "open my pit during flooding (flood out)", "use a neighbor's or other family member's latrine", "revert to open defecation", and "other". Visual aides were used to mitigate any literacy issues in respondents. During survey administration, respondents were shown Figure S2, a simplified version of Figure 1. Questions, attributes, levels and visual aides were field-tested for clarity in a rural Cambodian village that was not

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Table 1. Relevant Provincial Characteristics

province	population density (people per square km)[29]	multidimensional poverty index[a]	% rural latrine coverage[30]	% households intending to perform safe FSM practices[17]
Siem Reap	98	0.25	65	33
Kampong Thom	49	0.22	72	54
Kandal	376	0.14	84	71
Prey Veng	217	0.15	82	48
Svay Rieng	177	0.13	83	56

[a]Ranges from 0 to 1, where higher indicates more poverty.[31]

included during data collection (see S3). An example discrete choice question is shown in Figure S4.

Study Design. Households were surveyed in five of the 25 Cambodian provinces (Siem Reap, Kampong Thom, Kandal, Prey Veng, and Svay Rieng), which were selected because their geographic and demographic disparities (Table 1) allow for regionally specific results. Cluster randomized sampling of 5 villages per district and 6 households per village was used to survey households in all districts of each province, which allowed us to detect a difference of 8.2% between province-level results.[27] The sampling frame included households that (1) owned a pour-flush latrine for more than 2 years, and (2) were present in iDE's sales database; these criteria made households (1) likely to need FSM services due to their pit filling soon, which usually occurs after 2−5 years;[28] and (2) easy to locate, respectively. iDE's sales database of more than 300,000 latrines sold in these provinces over the past 15 years documents the sales from marketing campaigns that blanketed all households in the surveyed villages, making the database generalizable to all households in each surveyed village. Households were also randomly selected from within this database, mitigating any systematic sampling bias. Additionally, the latrine sales and installations recorded in this database were made by local latrine installers that had been trained to construct latrines by iDE but are not iDE employees, thus mitigating any source of social desirability bias. This DCE was administered at the end of a larger survey that evaluated many aspects of household decision-making about FSM in rural Cambodia. Including the DCE, the overall survey consisted of between 58 and 96 questions depending on household sanitation experiences and had a mean survey duration of 42 min.

A blocked fractional factorial study design was developed in SAS to balance the ease of survey administration, respondent fatigue, and the statistical power of the study's results (see S5).[32] The resulting design contained eight blocks, each with five DCE questions (40 unique combinations of levels describing options A and B). The levels of the options shown in each question were determined by this design, and each household was randomly assigned to a block of five questions.

Data Collection. iDE research assistants that live locally and speak native Khmer were trained to ensure accurate and repeatable survey administration (see S3). Surveys were administered in-person, and iDE's Monitoring and Evaluation managers and the authors reviewed the data collected for accuracy and completeness. After software randomly assigned a household to a question block, iDE research assistants were prompted with instructions and questions throughout each survey within Taroworks[33] on tablets (see S6). Although all responses were recorded digitally, all DCE questions were presented on paper field packets (Figure S6) to display the visual aids of the DCE questions and improve clarity. Each field packet contained two flip booklets: one showed all combinations of levels for options A and B as dictated by the blocked fractional factorial design; and the other contained the four non-service options for option C. Each DCE question was identified by a code that included its block and question number.

Between August 13 and September 12, 2019, 16 trained research assistants visited 2281 households but surveyed only 1461 because many households were either unavailable at the time of surveying (working in agricultural fields is common in rural Cambodia) or had stopped using their latrine. Between 394 and 590 households were surveyed in each province, and a total of 241 villages were visited across 49 districts and 196 communes. Latrines were 2.8 years old on average (SD = 0.8), and 86% of households had latrines for 2 to 3 years. Household poverty levels were self-reported based on the Cambodian National Government's Identification of Poor Households (IDPoor) Programme.[34] The highest education level achieved by a household member were also self-reported. Household poverty and education levels can influence sanitation decision-making in rural Cambodia;[17] these metrics of the households surveyed in this study were not significantly different from those of the rural populations' census averages in the studied provinces, allowing generalizability of this study's results to the rural populations of each surveyed province (see S7).[34,35] These similarities also imply that there were no substantial differences between the households who participated in the survey and those that were visited but did not participate in the survey. Surveying costs are described in S8.

Data Analysis. Mixed logit modeling was used to analyze the data in R using the mlogit package (see S9).[36] The dependent model variable was the option chosen by each respondent, and the independent model variables (henceforth "factors") included the DCE attributes, which were described by the levels of the options shown in each question, and the four non-service options. The levels of each attribute were represented by integer values that allowed model coefficients to be easily compared (see Table 2). The attribute reducing foul odor was split into two separate attributes to distinguish how households preferred a reduction in highly foul odors to a reduction in moderately foul odors. The levels of the cost variable in Cambodian Riel were divided by 50,000 to yield values similar in magnitude to those of the other attributes, preventing model singularity. All attributes except cost were assumed to be represented by a parametric curve and are thus represented in the model output by a mean and standard deviation that describe how preferences for each attribute vary across the population. The model coefficients describe the relative preferences of the study population for the five FSM-service attributes and four non-service options investigated in this study. The mean marginal WTP estimate for each FSM-

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Table 2. Representations of Attributes and Non-Service Options Used in the Models

factor	values used in models	description
prevents contact with FS	0 or 1	does not or does prevent contact with FS
produces fertilizer from FS	0 or 1	cannot or can use FS as fertilizer after emptying
reduces foul odor from high to moderate	0 or 1	does not or does reduce foul odor from high to moderate
reduces foul odor from moderate to none	0 or 1	does not or does reduce foul odor from moderate to none
increases time to service delivery by one week[a]	0, 0.14, 1 or 4.29	the number of weeks until service is delivered
increases cost by 50,000 Riel[a]	0, 1, 2, 3, 4 or 5	the cost of the service divided by 50,000 Riel
non-service options[b,c]		the non-service option selected by the household is...
flood out	0 or 1	...open their pit's lid during flooding.
revert to open defecation	0 or 1	...revert to open defecation.
use neighbor's latrine	0 or 1	...use a neighbor's latrine

[a]The zero values for these attributes were not shown to respondents because they do not accurately describe any FSM service: no service can be delivered instantly, and no service is free. However, the zero values are included in the models to represent non-service options. For example, an option C that represents the flood-out non-service option is represented in the models by zero values for all factors except the flood-out factor, which equals 1. [b]The variable describing the self-empty non-service option was removed from the model to achieve the following: (1) to remove the linear dependency between the non-service-option variables; and (2) because the option described when all variables equal 0 accurately describes the self-empty non-service option best. The self-empty non-service option is thus described by the intercepts of the models. [c]No household chose "other" as a non-service option.

service attribute was also calculated by dividing each model coefficient by the negative of the model coefficient for cost, describing what a household would be willing to pay in addition to a basic FSM service that did not have these attributes. We report unstandardized model coefficients along with WTP estimates (see S10).

Various models were developed to evaluate the data from different perspectives. First, all DCE data were evaluated together to describe how rural Cambodian households as a whole prefer different FSM-service attributes. Next, data were disaggregated by province to determine how FSM-service attributes are preferred within each province. Lastly, data were disaggregated by household poverty level and the highest education level achieved by a household member to determine how different segments of the population prefer FSM-service attributes. Based on the similar cultures, economies, social structures, and lifestyles found in the rural populations of the other 20 Cambodian provinces and nearby countries of Thailand, Laos and Vietnam,[21] these results can also be generalized to describe those populations' preferences for FSM service attributes.

Following new recommendations from the American Statistics Association,[37] results that are of low uncertainty and practical benefit to rural FSM are reported and discussed. We define "low uncertainty" as "having a statistical significance (p) that is less than 0.1," and results of practical benefit will help predict rural FSM behaviors or improve rural FSM services, behavior-change campaigns, policies, or product design. Model quality was determined using McFadden's pseudo-R^2, indicating a high-quality model when above 0.2.[38] Preferences for each FSM-service attribute and non-service option were compared across models using the 95% confidence intervals of the WTP estimates for each model factor: if confidence intervals did not overlap, the associated preferences in each model were deemed statistically different with over 95% confidence.

RESULTS AND DISCUSSION

Preferences for FSM Across all Provinces. Considering all 1461 households across all studied provinces, mixed logit modeling yielded high-quality results (McFadden pseudo-R^2 = 0.31, Table 3). Preferences for FSM-service attributes and non-service options are described by model coefficients (β): a more positive coefficient indicates stronger preference for a factor; a more negative coefficient indicates stronger aversion to a factor; and a coefficient near zero indicates a lack of

Table 3. Preferences and Willingness-To-Pay Estimates for FSM-Service Attributes and Non-Service Options Across all provinces[d]

factor type	factor	preference for factor[a,b]				willingness to pay for factor[b,c]	
		mean (β)		standard deviation			
	(intercept)	0.0	(0.1)				
FSM-service attribute	prevents contact with FS	2.1***	(0.1)	2.7***	(0.1)	263	(23)
	produces fertilizer from FS	0.9***	(0.1)	1.8***	(0.1)	113	(15)
	reduces foul odor from high to moderate	0.5***	(0.1)	1.3***	(0.1)	63	(13)
	reduces foul odor from moderate to none	0.7***	(0.1)	1.4***	(0.1)	88	(14)
	increases time to service delivery by one week	−0.2***	(0.02)	0.05***	(0.01)	−25	(13)
	increases cost by 50,000 Riel	−0.4***	(0.03)				
non-service option	flood out	−2.0***	(0.5)	6.4***	(0.8)		
	revert to open defecation	−6.3***	(0.8)	6.3***	(0.8)		
	use neighbor's latrine	−10.0***	(1.4)	9.5***	(1.2)		
number of DCE questions asked		7305					
% non-service option selected		21%					
McFadden pseudo-R^2		0.31					

[a]Shown as model coefficients, β. [b]Standard errors are shown in parentheses. [c]Shown as 10^3 Riel. Also, ~4000 Riel = $1 USD.[26] [d]*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

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Table 4. Preferences and Willingness-To-Pay Estimates for FSM-Service Attributes and Non-Service Options Disaggregated by Province[c]

factor type	province →	preference[a] (left) and willingness to pay[b] (right) for factor											
		all provinces		Siem Reap		Kampong Thom		Kandal		Prey Veng		Svay Rieng	
	factor ↓												
	(intercept)	0.0		0.9*		−0.1		−0.3		−0.57*		−0.2	
FSM-service attribute	prevents contact w/FS	2.1***	263	3.2***	1,100^	1.4***	115^	2.7***	270	2.5***	250	1.0***	156
	produces fertilizer from FS	0.9***	113	1.3***	430	0.8***	66	0.8***	80	0.6***	60^	1.2***	190
	reduces foul odor from high to moderate	0.5***	63	0.4*	130	0.6**	50	0.6*	60	0.4**	40	0.6**	94
	reduces foul odor from moderate to none	0.7***	88	0.5*	170	0.9***	74	−0.02		1.0***	100	0.8***	125
	increases time to service delivery by one week	−0.2***	−25	−0.1***	−33	−0.2***	−16	−0.2***	−20	−0.3***	−30	−0.2***	−31
	increases cost by 50,000 Riel	−0.39***		−0.15**		−0.61***		−0.50***		−0.50***		−0.32***	
non-service option	flood out	−2.0***		−2.0		5.9*		1.4		1.9***		−4.8*	
	revert to open defecation	−6.3***		−6.2***		−6.1***		−18.2***		−9.4		−4.3***	
	use neighbor's latrine	−10.0***		−7.1**		−3.3***		−29.0*		−7.2*		−5.3*	
number of DCE questions asked		7305		1795		1190		1330		1790		1200	
% non-service option selected		21%		15%		23%		21%		23%		27%	
McFadden pseudo-R^2		0.31		0.36		0.30		0.38		0.32		0.24	

[a]Shown as mean model coefficient, β. [b]Shown as 10^3 Riel. Also, ~4000 Riel = $1 USD.[26] [c]*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$ within each model. ^: provincial willingness to pay for factor is statistically different at 95% confidence from all-province willingness to pay for factor (see Table S11).

consideration of a factor. The ratio of two factors' coefficients describes how much the studied population of households prefers one factor more than or less than the another.

Modeling shows that households prefer preventing contact with FS most among the tested FSM-service attributes (β = 2.1, Table 3). This attribute is preferred nearly twice as much as reducing foul odor (β = 0.5 + 0.7 = 1.2) and more than twice as much as producing fertilizer from FS (β = 0.9). Reducing time to service delivery was preferred comparably to producing fertilizer from FS when time to service delivery reached four weeks (β = −0.2). All preferences showed large standard deviations relative to their means, indicating preference heterogeneity in the population and thus motivation to analyze the preferences of subgroups in the population.

The preferences for FSM-service attributes support the results of previous research, which indicate that aversion to touching FS, foul odor related to FS, and cost are factors that strongly affect households' decision-making in rural Cambodia.[17,22−24] Substances that cause disease or bad smells are referred to as meruk in the native Khmer language and are thought of as something to be strongly avoided in Cambodia.[39] This desire to avoid meruk makes coming into contact with FS and smelling FS disgusting to Cambodians.[39] These cultural norms help explain households' preference for FSM services that prevent contact with FS and reduce foul odor. However, rural Cambodians have been using FS as fertilizer since the reign of the Khmer Rouge in the 1970s.[22] This cultural norm explains households' preference for being able to use FS as fertilizer after emptying, either on crop fields or vegetable gardens. However, these results also describe a clear dichotomy that pulls households away from FS meruk while pushing them towards using FS to improve the nutrition and yield of their crops. These conflicting preferences also likely explain the large preference heterogeneities of the population toward FSM.

WTP estimates, which describe what a household would be willing to pay in addition to a basic FSM service that does not have these attributes, were similar to the cost of emptying or installing a new pit (60k to 300k Riel, or US$15 to 75) and equaled between 8 and 40% of the mean monthly household income of rural Cambodians (750k Riel, or US$188).[18,20] Because it is unlikely that households would be willing to pay such a high premium for a service with a given attribute, the reported WTP estimates can be interpreted as too large. Thus, reported WTP estimates describe the relative preferences for FSM-service attributes and should not be considered as true representations of the cost households would actually pay.

Table 3 also shows negative coefficients for the non-service options, indicating that households were generally averse to non-service options. However, non-service options were still frequently selected: 31% of households selected non-service options at least once, and non-service options were selected in 21% of all questions. Of the non-service options, flooding out was most preferred (β = −2.0), followed by reverting to open defecation (β = −6.3), using a neighbor's latrine (β = −10.0), and self-empty (represented by intercept; not significant). However, flooding out is typically only possible during the wet season for households that experience flooding. The relatively high frequency that non-service options were selected was expected based on previous research, which states that households tend to manage their own FS and not hire services.[20] These negative coefficients for non-service options also indicate that households prefer safe FSM services.

Preferences for FSM by Province. Regionally accurate preferences for FSM-service attributes would provide practical benefits to sanitation development via improved customer

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segmentation. Mixed logit modeling for each province yielded high-quality results (McFadden pseudo-R^2 = 0.24 to 0.38; Table 4). Because model coefficients cannot be compared across models, we compared the 95% confidence intervals of the WTP estimates for each factor to identify provincial variations in preferences for FSM-service attributes and non-service options (Table S11). WTP estimates within each province were typically similar to those across all provinces; however, there was some variance. Households in Siem Reap were more willing to pay for services that prevent contact with FS (1100k Riel or US$275) compared to the all-province WTP estimate for preventing contact with FS (263k Riel, or US$66). Conversely, households in Kampong Thom were less willing to pay for such a service (115k Riel or US$29). Willingness to pay should decrease as poverty increases, as shown in Kampong Thom; however, this trend does not hold in Siem Reap, where the strong preference for preventing contact with FS appears to override this trend (Tables 1 and 4).

Preferences for non-service options within each province were typically similar to those across all provinces; however, there was some variance. The percentage of households selecting a non-service option varied from 15% in Siem Reap to 27% in Svay Rieng. These results indicate that FSM services are likely more in demand in Siem Reap than in Svay Rieng. These variations in preferences for non-service options across provinces could not be explained by available data.

The positive, significant, and relatively large coefficients for flooding out in Kampong Thom (β = 5.9) and Prey Veng (β = 1.9) indicate that households in Kampong Thom and Prey Veng prefer flooding out over service options. This finding supports the lower relative preference for preventing contact with FS in Kampong Thom. However, as noted above, flooding out is only available when flooding occurs, which occurs infrequently for many households in these provinces, limiting the selection of this option in practice.

Also, the large negative coefficients for revert to open defecation and use a neighbor's latrine and insignificant intercept and coefficient for flood out in Kandal indicate that households in Kandal view non-service options more negatively than in other provinces. FSM services are thus more strongly preferred in Kandal than non-service options. Kandal's lower poverty levels and higher population density likely supports households' preference for FSM services (Table 1).

Lastly, as with all-province preferences, the provincial-preference standard deviations are significant and typically large relative to their means, indicating strong preference heterogeneity in each provincial population. Thus, household preferences within the same province can vary widely.

Preferences for FSM by Demographics. We analyzed preferences by disaggregating respondents by poverty (the household's IDPoor status) and education (the highest education level achieved by a household member). We found a weak association between IDPoor status and the highest education level achieved by a household member (Cramer's v = 0.12, p = 0.000): IDPoor households tended to be less educated, which may explain some of the results presented below.

Poverty. The poverty level (IDPoor status) of households influenced preferences for FSM-service attributes and non-service options. Mixed logit modeling for IDPoor and non-IDPoor households yielded high-quality results (McFadden pseudo-R^2 = 0.33 and 0.32; Tables 5 and S12). Although the mean WTP estimates for IDPoor households were typically lower than those of non-IDPoor households (Table 5), their 95% confidence intervals overlap (Table S12); thus, there is no statistical difference in the WTP estimates for IDPoor and non-IDPoor households. However, important exceptions exist. First, IDPoor households showed no preference for shorter time to service, while non-IDPoor households did prefer a shorter time to service and were willing to pay 24k Riel (US $6) to reduce the time to service by one week (Table 5). Supporting existing literature, these results illustrate that wealthier households tend to prefer reducing their time burden because their time is more valuable than that of poor households.[40] Second, IDPoor households did not prefer to flood out or use a neighbor's latrine, while non-IDPoor households did prefer these non-service options. Unfortunately, existing data does not provide a potential explanation for these differences.

Table 5. Preferences and Willingness-To-Pay Estimates for FSM-Service Attributes and Non-service Options Disaggregated by Poverty level[d]

factor type		preference[a] (left) and willingness to pay[b] (right) for factor			
	poverty level[c] →	IDPoor		Not IDPoor	
	factor ↓				
	(intercept)	0.2		−0.1	
FSM-service attribute	prevents contact w/FS	2.3***	245	2.3***	280
	produces fertilizer from FS	0.8***	85	1.0***	123
	reduces foul odor from high to moderate	0.6***	64	0.5**	61
	reduces foul odor from moderate to none	0.7**	74	0.7***	85
	increases time to service delivery by one week	−0.1		−0.2***	−24
	increases cost by 50,000 Riel	−0.47***		−0.41***	
non-service option	flood out	−0.9		−1.9***	
	revert to open defecation	−5.3***		−7.1***	
	use neighbor's latrine	−53.3		−14.8***	
number of DCE questions asked		975		6080	
% non-service option selected		23%		21%	
McFadden pseudo-R^2		0.33		0.32	

[a]Shown as mean model coefficient, β. [b]Shown as 10^3 Riel. Also, ~4000 Riel = $1 USD.[26] [c]Self-reported by households based on the Cambodian National Government's Identification of Poor Households (IDPoor) Programme. [d]*p < 0.10; **p < 0.05; ***p < 0.01 within each model.

Education. The highest education level achieved by a household member also influenced preferences for FSM-service attributes and non-service options. Mixed logit modeling for households with varying levels of education yielded high-quality results (McFadden pseudo-R^2 = 0.30 to 0.40; Tables 6 and S13). Households that had a member that completed primary or secondary education preferred all tested attributes similarly to each other and to the means for all provinces (Tables 3 and 6). However, households that did not have a member that completed primary education only preferred services that prevent contact with FS and, to a

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Table 6. Preferences and Willingness-To-Pay Estimates for FSM-Service Attributes and Non-service Options Disaggregated by Highest Education Level Achieve by a Household Member[c]

factor type		preference[a] (left) and willingness to pay[b] (right) for factor					
	education level →	did not complete primary education		completed primary education		completed secondary education	
	factor ↓						
	(intercept)	−1.1*		−0.1		0.06	
FSM-service attribute	prevents contact w/FS	3.2***	242	2.2***	256	2.3***	295
	produces fertilizer from FS	0.1		1.0***	116	1.1***	141
	reduces foul odor from high to moderate	0.4		0.7***	81	0.4***	51
	reduces foul odor from moderate to none	0.6		0.9***	105	0.6***	77
	increases time to service delivery by one week	−0.2**	−15	−0.2***	−23	−0.2***	−26
	increases cost by 50,000 Riel	−0.66***		−0.43***		−0.39***	
non-service option	flood out	39.6		−2.2		−1.9***	
	revert to open defecation	−15.0***		−4.3***		−6.8***	
	use neighbor's latrine	−52.1		−8.9***		−11.0***	
number of DCE questions asked		815		1775		4715	
% non-service option selected		29%		20%		20%	
McFadden pseudo-R^2		0.40		0.30		0.31	

[a]Shown as mean model coefficient, β. [b]Shown as 10^3 Riel. Also, ~4000 Riel = $1 USD.[26] [c]*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$ within each model. ^: Willingness to pay for factor is statistically different at 95% confidence from willingness to pay for factor in other model (see Table S13).

much smaller extent, that reduce time to service delivery. Education may thus increase household valuation of using FS as fertilizer and reducing foul odor. Households with less formal education also selected non-service options 9% more often than households with more formal education (Table 6), implying that education may increase household valuation for FSM services in general.

Limitations. Various aspects of the study design may have affected the results. Survey fatigue may have affected respondents' ability to consider all attributes due to the DCE questions being asked at the end of the larger survey in this study, which required approximately 30 min of questioning prior to beginning the DCE. Also, by including five attributes in this DCE, attribute non-attendance may have caused some respondents to ignore some attributes, biasing results.[11] Primacy effect may have also biased results by presenting FSM-service attributes in the same order in every question;[41] randomizing attribute order was considered during the design of this study but deemed too difficult to implement in practice. The relatively high WTP estimates for FSM-service attributes likely indicate hypothetical bias, which describes how respondents may not consider what choice they would make if actually faced with the choice in real life;[42] this bias could be mitigated by providing respondents with additional time to think about their responses to the DCE questions.[43] Selecting the levels of cost used in this DCE were viewed by some households as too expensive, which may have made it difficult for households to value the service options presented in their questions.[44] While the sample design and measured demographic variables provide confidence that the results of this study can be generalized to all rural populations in the five surveyed provinces, the remaining 20 Cambodian provinces, and the nearby countries of Thailand, Lao PDR, and Vietnam, it is possible that sampling bias is still present in the data due to only 64% of households being available at the time of surveying. Lastly, this study only describes households' stated preferences and WTP estimates for FSM-service attributes and non-service options.

Recommendations. Based on the results of this study, we recommend that the rural sanitation sector of Cambodia develop an FSM-service model that focuses on preventing human contact with FS. This service should also ideally minimize foul odors and produce fertilizer that is useful for agriculture at the household. The ideal cost of this service is currently unknown. This service must be developed collaboratively with service providers to directly incorporate service providers' needs, and with community organizations to incorporate households' values and preferences. Mixed methods approaches that incorporate focus groups and in-depth interviews should be used to help interpret and contextualize quantitative results.

To facilitate the development of this service, the sector should investigate the actual market values (revealed WTP) for FSM-service attributes. While this study's description of household preferences and stated WTP estimates for FSM-service attributes is a good first step, a real and healthy FSM service market will require actual market valuation of FSM-service attributes. Revealed WTP could be determined by pilot-testing different FSM service delivery options in partnership with service providers. Additionally, this study supports the recommendation that pricing tiers for different levels of FSM service be developed. For example, a basic FSM service must achieve all requirements of safe sanitation (safe emptying, transport, treatment and disposal or reuse of FS). However, premium tiers of service could provide reduced foul odor, fertilizer from FS after emptying, and/or reduced time to service, and would likely appeal to non-IDPoor households and households with more formal education. Each of these attributes could be offered at a premium price and selected by households that value them.

We also recommend that the sector promote FSM services across Cambodia by highlighting their ability to prevent contact with FS and the pathogens it contains, particularly where preventing contact with FS is preferred strongly (e.g., Siem Reap) and where FSM services are less preferred (e.g., Svay Rieng). More generally, FSM services should be more strongly promoted to households with less formal education. We also recommend that behavior change communication dissuade flooding out, particularly in Kampong Thom and Prey Veng. For households that experience flooding, flooding out is

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free, easy, and allows a latrine to be used during flood events. Any conceivable FSM service cannot hope to achieve such appealing properties; thus, the behavior of flooding out must be dissuaded, while the alternative of FSM services is encouraged.

Lastly, we recommend that the sector consider the strong preference heterogeneity for FSM-service attributes of households across all provinces and within each province. When developing and promoting FSM services, different households will prefer different FSM-service attributes; thus, FSM services must appeal to and ideally be adaptable to various household values.

This study significantly contributes to the literature in rural sanitation by describing household valuation of FSM service attributes in rural Cambodia. Future research in rural sanitation will also benefit from the methods used in this study, which could be easily modified to investigate household valuation of rural FSM in populations with different cultures, economies, or lifestyles.

Household needs and values should be central to defining and implementing FSM service models. Service delivery methods must be made locally and democratically in a way that ensures that benefits accrue to communities and individuals most affected by this environmental health challenge. We believe that these recommendations will provide practical benefits to rural FSM safety and ultimately improve rural public health.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.0c04636.

> Photo of a rural Cambodian emptying his household's latrine pit, attributes and levels shown to respondents, training enumerators, field testing of DCE questions, example DCE question, blocked fractional factorial design, details of data collection, comparison of household poverty and education levels in sample data and census metrics, cost of surveying, description of other models, and detailed preferences and willingness-to-pay estimates (PDF)

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Notes

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