Title
User preferences and willingness to pay for safe drinking water: Experimental evidence from rural Tanzania

Authors
Burt, Zachary
Njee, Robert M
Mbatia, Yolanda
et al.

Publication Date
2017

DOI
10.1016/j.socscimed.2016.11.031

Peer reviewed

Social Science & Medicine 173 (2017) 63–71

Contents lists available at ScienceDirect

Social Science & Medicine

journal homepage: www.elsevier.com/locate/socscimed

User preferences and willingness to pay for safe drinking water: Experimental evidence from rural Tanzania

Zachary Burt [a, *], Robert M. Njee [b], Yolanda Mbatia [b], Veritas Msimbe [b], Joe Brown [c, 1], Thomas F. Clasen [c, 2], Hamisi M. Malebo [b], Isha Ray [a, **]

[a] Energy and Resources Group, 310 Barrows Hall, University of California, Berkeley, CA 94720-3050, United States
[b] National Institute for Medical Research, 3 Barack Obama Drive, P. O. Box 9653, 11101 Dar es Salaam, Tanzania
[c] London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

ARTICLE INFO

Article history:
Received 16 June 2016
Received in revised form
21 November 2016
Accepted 23 November 2016
Available online 25 November 2016

Keywords:
Tanzania
Water and health
Household water treatment and safe storage
Point of use
Boiling
User preferences
Willingness to pay

ABSTRACT

Almost half of all deaths from drinking microbiologically unsafe water occur in Sub-Saharan Africa. Household water treatment and safe storage (HWTS) systems, when consistently used, can provide safer drinking water and improve health. Social marketing to increase adoption and use of HWTS depends both on the prices of and preferences for these systems. This study included 556 households from rural Tanzania across two low-income districts with low-quality water sources. Over 9 months in 2012 and 2013, we experimentally evaluated consumer preferences for six "low-cost" HWTS options, including boiling, through an ordinal ranking protocol. We estimated consumers' willingness to pay (WTP) for these options, using a modified auction. We allowed respondents to pay for the durable HWTS systems with cash, chickens or mobile money; a significant minority chose chickens as payment. Overall, our participants favored boiling, the ceramic pot filter and, where water was turbid, PuR™ (a combined flocculant-disinfectant). The revealed WTP for all products was far below retail prices, indicating that significant scale-up may need significant subsidies. Our work will inform programs and policies aimed at scaling up HWTS to improve the health of resource-constrained communities that must rely on poor-quality, and sometimes turbid, drinking water sources.

1. Introduction

In 2014 inadequate and unsafe drinking water was responsible for over half a million deaths from diarrheal diseases; in Africa 25% of all deaths in children under 5 years of age were attributable to diarrhea (Prüss-Ustün et al., 2014; Fischer Walker et al.,2012). Rural areas of Sub-Saharan Africa suffer from limited access to improved water sources and high risk of fecal contamination in drinking water. Household water treatment and safe storage (HWTS) has been proposed as an intermediate solution to provide safer drinking water and reduce the burden of disease (WHO/UNICEF, 2008; Wolf et al., 2014).

Whether or not HWTS systems are a scalable intervention for poor rural populations is an area of active policy debate (Schmidt and Cairncross, 2009; Schmidt, 2014). Low rates of consistent use have been observed for several types of HWTS systems, (Luby et al., 2008; Brown et al., 2009) and finding the best method to promote adoption and consistent use is an active area of research (Parker Fiebelkorn et al., 2012). In particular, social marketing research has found that consumer preferences and viable price points strongly influence effective demand and the likelihood of consistent use (Evans et al., 2014). This has led to several studies on user perceptions and willingness to pay for HWTS products (Luoto et al., 2012; Albert et al., 2010; Poulos et al., 2012).

This study experimentally investigates which HWTS systems rural households prefer and why they prefer them. We also

* Corresponding author. Present address: Climate and Health Group, Mailman School of Public Health, Columbia University, 722West 168th St., NY 10032, United States.
** Corresponding author.
E-mail addresses: zzburt@gmail.com, zb2219@cumc.columbia.edu (Z. Burt), robertmussa@gmail.com (R.M. Njee), yolanda.mbatia@gmail.com (Y. Mbatia), Joe.Brown@lshtm.ac.uk (J. Brown), Thomas.Clasen@lshtm.ac.uk (T.F. Clasen), malebo@hotmail.com (H.M. Malebo), isharay@berkeley.edu (I. Ray).
[1] Present address. School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. NW, Atlanta, GA 30332.
[2] Present address. Rollins School of Public Health, Emory University, 1518 Clifton Rd, Atlanta, GA 30322.

http://dx.doi.org/10.1016/j.socscimed.2016.11.031
0277-9536/

estimate willingness to pay (WTP) for HWTS products, and compare them with user preferences. We do not evaluate water quality effects or health impacts. We assessed preferences and price points for only those HWTS systems that are known to be effective when correctly and consistently used.

We located our study in rural Tanzania, where 56% of the population does not have access to an improved water source (WHO/UNICEF, 2014). The Tanzanian government has concluded that piped and treated water will not be viable for rural areas for some years, and that HWTS should be scaled up as an intermediate strategy (MHSW, 2014). Credible information on which HWTS systems to scale up is critical for any future social marketing and product dissemination (Evans et al., 2014).

We experimentally evaluated user preferences and willingness to pay for six HWTS approaches. The preference for boiling has not been compared to other HWTS preferences in previous research, despite its high global usage relative to other treatment technologies (Rosa and Clasen, 2010; Ahuja et al., 2010; Amrose et al., 2015). We found few journal articles that compared several HWTS products, for either user preferences or WTP (e.g. Luoto et al., 2011, 2012; Albert et al., 2010). The literature on preventative health products indicates that users' willingness to pay, even when they are liked, is generally low; the evidence suggests that unfavorable opinions would be consistent with low valuations (i.e. WTP) and lower usage rates (Luoto et al., 2011; Ashraf et al., 2007; Dupas, 2011).

Based on this research, we went into the field with the following hypotheses:

(H_1) Households prefer boiling to the retail HWTS products.
(H_2) Households' WTP for HWTS products reflects their preferences.

The HWTS market is nascent but not absent in Tanzania. We focused on those HWTS systems that are already available, to assess which have the greatest potential for widespread adoption and sustained use without the need for a completely new supply chain (see below for the selection criteria).

Our study adds four new features to the user preference and WTP literatures on safe drinking water in low-income countries. First, this is the first study we are aware of to compare user preferences for boiling, a non-commercial and common practice, to those for retail-based water disinfection products. Second, we created a simple ordinal preference ranking protocol across many households and many HWTS methods; our protocol is innovative in that it explicitly solicits categorization of HWTS systems into 'like' or 'dislike', in addition to overall rankings. Third, we estimated WTP using a real auction; this is the first study to identify, and (partially) explain, discrepancies between expressed preferences and willingness to pay for HWTS. Fourth, to minimize respondent dropout, we allowed respondents to pay for the durable HWTS products with cash, mobile money or chickens. In this cash-poor rural economy, chickens are often sold when a little extra money is needed. Our work is relevant for social marketing programs and public health policies aimed at scaling up HWTS in resource-constrained communities that must rely on poor-quality, and sometimes turbid, drinking water sources.

2. Materials and methods

2.1. Site selection

We chose one predominantly Muslim, coastal-region district (Kisarawe) and one predominantly Christian, interior-region district (Geita), thus covering a range of cultures and geographies in Tanzania (Supporting Information (SI) Fig. S1). From each district we obtained a list of five "water challenged" villages, i.e., those in which water had to be fetched from unimproved sources, which had had recent outbreaks of waterborne illnesses, and where the median socio-economic status (SES) was similar to that for rural Tanzania. Two villages in each district matched our criteria and had village leaders willing to work with us (SI Fig. S2). Each village was at least a four-hour drive from the other village in the district, minimizing the risk of spillovers during the study. In each case we discussed our research goals and protocols, and the right of households to refuse to participate, with the village leadership.

Our field team included several of the authors and ten local enumerators whom the lead authors trained in survey techniques and ethical research practices. We visited study households in August of 2011 to conduct a baseline survey of household assets, construction material for houses, water access, fuel usage, education and income. We compared the baseline data with Census of Tanzania (2012) averages for all rural households (SI Table S2). The data show that our study villages were slightly better off than rural Tanzania overall. Latrine coverage was close to 90%, suggesting that poor sanitation should not attenuate the beneficial health effects of safe drinking water.

2.2. Sampling strategy

We conducted our own household census in all four villages prior to the baseline survey. We defined a household as a family group that shared meals and lived in the same compound, with one nominal head, i.e. an adult male or female with the authority to make decisions concerning medium-sized household purchases, such as buckets, shoes and clothing. Therefore one compound could accommodate more than one household, such as the families of three adult brothers who shared many activities but made their own spending decisions.

We covered the entire geographic areas of all the villages for the census, attempting to enumerate all of the households. This census was our sampling frame. We randomly selected our sample households, by name, at open meetings in every village, to reassure the residents that our selection process was fair. Our final sample size was 276 households for Geita and 280 for Kisarawe. The samples were large enough to detect a 10% difference across any two HWTS systems in the proportion of households that liked them, at the 95% confidence level (SI Fig. S3). We collected our data over nine months, starting in May of 2012.

2.3. The six HWTS options

Guided by the Tanzanian Ministry of Health, we selected the study HWTS options according to four criteria:

1) *Low cost.* We set the ceiling for the price of consumables at 4% of the median expenditure per capita (Amrose et al., 2015; Hutton, 2012), and the full price of durables at 33% of the median monthly household expenditure (National Bureau of Statistics Ministry of Finance, 2014). This yielded a maximum retail price of TZS 22 (TZS 1590 = USD 1 in 2012) per liter of water treated for consumable HWTS products (assuming 2 L per person per day for drinking); and TZS 57,000 for a durable HWTS product (National Bureau of Statistics Ministry of Finance, 2014).
2) *Commercially available in Tanzania.* The expansion of an existing supply chain is less challenging than the creation of a new product market.

3) *Portable.* Migration is common in sub-Saharan Africa and families cannot move with heavy systems such as bio-sand filters.
4) *Efficacious.* Turbid water is common in Tanzania; this criterion eliminated Solar Disinfection (SODIS) (EAWAG/SANDEC, 2002).

All HWTS products that fit these criteria were included in our study. Consumables included liquid sodium hypochlorite (Waterguard Liquid); sodium dichloroisocyanurate tablets (Waterguard Tablets); and sachets of Proctor and Gamble's PuR. The durables were ceramic pot filters (Safe Water Now, n.d.), and ceramic siphon filters (Basic Water Needs India Pvt Ltd, n. d.-a). All these options significantly reduce *E. coli* concentrations in the laboratory (LeChevallier and Au, 2004; Brown and Sobsey, 2010; Basic Water Needs India Pvt Ltd, n. d.-b), and in the field (Mohamed et al., 2015; Clasen et al., 2007; Souter et al., 2003; Ziff, 2008; Brown et al., 2008). Boiling served as a comparison for the HWTS retail products; it has been shown to significantly reduce *E. coli* in field conditions (Brown and Sobsey, 2012).

We distributed improved cookstoves to minimize the health impacts from any increased use of solid fuels from boiling (Anenberg et al., 2013). Boiling water contributes a small fraction of total household fuel use (Clasen et al., 2008), but the research team agreed that increasing exposure without any mitigation measures as part of an experimental study was not defensible. All households also received a safe storage container of 20 L to minimize recontamination of the treated water (Levy et al., 2008). The households retained their storage containers and cookstoves at no cost at the end of the study, as compensation for their time and effort.

2.4. Experimental design

Following Scott et al. (2007), we developed a short informational program based on social marketing principles for our study (Scott et al., 2007). Materials included an illustrated pamphlet on waterborne illnesses, catchy slogans on the importance of safe water, and a sticker with brief instructions for each HWTS system (see SI Fig. S4). These slogans, pamphlet and stickers were collaboratively developed with focus groups in non-study villages in Kisarawe. Our field team demonstrated the use of the HWTS system by treating a bucket of water in each study home. The household member being trained repeated all the steps back to our team, and, if any were incorrect, the training was repeated. We did this separately for each HWTS system being delivered, and affixed the appropriate informational sticker to the storage container before we left the household.

Households received the HWTS systems in a randomized sequence to avoid stated preference biases due to treatment order. Each participating household tested four of the six HWTS options that we evaluated, over the course of four rounds of evaluation. All were assigned a filter, a Waterguard product, boiling and PuR. Half the households received PuR in its original packaging; the other half received repackaged PuR with a label printed *Takasa Maji* ('Water Treatment' in Swahili), to test whether generic packaging might affect usage or preferences.

Each round started with a five day 'attachment period', after which a member of our field team visited the households. During this visit households were asked about their source water, perceived water quality, water collection and water usage practices. The households then had four to six weeks to use their assigned HWTS system, without any interim reminders. At the end of each round our field team visited the households to collect any durable HWTS products, distribute the next assigned HWTS system, and collect data on usage frequency, proper use, the water sources accessed and perceptions of the HWTS system. After the fourth round, we collected survey data on the ranked preferences for each HWTS system and conducted the WTP auction. In the auction the households had the chance to buy any of the products they had tested. We reminded them at the start of rounds one and four that they could bid for any of their assigned HWTS systems after all four rounds (SI Fig. S5).

2.4.1. Outcome measurement: user preferences

We defined usage as reported treatment by at least one household member in the previous two weeks. This showed recent use, rather than consistent daily use. Our field team also collected observational data on usage, and tested for chlorine presence in stored drinking water.

We created a simple, easily reproducible, ranking protocol for this study. At the end of all four rounds we presented our participants with four cards, each with a picture of one of their assigned HWTS systems. They sorted the cards into three categories: liked, disliked and neutral. They could put all four cards into one of the categories if they wished, and any category could remain empty. Within each category, they arranged the cards from the most liked to the least, and the most disliked to the least. We recorded HWTS preference rankings from the sorted cards, following Beggs et al., (1981), to obtain ranked, stated preferences (Beggs et al., 1981). We developed a discrete choice randomized utility model to estimate the relative preferences for each HWTS system across our study population (shown in SI Fig. S7); below we present a parametric analysis of the preference data (Train, 2009). We also asked the participants what they had liked and disliked about each assigned HWTS system, wording our questions in an open-ended way, and subsequently coding their responses.

2.4.2. Outcome measurement: willingness to pay (WTP)

We conducted an auction game with the participants, adapted from Luoto et al. (2012) and based on the original work of Becker et al. (1964), in order to elicit their WTP for any HWTS they had tried. Both liquid and tablet Waterguard products were included for all participants, as they were considered similar to one another (Lantagne et al., 2008). Revealed willingness to pay estimates after participants have tried the relevant products are potentially more conservative than "naïve" or stated valuations in the absence of such experience (Luoto et al., 2012). For our comparative study, the post-trial WTP method was essential, as the referent HWTS system was boiling, with which everyone was already familiar.

First, the participants stated the highest price they were willing to pay for each HWTS product. They then selected one of ten slips of folded paper from an opaque bag, blinding them to the prices available. Each paper had a different price, but all were less than or equal to the retail price of the product (SI Fig. S6 shows the price selection method). If the selected price was higher than their stated WTP, they "lost", and they could not purchase that product. If it was lower, they "won", and they could purchase that HWTS product for the selected (not their stated) price. This method gave them an incentive to state a high WTP for HWTS products that they wished to purchase, while preventing us from charging prices above retail. In order to avoid biasing participants' decisions to buy or not buy once they had actually "won", we said nothing about whether or not this randomly-drawn price was above or below the retail price. We explained the price-setting methods to all participants, and practiced the auction with each household using a bar of soap (a common purchase), to ensure that the rules of the game were fully understood.

When piloting the auction protocol, we observed that several households did not have cash on hand for durable purchases such as buckets or clothes. When these households needed cash, they borrowed the money or sold some of their assets (such as chickens). Since the bids for the filters were more likely to be impacted by cash constraints, we gave the participants a choice of payment method for these. They could bid using chickens, cash or mobile money, and so could play the auction game even if they were cash-limited.

2.5. Ethics statement

Our research protocol was approved for ethical compliance by the University of California at Berkeley's Office for the Protection of Human Subjects and Tanzania's National Institute for Medical Research.

3. Results

3.1. Usage of HWTS systems

Self-reported usage of the assigned HWTS systems was high; the average across all rounds was 91% in Kisarawe and 86% in Geita. High reported rates of use could reflect social desirability bias on the part of the households. Observational data and chlorine testing, however, were consistent with these stated rates of usage. In a random sub-sample of 179 households using Waterguard, PuR or *Takasa Maji*, 32 (17%) did not have treated drinking water available at the time of the visit, but 120 (67%) had total chlorine concentrations between 0.05 and 0.8 mg/L. These concentrations indicate usage more recent than the two-week recall period. For the pot filter, 96% of our observations showed that the equipment had been used recently enough for the filter to remain damp; for the siphon filter this was true for 90%. These data suggest that the majority had recently used their assigned HWTS system, and so reported preferences and WTP estimates were based on experiential knowledge.

Treatment responsibilities were highly gendered: 73% of households with adult women assigned the chore to women alone. Adults (above age 18) drank treated water more often than children (below age 5) did, though the latter are most vulnerable to waterborne illnesses: only 77% of households with small girls reported giving them treated water. Respondents also told us why they treated their drinking water. Most cited cleanliness, the importance of treatment, or the need to get rid of germs, all of which were messages included in our informational program.

3.2. User preferences

Based on the ordinal ranking protocol, boiling and the pot filter were the preferred HWTS systems (Fig. 1). These results support our H_1 (households prefer boiling to retail HWTS products), with the exception of the pot filter, which was also strongly preferred. The chlorine additives, siphon filter and PUR had a greater number of low rankings (Fig. 1). These same rankings were used to estimate a discrete choice randomized utility model, which yielded a similar pattern of preferences. The results of the discrete choice model are in SI Fig. S7.

In round four, households that reported their source water as “Clear, without any color” (58%) were classified as accessing sources with low turbidity, and households that reported “Cloudy/muddy/rusty” as accessing turbid sources. The villages were similar in terms of socio-economic status (SI Table S2), but differed in source water turbidity: in round four, only 16% of all households reporting highly turbid sources were in Geita. As such, we were not able to statistically disentangle the effects of district location from turbidity, and have interpreted turbidity as the most important factor, based on our field observations.

The percentage of participants that reported liking boiling, PuR, *Takasa Maji*, and the siphon filter varied significantly with source

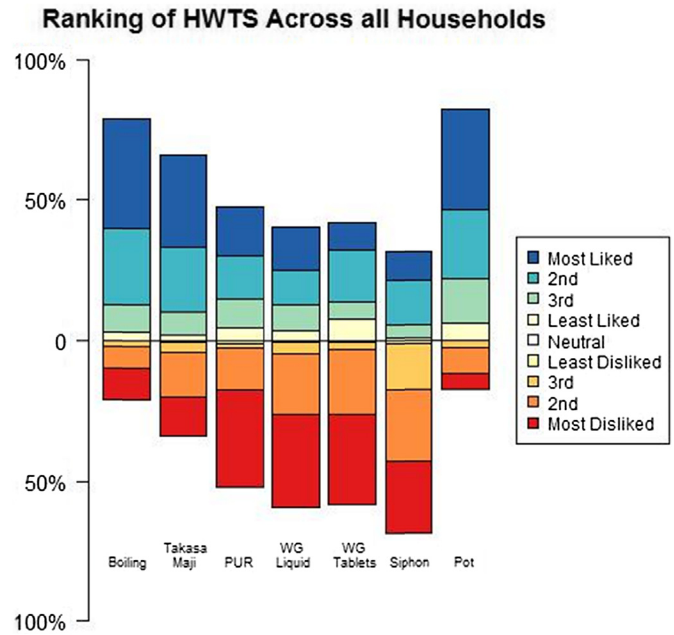

Fig. 1. Average Rank of HWTS systems, X-axis lists the HWTS. Y-axis shows the percentage of participants that gave the HWTS system a specific ranking.

water turbidity (Fig. 2). PuR removes turbidity, and households with turbid water liked it more; this has not been the case for some previous studies (Albert et al., 2010). *Takasa Maji* did better than PuR, so it seems that generic packaging did not negatively affect preferences (Figs. 1 and 2). The siphon filter also removes turbidity, but households complained that the flow rate slowed dramatically when treating turbid water; this may explain why many disliked it. Boiling and the Waterguard products do nothing for turbidity, yet only the rankings of the former seem affected by it; the difference for boiling was statistically significant in the discrete choice model, and nearly significant in the parametric analysis (see Fig. S7 in the

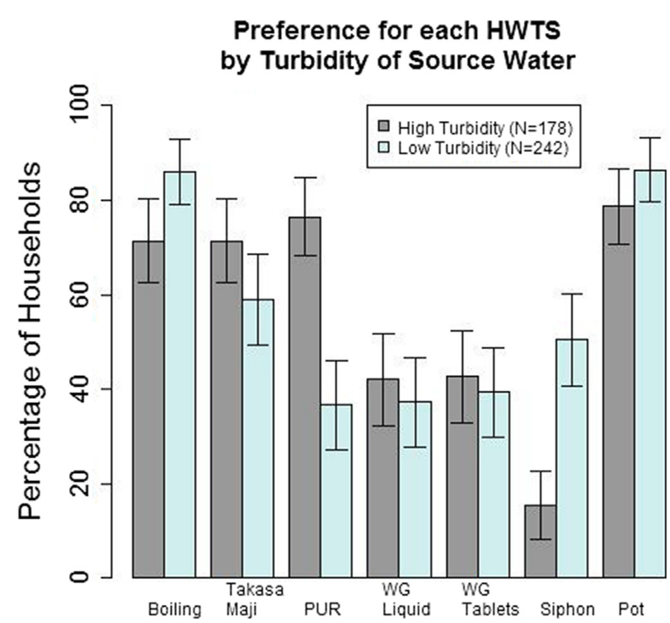

Fig. 2. Percentage of participants that liked each HWTS system, separated by high and low source water turbidity. X-axis lists the HWTS system. Y-axis shows the percentage of participants.

SI and Fig. 2, respectively). The HWTS systems most often ranked first or second by those who were assigned them were: boiling (66% of households), the pot filter (61% of households) and PuR/*Takasa Maji* (61% of those households with turbid source water).

We asked the participants what they liked and disliked about each HWTS system. The tally for specific attributes for each HWTS system, when it was ranked most or second-most (dis)liked, is shown on the Y-axis in Figs. 3 and 4. The number of responses varied by HWTS type; these are listed on the X-axis. A household could cite more than one attribute. Ease of use, taste and effectiveness were the most cited reasons for liking an HWTS system (Fig. 3). Those who disliked boiling or the filters objected to their high time requirements, and bad taste was the most common reason for disliking *Takasa Maji*, PuR, and the Waterguard products (Fig. 4).

3.3. Willingness to pay

At the end of the last round, 453 out of the original 556 households remained in the study (the drop-out rate averaged 6% per round, with no significant asset-ownership differences between retained participants and drop-outs; see Table S8). All our study households were willing to rank their assigned HWTS systems, but 26% of the households in Geita and 15% in Kisarawe declined to play the auction game. These households had roughly the same rankings for boiling as the households that did play, implying that they did not decline to play simply because they preferred the one system that did not require a purchase. Most respondents who declined to bid said they lacked the resources to make any purchases; as Whittington (1998) explains, it is not possible to distinguish willingness from ability to pay in stated preference exercises.

Table 1 shows the number of bids per HWTS product, along with their mean bids and retail prices. We did not include boiling as all participants retained their improved cookstoves for free. We incorporated the non-bidders' responses into our bid curves (see below), as their stated WTP was, in effect, zero for all of the commercial products. 93% of those who bid had not previously purchased any of the HWTS products, and did not know their retail prices. This shows that their WTP was not constrained by actual retail prices (a small number of bids were higher than retail). A sizable minority (12%) of the pot filter bids were placed using chickens instead of cash. 92% of all bidders "won" at least one auction, and, of those, 14% declined to purchase anything. If households won more than one auction, they could purchase any HWTS product for which they won. The probability of purchasing a pot-filter was 1.3 times that of purchasing PuR when both were won; pairwise comparisons for the other HWTS products are in the SI (Table S9).

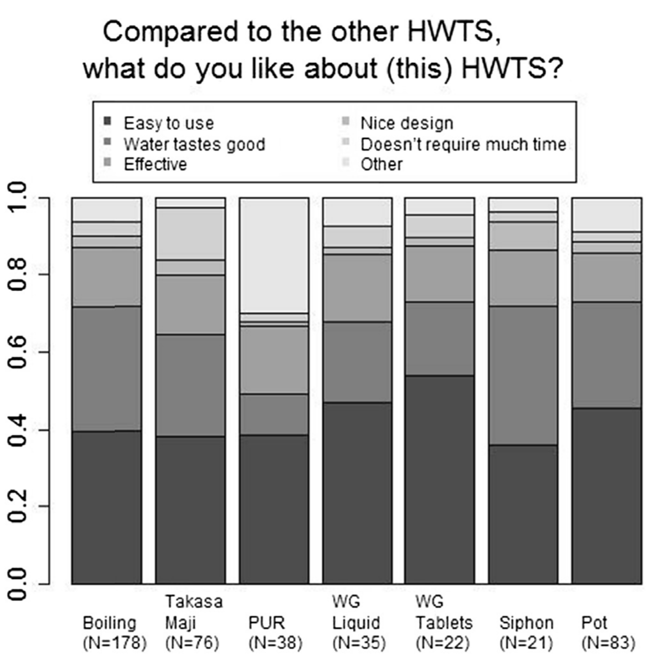

Fig. 3. Reasons given for why participants liked their assigned HWTS system when it was ranked most or second-most liked. The attributes reflect the respondents' subjective opinions. X-Axis shows number of responses for each HWTS system. Y-axis shows tally of reasons given for each HWTS system.

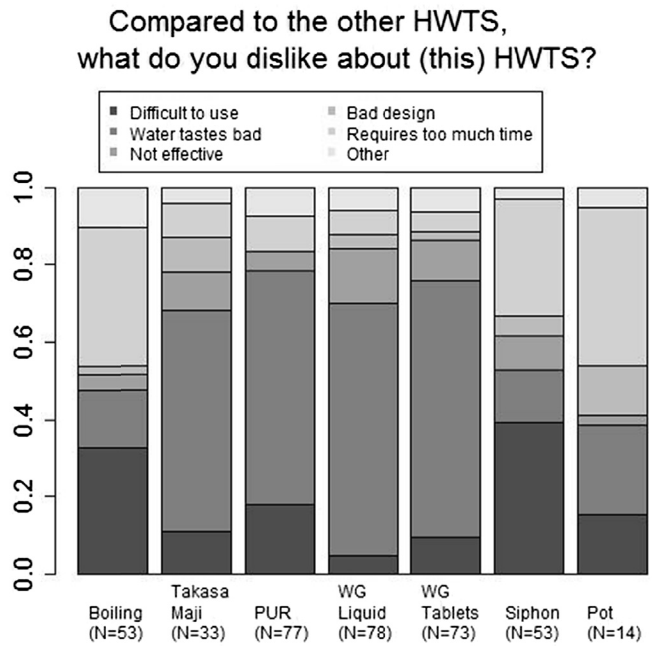

Fig. 4. Reasons given for why participants disliked their assigned HWTS system when it was ranked most or second-most disliked. The attributes reflect the respondents' subjective opinions. X-Axis shows number of responses for each HWTS system. Y-axis shows reasons given for each HWTS system.

We obtained retail prices for the commercially sold HWTS products from the organizations distributing them, and verified the prices at retail outlets in Dar es Salaam and the district capitals of Geita and Kisarawe. The median bid was half the retail price for PuR and roughly 1/3 of retail for the Waterguard products. Since the filters were durable products their bid prices were higher, but the median bids for the siphon filter and the pot filter were only 7% and 11% of retail, respectively (Fig. 5). Among our respondents, 28% were willing to pay the retail price for PuR and 1.8% for the pot filter. At the median bid price, 14.9% of demand for PUR and 5.3% of demand for the pot filter came from respondents that reported 'dislike' for those systems; for all HWTS a proportion of households with positive WTP reported 'dislike' for those systems (see Figs. 5 and SI Fig. S10).

The mean bid for households with highly turbid source water was higher than for those with low turbidity for all HWTS except the siphon filter. The difference was large for PuR (low turbidity: 373 ± 81, high turbidity: 662 ± 222, $p = 0.05$), *Takasa Maji* (low turbidity: 251 ± 82, high turbidity: 419 ± 135, $p = 0.05$) and the pot filter (low turbidity: 5023 ± 919, high turbidity: 7412 ± 2353, $p = 0.05$). All these HWTS products remove suspended solids. WTP

Table 1
WTP bids for HWTS. Mean bids include stated zero bids, including those who refused to participate in the auction. Results with zero bids excluded are found in SI Table S11. We use means here in order to express confidence intervals – a measure of the scatter or range of values. The average exchange rate in 2012 was TZS 1590 = USD 1 (IFEM, n.d.).

		Mean Bid (TZS)	95% CI	Number of Bids	Number of Bids = Zero	Retail Price (TZS)
Siphon Filter (1 Filter)	Kisarawe	1141	±367	94	33	15,000
	Geita	1238	±362	110	43	
	All	1194	±258	204	76	
Pot Filter (1 Filter + Container)	Kisarawe	9404	±1807	107	15	45,000
	Geita	3000	±441	123	26	
	All	5979	±964	230	41	
Water-Guard Liquid (1 Bottle)	Kisarawe	746	±168	201	60	1500
	Geita	443	±88	234	105	
	All	583	±92	435	165	
Water-Guard Tablets (10 Tablets)	Kisarawe	409	±82	201	72	1000
	Geita	268	±53	234	104	
	All	333	±48	435	176	
PuR (5 Packets)	Kisarawe	600	±134	107	28	1000
	Geita	304	±102	110	46	
	All	450	±86	217	74	
Takasa Maji (5 Packets)	Kisarawe	357	±107	94	24	–
	Geita	314	±108	124	54	
	All	332	±77	218	78	

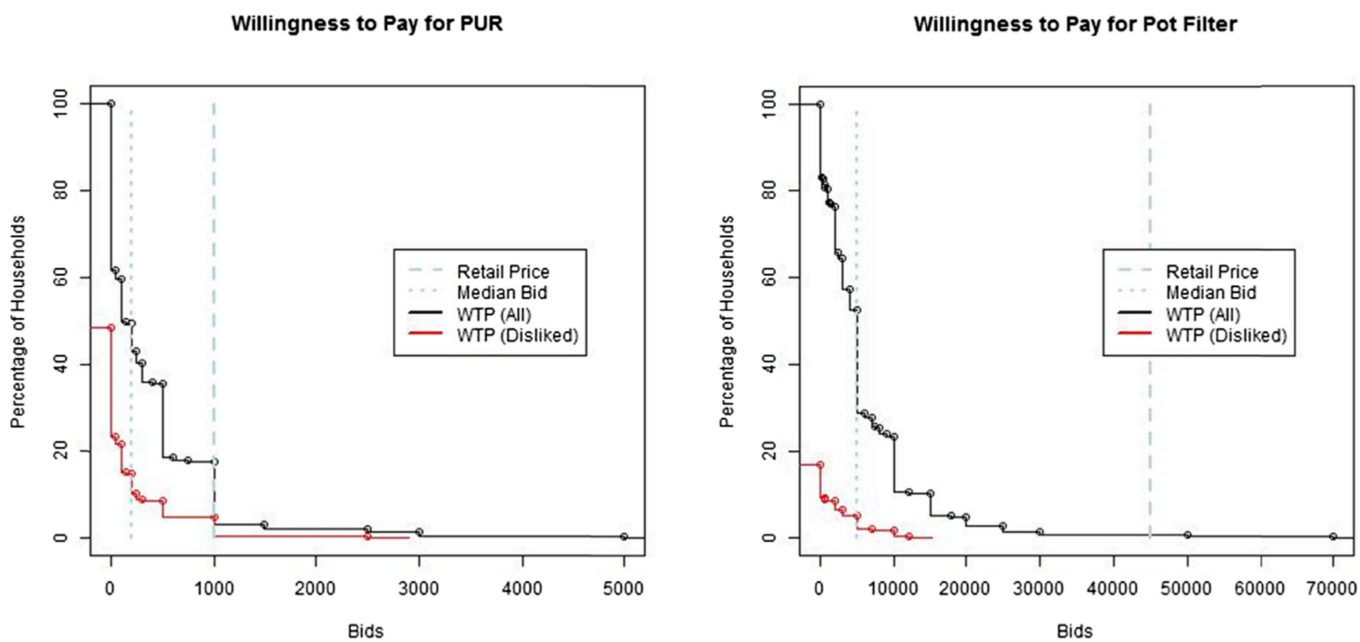

Fig. 5. The Ceramic Pot Filter and PuR Bid Curves (for all households and for households that disliked these HWTS) with Retail Prices and Median Bid Prices. X-Axis shows bid prices. Y-axis shows the percentage of all participants who were willing to pay at each bid price.

differences across districts are much reduced when the effects of turbidity are considered, but our sample size was not large enough to disentangle the effect of one from the other. The WTP data, taken at face value, indicate that significantly cheaper versions of the preferred HWTS products, or significant subsidies at current prices, will be needed for a successful scale up.

4. Conclusions and discussion

This study was motivated by the Tanzanian government's focus on safe drinking water and improved health of the rural poor through an HWTS-based strategy. We evaluated consumer preferences for six HWTS products in order to find the one(s) with the potential to reach the greatest number of households. We assessed revealed willingness to pay for the HWTS products that they had become familiar with, which the literature suggests yields a more conservative estimate of WTP than naïve estimates. Ours is the first study that we are aware of to compare user preferences for boiling to non-boiling HWTS systems, as well as the first to integrate both user preferences and WTP for HWTS. We maximized the number of households willing and able to bid for durable HWTS products by allowing them to bid with their assets (chickens), instead of with cash alone. This payment method mimicked the actions cash-poor households would have to take to buy durable goods. We do not argue that bartering for durable HWTS products is a useful way to scale up adoption; but our findings indicate that improving liquidity (e.g. through group micro-loans or conditional cash transfers) will increase adoption of these products, a finding that is in line with previous observations in South Asia (Freeman et al., 2012).

Following the household water literature, we argue that preferences are an important indicator of what might be adopted and regularly used (Albert et al., 2010). The user preference ranking exercise indicated that boiling (with an efficient stove) and the pot filter (with a storage container) were the most preferred HWTS options, before costs were factored in. The pot filter was preferred across districts and across source water quality, as has been observed in South Asia, but preferences for boiling were on par with the pot filter, a new finding (Luoto et al., 2012; Poulos et al., 2012). Where the source water was significantly turbid, an effective disinfectant-coagulant such as PuR was also preferred; this contrasts with previous observations from rural Kenya (Albert et al., 2010).

We found that some households, even when they reported disliking an HWTS system such as Waterguard, still bid on it. This potentially counter-intuitive result could be a result of consumers wanting to acquire a product at a low price for occasional use or for the chance to re-sell it at a later date. The safe water literature has argued that, unless a large majority of community members use HWTS systems correctly and consistently, they will not provide the health benefits of safe drinking water to the community as a whole (Brown and Clasen, 2012). Several health products require consistent use for a positive health impact, including HWTS, bed nets, and improved cookstoves. Our findings suggest that a positive WTP for a disliked product (such as Waterguard) is a potential indicator of future inconsistent use. We recommend that WTP studies of personal health products include independent user preference assessments, using a protocol similar to the one developed here (Fig. 5 and SI Fig. S10).

Additionally, among the Waterguard products and PuR, there is a negative correlation between bid price and the percentage of total demand held by households that disliked those HWTS. This observation could indicate that higher subsidies may not result in higher rates of consistent use (SI Fig. S12). Further study on the relationship between stated preferences, inconsistent use, and subsidies is warranted.

The WTP data are best interpreted as a guide to estimating (current) demand and the subsidies that might be needed to achieve desired levels of adoption. Our WTP estimates indicate that reaching 50% of the target population would require subsidies of up to 89% of retail for the pot filter with its container; the median bid in these low-income communities was 11% of the retail price. These low WTP figures have also been reported in previous research (Ahuja et al., 2010; Amrose et al., 2015) with revealed WTP studies almost always yielding lower numbers than stated WTP (Luoto et al., 2012; Ahuja et al., 2010; Kremer et al., 2009; Orgill et al., 2013). The development of less expensive alternatives is promising, however; we found that a generic disinfectant-coagulant would be as acceptable to consumers as PuR, indicating a potential market for a generic version of this type of HWTS technology.

Boiling is the most widely used option within our study population, as it is in other parts of the world (Rosa and Clasen, 2010). It is unclear whether the prevalence of boiling reflects a comparative preference for boiling; our results indicate that this may be the case. Gathering fuelwood and heating water requires time and labor; yet, for a majority of the households, the time savings or other advantages of the retail HWTS products were not enough to induce a WTP that was even close to retail prices. Our findings suggest that boiling, the only HWTS system currently practiced at a global scale, and one with no commercial backing, could be preferred by many communities to several highly-marketed retail products, even when these become more familiar. In all dimensions other than time required, boiling beat PuR, Waterguard and the siphon filter, and it was a strong rival to the pot filter.

Because of recontamination during storage, if the Tanzanian government decides to promote boiling water as a health measure, we recommend including a safe storage container at minimal cost. In our study all of the households owned buckets, but not all of these had lids, and none had spigots attached. The retail value of our safe storage container was TZS 8000; this, too, would require significant subsidies for a national scale up in rural areas.

Based on the median bids in our study, we estimate that half of rural households might adopt the pot filter with a storage container if a combination of subsidies and price reductions totaling TZS 42,500 (USD 28) per household were provided. Therefore the initial subsidy needed to create demand sufficient to provide 50% of the rural population with pot filters would equal TZS 263 billion, not counting administration costs (SI Table S13 shows subsidy estimates for the other HWTS products). Likewise, if PuR, or a similar coagulant-disinfectant, were to sell for TZS ~50 per packet, then this might be a “sweet spot” where households with turbid source water could afford to regularly purchase it.

We find that consumer-approved and efficacious household water treatments exist for rural Tanzania, but the degree to which households are both willing and able to pay for these is modest and will constrain scale-up. The estimation and appropriate targeting of subsidies is a contested topic in the development literature, but many researchers have argued that, without subsidies, universal access to safe drinking water will not be possible (Ahuja et al., 2010; Amrose et al., 2015). We conclude that, for a low-income country looking to improve the health of its citizens through scaling up HWTS, there may be no “low-cost” options to safe drinking water for all.

Our study had several limitations. First, the duration of use for each HWTS system – 4–6 weeks – was arguably short. Our relatively short evaluation period, however, allowed us to include a greater number of HWTS systems. The duration was sufficient for the participants to understand correct use of the HWTS systems and the effort involved therein, as well as to become acquainted with the taste and smell of treated water.

Second, we provided the pot filter within a container designed by our research team. In Tanzanian markets the ceramic filter is sold by itself and put inside a 20 L bucket, but, during pre-survey piloting, we found that the standard bucket had insufficient storage space. Our preference and WTP results thus reference the filter and container together.

Third, we provided a locally manufactured efficient stove as part of the boiling treatment; therefore, an expressed preference for boiling could have partly reflected an affinity for the cookstoves. This limitation was an explicit part of our study design, since we decided that we could not recommend, either to our study participants or to policy makers, an HWTS system that might increase the burning of solid fuels but do nothing to mitigate its negative impacts. We note that all participants understood that they could keep the cookstoves whatever their preferences for the various HWTS systems.

Fourth, filters and consumables are inherently difficult to compare because the former retain their value despite repeated use. We encouraged households to express their HWTS preferences based on ease of use, taste, aesthetics, perceived effectiveness and time required. We thus tried to elicit user preferences that were based on product characteristics besides resale value. Our results show that even if durability affected preferences, it did not eclipse other product features (such as ease of use) or relevant household characteristics (such as source water turbidity).

Fifth, usage rates (reported or observed) are a potential indicator for the frequency of use after adoption. But households may have been influenced by our repeated visits over the course of the study, resulting in a reactivity bias. Therefore our reported rates may overestimate use in the long term. Even if this bias occurred, if it was consistent across HWTS options, it should not have biased the relative differences in user preferences and WTP amongst the

HWTS systems.

Finally, it is unclear what other challenges exist to making any of these HWTS systems available throughout Tanzania; supply chain constraints were not explicitly addressed in this paper. Further study is warranted on the creation of a reliable supply chain for multiple HWTS systems, in particular for the pot filter, safe storage containers and efficient cookstoves.

Acknowledgments

We are grateful to the ERG Water Group, Michaelangelo Tabone, Kara Nelson and Jack Colford, for comments and suggestions; and for the support of UNICEF, and in particular Sarah House, Rebecca Budimu and Astrid Van Agthoven. We thank our field team: Frank Semindu, Alfa Gonzi, Zinduna Donald, Diana Joseph, Mohamed Masenga, Rosemary J. Muna, Jafari Mwilola, Lucy Shila, Bavon Berthold, Devotha Augustine, Jastin Jason, Ludano Nzagamba, Maimuna Sizya, Hawa F. Muyaga, Joyce John, Mapinduzi Amon, Omary Rashid, Silas Shadrack; also our field supervisors Valencia Msimbe, Vestina Marcelino, Simon Kitobelo, and Veronica Massaga. Without them our research would never have been possible. We thank the Center for African Studies and the Institute of International Studies, University of California at Berkeley, for their support during the data analysis and writing phases of this project.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.socscimed.2016.11.031.

References

Ahuja, A., Kremer, M., Zwane, A.P., 2010. Providing safe water: evidence from randomized evaluations. Annu. Rev. Resour. Econ. 2 (1), 237–256. https://doi.org/10.1146/annurev.resource.012809.103919.

Albert, J., Luoto, J., Levine, D., 2010. End-user preferences for and performance of competing POU water treatment technologies among the rural poor of Kenya. Environ. Sci. Technol. 44 (12), 4426–4432.

Amrose, S., Burt, Z., Ray, I., 2015. Safe drinking water for low-income regions. Annu. Rev. Environ. Resour. 40 (1).

Anenberg, S.C., Balakrishnan, K., Jetter, J., Masera, O., Mehta, S., Moss, J., Ramanathan, V., 2013. Cleaner cooking solutions to achieve health, climate, and economic cobenefits. Environ. Sci. Technol. 47 (9), 3944–3952. https://doi.org/10.1021/es304942e.

Ashraf, N., Berry, J., Shapiro, J.M., 2007. Can Higher Prices Stimulate Product Use? Evidence from a Field Experiment in Zambia (Working Paper No. w13247). National Bureau of Economic Research.

Basic Water Needs India Pvt Ltd About Basic Water Needs India Pvt Ltd. (n.d.-a). About Basic Water Needs. Retrieved March 3, 2015, from http://www.basicwaterneeds.com/#.

Basic Water Needs India Pvt Ltd, Basic Water Needs India Pvt Ltd. (n.d.-b). Summary of testing reports from Basic Water Needs ceramic water filters. Retrieved from http://www.basicwaterneeds.com/wp-content/uploads/qaqc/Netherlands/Netherlands/Netherlands%20Waterlab%20Noord%20Analysis.pdf.

Becker, G.M., DeGroot, M.H., Marschak, J., 1964. Measuring utility by a single-response sequential method. Jacob Behav. Sci. 9 (3), 226.

Beggs, S., Cardell, S., Hausman, J., 1981. Assessing the potential demand for electric cars. J. Econ. 17 (1), 1–19.

Bierlaire, M. (2003). BIOGEME: a free package for the estimation of discrete choice models. In Proc. 23rd WEDC Conf., Sept. 1–5, Durban, S. Afr. Ascona.

Brown, J., Clasen, T., 2012. High adherence is necessary to realize health gains from water quality interventions. PLoS One 7 (5), e36735.

Brown, J., Sobsey, M.D., 2010. Microbiological effectiveness of locally produced ceramic filters for drinking water treatment in Cambodia. J. Water Health 08 (1), 1. https://doi.org/10.2166/wh.2009.007.

Brown, J., Sobsey, M.D., 2012. Boiling as household water treatment in Cambodia: a longitudinal study of boiling practice and microbiological effectiveness. Am. J. Trop. Med. Hyg. 87 (3), 394–398. https://doi.org/10.4269/ajtmh.2012.11-0715.

Brown, J., Sobsey, M.D., Loomis, D., 2008. Local drinking water filters reduce diarrheal disease in Cambodia: a randomized, controlled trial of the ceramic water purifier. Am. J. Trop. Med. Hyg. 79 (3), 394–400.

Brown, J., Proum, S., Sobsey, M.D., 2009. Sustained use of a household-scale water filtration device in rural Cambodia. J. Water Health 07 (3), 404. https://doi.org/10.2166/wh.2009.085.

Clasen, T., Saeed, T.F., Boisson, S., Edmondson, P., Shipin, O., 2007. Household water treatment using sodium dichloroisocy anurate (NaDCC) tablets: a randomized, controlled trial to assess microbiological effectiveness in Bangladesh. Am. J. Trop. Med. Hyg. 76 (1), 187–192.

Clasen, T., McLaughlin, C., Nayaar, N., Boisson, S., Gupta, R., Desai, D., Shah, N., 2008. Microbiological effectiveness and cost of disinfecting water by boiling in semi-urban India. Am. J. Trop. Med. Hyg. 79 (3), 407–413.

Dupas, P., 2011. Health behavior in developing countries. Annu. Rev. Econ. 3 (1), 425–449. https://doi.org/10.1146/annurev-economics-111809-125029.

EAWAG/SANDEC, 2002. Solar Water Disinfection: a Guide for the Application of SODIS (SANDEC Report No. 06/02). Swiss Federal Institute of Environmental Science and Technology (EAWAG) & Department of Water and Sanitation in Developing Countries (SANDEC), Dübendorf, Germany.

Efficacious. Turbid water is common in Tanzania; this criterion eliminated Solar Disinfection (SODIS) (EAWAG/SANDEC, 2002).

Evans, W.D., Pattanayak, S.K., Young, S., Buszin, J., Rai, S., Bihm, J.W., 2014. Social marketing of water and sanitation products: a systematic review of peer-reviewed literature. Soc. Sci. Med. 110, 18–25. https://doi.org/10.1016/j.socscimed.2014.03.011.

Freeman, M.C., Trinies, V., Boisson, S., Mak, G., Clasen, T., 2012. Promoting household water treatment through Women's self help groups in rural India: assessing impact on drinking water quality and equity. PLoS ONE 7 (9), e44068. https://doi.org/10.1371/journal.pone.0044068.

Hutton, G., 2012. Monitoring “Affordability” of water and sanitation services after 2015: review of global indicator options. In: A Paper Submitted to the UN Office of the High Commissioner for Human Rights, 20 March. Retrieved from http://www.wssinfo.org/fileadmin/user_upload/resources/end-wash-affordability-review.pdf.

IFEM. (n.d.). Interbank Foreign Exchange Market (IFEM) Summaries. Retrieved March 3, 2015, from https://www.bot-tz.org/FinancialMarkets/IFEMsummaries/IFEMsummaries.asp.

Kols, A. (n.d.). Safe Water Situation in Four Countries: 2007 Findings in Brief. PATH.

Kremer, M., Leino, J., Miguel, E., Zwane, A.P., 2009. Spring cleaning: Rural Water Impacts, Valuation and Property Rights Institutions. National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w15280.

Lantagne, D., Meierhofer, R., Allgood, G., McGuigan, K.G., Quick, R., 2008. Comment on “Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world.” Environ. Sci. Technol. 43 (3), 968–969.

LeChevallier, M.W., Au, K.-K., 2004. Water Treatment and Pathogen Control Process Efficiency in Achieving Safe Drinking-water. Published on behalf of the World Health Organization by IWA Pub, London. Retrieved from http://site.ebrary.com/id/10137824.

Levy, K., Nelson, K.L., Hubbard, A., Eisenberg, J.N.S., 2008. Following the water: a controlled study of drinking water storage in northern coastal Ecuador. Environ. Health Perspect. 116 (11), 1533–1540. https://doi.org/10.1289/ehp.11296.

Luby, S.P., Mendoza, C., Keswick, B.H., Chiller, T.M., Hoekstra, R.M., 2008. Difficulties in bringing point-of-use water treatment to scale in rural Guatemala. Am. J. Trop. Med. Hyg. 78 (3), 382–387.

Luoto, J., Najnin, N., Mahmud, M., Albert, J., Islam, M.S., Luby, S., Levine, D.I., 2011. What point-of-use water treatment products do consumers Use? Evidence from a randomized controlled trial among the urban poor in Bangladesh. PLoS ONE 6 (10), e26132. https://doi.org/10.1371/journal.pone.0026132.

Luoto, J., Mahmud, M., Albert, J., Luby, S., Najnin, N., Unicomb, L., Levine, D.I., 2012. Learning to dislike safe water products: results from a randomized controlled trial of the effects of direct and peer experience on willingness to pay. Environ. Sci. Technol. 46 (11), 6244–6251. https://doi.org/10.1021/es2027967.

McFadden, D., Train, K., 2000. Mixed MNL models for discrete response. J. Appl. Econ. 15 (5), 447–470.

MHSW, 2014. National plan for scaling up household water treatment and safe storage 2014-2019. Ministry of Health and Social Welfare, Department of Preventative Services, Environmental Health and Sanitation Section.

Ministry of Finance, United Republic of Tanzania. (n.d.). Government Budget for Financial Year 2013/2014 Citizen Budget Edition. Dar es Salaam, Tanzania: Ministry of Finance, United Republic of Tanzania.

Mohamed, H., Brown, J., Njee, R.M., Clasen, T., Malebo, H.M., Mbuligwe, S., 2015. Point-of-use chlorination of turbid water: results from a field study in Tanzania. J. Water Health 13 (2), 544–552.

National Bureau of Statistics. (n.d.). Household Budget Survey Main Report 2011/2012. Dar es Salaam, Tanzania: Ministry of Finance, United Republic of Tanzania.

National Bureau of Statistics Ministry of Finance, 2014. Tanzania Mainland Household Budget Survey Main Report 2011/2012. Tanzania, Dar es Salaam. Retrieved from http://www.nbs.go.tz/nbs/takwimu/hbs/The_2011-12_HBSFinalReport.zip.

Orgill, J., Shaheed, A., Brown, J., Jeuland, M., 2013. Water quality perceptions and willingness to pay for clean water in peri-urban Cambodian communities. J. Water Health 11 (3), 489. https://doi.org/10.2166/wh.2013.212.

Parker Fiebelkorn, A., Person, B., Quick, R.E., Vindigni, S.M., Jhung, M., Bowen, A., Riley, P.L., 2012. Systematic review of behavior change research on point-of-use water treatment interventions in countries categorized as low- to medium-development on the human development index. Soc. Sci. Med. 75 (4), 622–633. https://doi.org/10.1016/j.socscimed.2012.02.011.

Poulos, C., Yang, J.-C., Patil, S.R., Pattanayak, S., Wood, S., Goodyear, L., Gonzalez, J.M., 2012. Consumer preferences for household water treatment products in Andhra Pradesh, India. Soc. Sci. Med. 75 (4), 738–746. https://doi.org/10.1016/j.socscimed.2012.02.059.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J.M., Cumming, O., Curtis, V., Cairncross, S., 2014. Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. Trop. Med. Int. Health 19 (8), 894–905. https://doi.org/10.1111/tmi.12329.

Rosa, G., Clasen, T., 2010. Estimating the scope of household water treatment in low- and medium-income countries. Am. J. Trop. Med. Hyg. 82 (2), 289–300. https://doi.org/10.4269/ajtmh.2010.09-0382.

Safe Water Now. (n.d.). Ceramic Water Filter. Retrieved March 3, 2015, from http://www.safewaternow.org/?page_id=31.

Schmidt, W.-P., 2014. The elusive effect of water and sanitation on the global burden of disease. Trop. Med. Int. Health 19 (5), 522–527. https://doi.org/10.1111/tmi.12286.

Schmidt, W.-P., Cairncross, S., 2009. Household water treatment in poor populations: is there enough evidence for scaling up Now? Environ. Sci. Technol. 43 (4), 986–992. https://doi.org/10.1021/es802232w.

Scott, B., Curtis, V., Rabie, T., Garbrah-Aidoo, N., 2007. Health in our hands, but not in our heads: understanding hygiene motivation in Ghana. Health Policy Plan. 22 (4), 225–233. https://doi.org/10.1093/heapol/czm016.

Souter, P., Cruickshank, G., Tankerville, M., Keswick, B., Ellis, B., Langworthy, D., 2003. Evaluation of a new water treatment for point-of-use household applications to remove microorganisms and arsenic from drinking water. J. Water Health 1, 73–84.

Train, K., 2009. Discrete Choice Methods With Simulation. Cambridge university press.

Fischer Walker, C.L., Aryee, M.J., Boschi-Pinto, C., Black, R.E., 2012. Estimating diarrhea mortality among young children in low and middle income countries. PLoS ONE 7 (1), e29151. https://doi.org/10.1371/journal.pone.0029151.

Whittington, D., 1998. Administering contingent valuation surveys in developing countries. World Dev. 26 (1), 21–30.

WHO/UNICEF, 2008. Progress on Drinking Water and Sanitation: Special Focus on Sanitation. UNICEF ; World Health Organization, New York, NY; Geneva.

WHO/UNICEF, 2014. Progress on Drinking Water and Sanitation: 2014 Update.

Wolf, J., Prüss-Ustün, A., Cumming, O., Bartram, J., Bonjour, S., Cairncross, S., Higgins, J.P.T., 2014. Systematic review: assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. Trop. Med. Int. Health 19 (8), 928–942. https://doi.org/10.1111/tmi.12331.

Ziff, S.E., 2008. Siphon filter assessment for Northern Ghana. Massachusetts Institute of Technology. Retrieved from. http://web.mit.edu/watsan/Docs/Student%20Theses/Ghana/2009/Thesis%20-%20Final,%20Sara%20Ziff,%205-15-09.pdf.