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User Preferences and Willingness to Pay for Safe Drinking Water: Experimental Evidence from Rural Tanzania

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1   User Preferences and Willingness to Pay for Safe Drinking Water: Experimental

2   Evidence from Rural Tanzania

3   KEYWORDS: Tanzania, Water and health, household water treatment and safe storage, point of

4   use, boiling, user preferences, willingness to pay

5   ABSTRACT

6   Almost half of all deaths from drinking microbiologically unsafe water occur in Sub-Saharan

7   Africa. Household water treatment and safe storage (HWTS) systems, when consistently used,

8   can provide safer drinking water and improve health. Social marketing to increase adoption and

9   use of HWTS depends both on the prices of and preferences for these systems. This study

10   included 556 households from rural Tanzania across two low-income districts with low-quality

11   water sources. Over 9 months in 2012 and 2013, we experimentally evaluated consumer

12   preferences for six "low-cost" HWTS options, including boiling, through an ordinal ranking

13   protocol. We estimated consumers' willingness to pay (WTP) for these options, using a modified

14   auction. We allowed respondents to pay for the durable HWTS systems with cash, chickens or

15   mobile money; a significant minority chose chickens as payment. Overall, our participants

16   favored boiling, the ceramic pot filter and, where water was turbid, PuR™ (a combined

17   flocculant-disinfectant). The revealed WTP for all products was far below retail prices,

18   indicating that significant scale-up may need significant subsidies. Our work will inform

19   programs and policies aimed at scaling up HWTS to improve the health of resource-constrained

20   communities that must rely on poor-quality, and sometimes turbid, drinking water sources.

21   INTRODUCTION

22   In 2014 inadequate and unsafe drinking water was responsible for over half a million deaths

23   from diarrheal diseases; in Africa 25% of all deaths in children under 5 years of age were

24   attributable to diarrhea.(Prüss-Ustün et al., 2014; Fischer Walker, Aryee, Boschi-Pinto, & Black,

25   2012). Rural areas of Sub-Saharan Africa suffer from limited access to improved water sources

26   and high risk of fecal contamination in drinking water. Household water treatment and safe

27   storage (HWTS) has been proposed as an intermediate solution to provide safer drinking water

28   and reduce the burden of disease (WHO/UNICEF, 2008; Wolf et al., 2014).

29   Whether or not HWTS systems are a scalable intervention for poor rural populations is an area

30   of active policy debate (Schmidt & Cairncross, 2009; Schmidt, 2014). Low rates of consistent

31   use have been observed for several types of HWTS systems, (Luby et al., 2008; Brown, Proum,

32   & Sobsey, 2009) and finding the best method to promote adoption and consistent use is an active

33   area of research (Parker Fiebelkorn et al., 2012). In particular, social marketing research has

34   found that consumer preferences and viable price points strongly influence effective demand and

35   the likelihood of consistent use (Evans et al., 2014). This has led to several studies on user

36   perceptions and willingness to pay for HWTS products (Luoto et al., 2012; Albert, Luoto, &

37   Levine, 2010; Poulos et al., 2012) .

38   This study experimentally investigates which HWTS systems rural households prefer and why

39   they prefer them. We also estimate willingness to pay (WTP) for HWTS products, and compare

40   them with user preferences. We do not evaluate water quality effects or health impacts. We

41   assessed preferences and price points for only those HWTS systems that are known to be

42   effective when correctly and consistently used.

43   We located our study in rural Tanzania, where 56% of the population does not have access to

44   an improved water source (WHO/UNICEF, 2014). The Tanzanian government has concluded

45   that piped and treated water will not be viable for rural areas for some years, and that HWTS

46   should be scaled up as an intermediate strategy (MHSW, 2014). Credible information on which

47   HWTS systems to scale up is critical for any future social marketing and product dissemination

48   (Evans et al., 2014).

49   We experimentally evaluated user preferences and willingness to pay for six HWTS

50   approaches. The preference for boiling has not been compared to other HWTS preferences in

51   previous research, despite its high global usage relative to other treatment technologies (Rosa &

52   Clasen, 2010; Ahuja, Kremer, & Zwane, 2010; Amrose, Burt, & Ray, 2015). We found few

53   journal articles that compared several HWTS products, for either user preferences or WTP (e.g.

54   Luoto et al., 2012; Albert et al., 2010; Luoto et al., 2011). The literature on preventative health

55   products indicates that users' willingness to pay, even when they are liked, is generally low; the

56   evidence suggests that unfavorable opinions would be consistent with low valuations (i.e. WTP)

57   and lower usage rates (Luoto et al., 2011; Ashraf, Berry, & Shapiro, 2007; Dupas, 2011).

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

59   (H$_1$) Households prefer boiling to the retail HWTS products.

60   (H$_2$) Households' WTP for HWTS products reflects their preferences.

61   The HWTS market is nascent but not absent in Tanzania. We focused on those HWTS systems

62   that are already available, to assess which have the greatest potential for widespread adoption

63   and sustained use without the need for a completely new supply chain (see below for the

64   selection criteria).

3

65   Our study adds four new features to the user preference and WTP literatures on safe drinking

66   water in low-income countries. First, this is the first study we are aware of to compare user

67   preferences for boiling, a non-commercial and common practice, to those for retail-based water

68   disinfection products. Second, we created a simple ordinal preference ranking protocol across

69   many households and many HWTS methods; our protocol is innovative in that it explicitly

70   solicits categorization of HWTS systems into 'like' or 'dislike', in addition to overall rankings.

71   Third, we estimated WTP using a real auction; this is the first study to identify, and (partially)

72   explain, discrepancies between expressed preferences and willingness to pay for HWTS. Fourth,

73   to minimize respondent dropout, we allowed respondents to pay for the durable HWTS products

74   with cash, mobile money or chickens. In this cash-poor rural economy, chickens are often sold

75   when a little extra money is needed. Our work is relevant for social marketing programs and

76   public health policies aimed at scaling up HWTS in resource-constrained communities that must

77   rely on poor-quality, and sometimes turbid, drinking water sources.

78

79   MATERIALS AND METHODS

80   **Site Selection**

81   We chose one predominantly Muslim, coastal-region district (Kisarawe) and one

82   predominantly Christian, interior-region district (Geita), thus covering a range of cultures and

83   geographies in Tanzania (Supporting Information (SI) Figure S1) [LINK TO SI]. From each

84   district we obtained a list of five "water challenged" villages, i.e., those in which water had to be

85   fetched from unimproved sources, which had had recent outbreaks of waterborne illnesses, and

86   where the median socio-economic status (SES) was similar to that for rural Tanzania. Two

87   villages in each district matched our criteria and had village leaders willing to work with us (SI

88   Figure S2) [LINK TO SI]. Each village was at least a four-hour drive from the other village in

89   the district, minimizing the risk of spillovers during the study. In each case we discussed our

90   research goals and protocols, and the right of households to refuse to participate, with the village

91   leadership.

92   Our field team included several of the authors and ten local enumerators whom the lead

93   authors trained in survey techniques and ethical research practices. We visited study households

94   in August of 2011 to conduct a baseline survey of household assets, construction material for

95   houses, water access, fuel usage, education and income. We compared the baseline data with

96   Census of Tanzania (2012) averages for all rural households (SI Table S2) [LINK TO SI]. The

97   data show that our study villages were slightly better off than rural Tanzania overall. Latrine

98   coverage was close to 90%, suggesting that poor sanitation should not attenuate the beneficial

99   health effects of safe drinking water.

100

101   **Sampling Strategy**

102   We conducted our own household census in all four villages prior to the baseline survey. We

103   defined a household as a family group that shared meals and lived in the same compound, with

104   one nominal head, i.e. an adult male or female with the authority to make decisions concerning

105   medium-sized household purchases, such as buckets, shoes and clothing. Therefore one

106   compound could accommodate more than one household, such as the families of three adult

107   brothers who shared many activities but made their own spending decisions.

108   We covered the entire geographic areas of all the villages for the census, attempting to

109   enumerate all of the households. This census was our sampling frame. We randomly selected our

110   sample households, by name, at open meetings in every village, to reassure the residents that our

111 selection process was fair. Our final sample size was 276 households for Geita and 280 for

112 Kisarawe. The samples were large enough to detect a 10% difference across any two HWTS

113 systems in the proportion of households that liked them, at the 95% confidence level (SI Figure

114 S3). [LINK TO SI] We collected our data over nine months, starting in May of 2012.

115

116 **The Six HWTS Options**

117   Guided by the Tanzanian Ministry of Health, we selected the study HWTS options according

118 to four criteria:

119   1) *Low cost.* We set the ceiling for the price of consumables at 4% of the median expenditure

120   per capita (Amrose et al., 2015; Hutton, 2012), and the full price of durables at 33% of the

121   median monthly household expenditure (National Bureau of Statistics Ministry of Finance,

122   2014). This yielded a maximum retail price of TZS 22 (TZS 1590 = USD 1 in 2012) per

123   liter of water treated for consumable HWTS products (assuming 2 liters per person per day

124   for drinking); and TZS 57,000 for a durable HWTS product (ibid.).

125   2) *Commercially available in Tanzania.* The expansion of an existing supply chain is less

126   challenging than the creation of a new product market.

127   3) *Portable.* Migration is common in sub-Saharan Africa and families cannot move with

128   heavy systems such as bio-sand filters.

129   4) *Efficacious.* Turbid water is common in Tanzania; this criterion eliminated Solar

130   Disinfection (SODIS) (EAWAG/SANDEC, 2002).

131   All HWTS products that fit these criteria were included in our study. Consumables included

132 liquid sodium hypochlorite (Waterguard Liquid); sodium dichloroisocyanurate tablets

133 (Waterguard Tablets); and sachets of Proctor and Gamble's PuR. The durables were ceramic pot

134 filters (Safe Water Now, n.d.), and ceramic siphon filters (Basic Water Needs India Pvt Ltd,

135 n.d.-a). All these options significantly reduce *E. coli* concentrations in the laboratory

136 (LeChevallier & Au, 2004; Brown & Sobsey, 2010; Basic Water Needs India Pvt Ltd, n.d.-b),

137 and in the field (Mohamed et al., 2015; Clasen et al., 2007; Souter et al., 2003; Ziff, 2008;

138 Brown, Sobsey, & Loomis, 2008). Boiling served as a comparison for the HWTS retail products;

139 it has been shown to significantly reduce *E. coli* in field conditions (Brown & Sobsey, 2012).

140   We distributed improved cookstoves to minimize the health impacts from any increased use of

141 solid fuels from boiling (Anenberg et al., 2013). Boiling water contributes a small fraction of

142 total household fuel use (Clasen et al., 2008), but the research team agreed that increasing

143 exposure without any mitigation measures as part of an experimental study was not defensible.

144 All households also received a safe storage container of 20 liters to minimize recontamination of

145 the treated water (Levy et al., 2008). The households retained their storage containers and

146 cookstoves at no cost at the end of the study, as compensation for their time and effort.

147

148   **Experimental Design**

149   Following Scott et al. (2007), we developed a short informational program based on social

150 marketing principles for our study (Scott et al., 2007). Materials included an illustrated pamphlet

151 on waterborne illnesses, catchy slogans on the importance of safe water, and a sticker with brief

152 instructions for each HWTS system (see SI Figure S4) [LINK TO SI]. These slogans, pamphlet

153 and stickers were collaboratively developed with focus groups in non-study villages in Kisarawe.

154 Our field team demonstrated the use of the HWTS system by treating a bucket of water in each

155 study home. The household member being trained repeated all the steps back to our team, and, if

156 any were incorrect, the training was repeated. We did this separately for each HWTS system

157 being delivered, and affixed the appropriate informational sticker to the storage container before

158 we left the household.

159   Households received the HWTS systems in a randomized sequence to avoid stated preference

160 biases due to treatment order. Each participating household tested four of the six HWTS options

161 that we evaluated, over the course of four rounds of evaluation. All were assigned a filter, a

162 Waterguard product, boiling and PuR. Half the households received PuR in its original

163 packaging; the other half received repackaged PuR with a label printed *Takasa Maji* ('Water

164 Treatment' in Swahili), to test whether generic packaging might affect usage or preferences.

165   Each round started with a five day 'attachment period', after which a member of our field team

166 visited the households. During this visit households were asked about their source water,

167 perceived water quality, water collection and water usage practices. The households then had

168 four to six weeks to use their assigned HWTS system, without any interim reminders. At the end

169 of each round our field team visited the households to collect any durable HWTS products,

170 distribute the next assigned HWTS system, and collect data on usage frequency, proper use, the

171 water sources accessed and perceptions of the HWTS system. After the fourth round, we

172 collected survey data on the ranked preferences for each HWTS system and conducted the WTP

173 auction. In the auction the households had the chance to buy any of the products they had tested.

174 We reminded them at the start of rounds one and four that they could bid for any of their

175 assigned HWTS systems after all four rounds (SI Figure S5) [LINK TO SI].

176

177 **Outcome Measurement: User Preferences**

178   We defined usage as reported treatment by at least one household member in the previous two

179   weeks. This showed recent use, rather than consistent daily use. Our field team also collected

180   observational data on usage, and tested for chlorine presence in stored drinking water.

181   We created a simple, easily reproducible, ranking protocol for this study. At the end of all four

182   rounds we presented our participants with four cards, each with a picture of one of their assigned

183   HWTS systems. They sorted the cards into three categories: liked, disliked and neutral. They

184   could put all four cards into one of the categories if they wished, and any category could remain

185   empty. Within each category, they arranged the cards from the most liked to the least, and the

186   most disliked to the least. We recorded HWTS preference rankings from the sorted cards,

187   following Beggs and Cardell (1981), to obtain ranked, stated preferences (Beggs, Cardell, &

188   Hausman, 1981). We developed a discrete choice randomized utility model to estimate the

189   relative preferences for each HWTS system across our study population (shown in SI Figure S7)

190   [LINK TO SI]; below we present a parametric analysis of the preference data (Train, 2009). We

191   also asked the participants what they had liked and disliked about each assigned HWTS system,

192   wording our questions in an open-ended way, and subsequently coding their responses.

193

194   **Outcome Measurement: Willingness to Pay (WTP)**

195   We conducted an auction game with the participants, adapted from Luoto et al (2012) and

196   based on the original work of Becker et al. (1964), in order to elicit their WTP for any HWTS

197   they had tried. Both liquid and tablet Waterguard products were included for all participants, as

198   they were considered similar to one another (Lantagne et al., 2008). Revealed willingness to pay

199   estimates after participants have tried the relevant products are potentially more conservative

200   than "naïve" or stated valuations in the absence of such experience (Luoto et al., 2012). For our

201   comparative study, the post-trial WTP method was essential, as the referent HWTS system was

202   boiling, with which everyone was already familiar.

203   First, the participants stated the highest price they were willing to pay for each HWTS product.

204   They then selected one of ten slips of folded paper from an opaque bag, blinding them to the

205   prices available. Each paper had a different price, but all were less than or equal to the retail

206   price of the product (SI Figure S6 shows the price selection method) [LINK TO SI]. If the

207   selected price was higher than their stated WTP, they "lost", and they could not purchase that

208   product. If it was lower, they "won", and they could purchase that HWTS product for the

209   selected (not their stated) price. This method gave them an incentive to state a high WTP for

210   HWTS products that they wished to purchase, while preventing us from charging prices above

211   retail. In order to avoid biasing participants' decisions to buy or not buy once they had actually

212   "won", we said nothing about whether or not this randomly-drawn price was above or below the

213   retail price. We explained the price-setting methods to all participants, and practiced the auction

214   with each household using a bar of soap (a common purchase), to ensure that the rules of the

215   game were fully understood.

216   When piloting the auction protocol, we observed that several households did not have cash on

217   hand for durable purchases such as buckets or clothes. When these households needed cash, they

218   borrowed the money or sold some of their assets (such as chickens). Since the bids for the filters

219   were more likely to be impacted by cash constraints, we gave the participants a choice of

220   payment method for these. They could bid using chickens, cash or mobile money, and so could

221   play the auction game even if they were cash-limited.

222   **Ethics Statement**

223   Our research protocol was approved for ethical compliance by the University of California at

224   Berkeley's Office for the Protection of Human Subjects and Tanzania's National Institute for

225   Medical Research.

226

227   RESULTS

228   **Usage of HWTS Systems**

229   Self-reported usage of the assigned HWTS systems was high; the average across all rounds

230   was 91% in Kisarawe and 86% in Geita. High reported rates of use could reflect social

231   desirability bias on the part of the households. Observational data and chlorine testing, however,

232   were consistent with these stated rates of usage. In a random sub-sample of 179 households using

233   Waterguard, PuR or *Takasa Maji*, 32 (17 %) did not have treated drinking water available at the

234   time of the visit, but 120 (67%) had total chlorine concentrations between 0.05 and 0.8 mg/L.

235   These concentrations indicate usage more recent than the two-week recall period. For the pot

236   filter, 96% of our observations showed that the equipment had been used recently enough for the

237   filter to remain damp; for the siphon filter this was true for 90%. These data suggest that the

238   majority had recently used their assigned HWTS system, and so reported preferences and WTP

239   estimates were based on experiential knowledge.

240   Treatment responsibilities were highly gendered: 73% of households with adult women

241   assigned the chore to women alone. Adults (above age 18) drank treated water more often than

242   children (below age 5) did, though the latter are most vulnerable to waterborne illnesses: only

243   77% of households with small girls reported giving them treated water. Respondents also told us

244   why they treated their drinking water. Most cited cleanliness, the importance of treatment, or the

245   need to get rid of germs, all of which were messages included in our informational program.

246

247   **User Preferences**

248   Based on the ordinal ranking protocol, boiling and the pot filter were the preferred HWTS

249   systems (Figure 1). These results support our H_1 (households prefer boiling to retail HWTS

250   products), with the exception of the pot filter, which was also strongly preferred. The chlorine

251   additives, siphon filter and PUR had a greater number of low rankings (Figure 1). These same

252   rankings were used to estimate a discrete choice randomized utility model, which yielded a

253   similar pattern of preferences. The results of the discrete choice model are in SI Figure S7 [LINK

254   TO SI].

255   In round four, households that reported their source water as "Clear, without any color" (58%)

256   were classified as accessing sources with low turbidity, and households that reported "Cloudy

257   /muddy/ rusty" as accessing turbid sources. The villages were similar in terms of socio-economic

258   status (SI Table S2) [LINK TO SI], but differed in source water turbidity: in round four, only

259   16% of all households reporting highly turbid sources were in Geita. As such, we were not able

260   to statistically disentangle the effects of district location from turbidity, and have interpreted

261   turbidity as the most important factor, based on our field observations.

262   The percentage of participants that reported liking boiling, PuR, *Takasa Maji*, and the siphon

263   filter varied significantly with source water turbidity (Figure 2). PuR removes turbidity, and

264   households with turbid water liked it more; this has not been the case for some previous studies

265   (Albert et al., 2010). *Takasa Maji* did better than PuR, so it seems that generic packaging did not

266   negatively affect preferences (Figures 1 and 2). The siphon filter also removes turbidity, but

267   households complained that the flow rate slowed dramatically when treating turbid water; this

268   may explain why many disliked it. Boiling and the Waterguard products do nothing for turbidity,

269   yet only the rankings of the former seem affected by it; the difference for boiling was statistically

270   significant in the discrete choice model, and nearly significant in the parametric analysis (see

271   Figure S7 in the SI and Figure 2, respectively) [LINK TO SI]. The HWTS systems most often

272   ranked first or second by those who were assigned them were: boiling (66% of households), the

273   pot filter (61% of households) and PuR / *Takasa Maji* (61% of those households with turbid

274   source water).

275   We asked the participants what they liked and disliked about each HWTS system. The tally for

276   specific attributes for each HWTS system, when it was ranked most or second-most (dis)liked, is

277   shown on the Y-axis in Figures 3 and 4. The number of responses varied by HWTS type; these

278   are listed on the X-axis. A household could cite more than one attribute. Ease of use, taste and

279   effectiveness were the most cited reasons for liking an HWTS system (Figure 3). Those who

280   disliked boiling or the filters objected to their high time requirements, and bad taste was the most

281   common reason for disliking *Takasa Maji*, PuR, and the Waterguard products (Figure 4).

282

283   **Willingness to pay**

284   At the end of the last round, 453 out of the original 556 households remained in the study (the

285   drop-out rate averaged 6% per round, with no significant asset-ownership differences between

286   retained participants and drop-outs; see Table S8). All our study households were willing to rank

287   their assigned HWTS systems, but 26% of the households in Geita and 15% in Kisarawe

288   declined to play the auction game. These households had roughly the same rankings for boiling

289   as the households that did play, implying that they did not decline to play simply because they

290   preferred the one system that did not require a purchase. Most respondents who declined to bid

291 said they lacked the resources to make any purchases; as Whittington (1998) explains, it is not

292 possible to distinguish willingness from ability to pay in stated preference exercises.

293   Table 1 shows the number of bids per HWTS product, along with their mean bids and retail

294 prices. We did not include boiling as all participants retained their improved cookstoves for free.

295 We incorporated the non-bidders' responses into our bid curves (see below), as their stated WTP

296 was, in effect, zero for all of the commercial products. 93% of those who bid had not previously

297 purchased any of the HWTS products, and did not know their retail prices. This shows that their

298 WTP was not constrained by actual retail prices (a small number of bids were higher than retail).

299 A sizable minority (12%) of the pot filter bids were placed using chickens instead of cash. 92%

300 of all bidders "won" at least one auction, and, of those, 14% declined to purchase anything. If

301 households won more than one auction, they could purchase any HWTS product for which they

302 won. The probability of purchasing a pot-filter was 1.3 times that of purchasing PuR when both

303 were won; pairwise comparisons for the other HWTS products are in the SI (Table S9) [LINK

304 TO SI].

305   We obtained retail prices for the commercially sold HWTS products from the organizations

306 distributing them, and verified the prices at retail outlets in Dar es Salaam and the district

307 capitals of Geita and Kisarawe. The median bid was half the retail price for PuR and roughly 1/3

308 of retail for the Waterguard products. Since the filters were durable products their bid prices

309 were higher, but the median bids for the siphon filter and the pot filter were only 7% and 11% of

310 retail, respectively (Figure 5). Among our respondents, 28% were willing to pay the retail price

311 for PuR and 1.8% for the pot filter. At the median bid price, 14.9% of demand for PUR and 5.3%

312 of demand for the pot filter came from respondents that reported 'dislike' for those systems; for

313   all HWTS a proportion of households with positive WTP reported 'dislike' for those systems

314   (see Figure 5 and SI Figure S10) [LINK TO SI].

315   The mean bid for households with highly turbid source water was higher than for those with

316   low turbidity for all HWTS except the siphon filter. The difference was large for PuR (low

317   turbidity: 373 ± 81, high turbidity: 662 ± 222, p=0.05), *Takasa Maji* (low turbidity: 251 ± 82,

318   high turbidity: 419 ± 135, p=0.05) and the pot filter (low turbidity: 5023 ± 919, high turbidity:

319   7412 ± 2353, p=0.05). All these HWTS products remove suspended solids. WTP differences

320   across districts are much reduced when the effects of turbidity are considered, but our sample

321   size was not large enough to disentangle the effect of one from the other. The WTP data, taken at

322   face value, indicate that significantly cheaper versions of the preferred HWTS products, or

323   significant subsidies at current prices, will be needed for a successful scale up.

324

325   **Conclusions and Discussion**

326   This study was motivated by the Tanzanian government's focus on safe drinking water and

327   improved health of the rural poor through an HWTS-based strategy. We evaluated consumer

328   preferences for six HWTS products in order to find the one(s) with the potential to reach the

329   greatest number of households. We assessed revealed willingness to pay for the HWTS products

330   that they had become familiar with, which the literature suggests yields a more conservative

331   estimate of WTP than naïve estimates. Ours is the first study that we are aware of to compare

332   user preferences for boiling to non-boiling HWTS systems, as well as the first to integrate both

333   user preferences and WTP for HWTS. We maximized the number of households willing and able

334   to bid for durable HWTS products by allowing them to bid with their assets (chickens), instead

335   of with cash alone. This payment method mimicked the actions cash-poor households would

336   have to take to buy durable goods. We do not argue that bartering for durable HWTS products is

15

337   a useful way to scale up adoption; but our findings indicate that improving liquidity (e.g. through

338   group micro-loans or conditional cash transfers) will increase adoption of these products, a

339   finding that is in line with previous observations in South Asia (Freeman et al., 2012).

340   Following the household water literature, we argue that preferences are an important indicator

341   of what might be adopted and regularly used (Albert et al., 2010). The user preference ranking

342   exercise indicated that boiling (with an efficient stove) and the pot filter (with a storage

343   container) were the most preferred HWTS options, before costs were factored in. The pot filter

344   was preferred across districts and across source water quality, as has been observed in South

345   Asia, but preferences for boiling were on par with the pot filter, a new finding (Luoto et al.,

346   2012; Poulos et al., 2012). Where the source water was significantly turbid, an effective

347   disinfectant-coagulant such as PuR was also preferred; this contrasts with previous observations

348   from rural Kenya (Albert et al., 2010).

349   We found that some households, even when they reported disliking an HWTS system such as

350   Waterguard, still bid on it. This potentially counter-intuitive result could be a result of consumers

351   wanting to acquire a product at a low price for occasional use or for the chance to re-sell it at a

352   later date. The safe water literature has argued that, unless a large majority of community

353   members use HWTS systems correctly and consistently, they will not provide the health benefits

354   of safe drinking water to the community as a whole (Brown & Clasen, 2012). Several health

355   products require consistent use for a positive health impact, including HWTS, bed nets, and

356   improved cookstoves. Our findings suggest that a positive WTP for a disliked product (such as

357   Waterguard) is a potential indicator of future inconsistent use. We recommend that WTP studies

358   of personal health products include independent user preference assessments, using a protocol

359   similar to the one developed here (Figure 5 and SI Figure S10) [LINK TO SI].

16

360   Additionally, among the Waterguard products and PuR, there is a negative correlation between

361   bid price and the percentage of total demand held by households that disliked those HWTS. This

362   observation could indicate that that higher subsidies may not result in higher rates of consistent

363   use (SI Figure S12) [LINK TO SI]. Further study on the relationship between stated preferences,

364   inconsistent use, and subsidies is warranted.

365   The WTP data are best interpreted as a guide to estimating (current) demand and the subsidies

366   that might be needed to achieve desired levels of adoption. Our WTP estimates indicate that

367   reaching 50% of the target population would require subsidies of up to 89% of retail for the pot

368   filter with its container; the median bid in these low-income communities was 11% of the retail

369   price. These low WTP figures have also been reported in previous research (Ahuja et al., 2010;

370   Amrose et al., 2015) with revealed WTP studies almost always yielding lower numbers than

371   stated WTP (Luoto et al., 2012; Ahuja et al., 2010; Kremer et al., 2009; Orgill et al., 2013). The

372   development of less expensive alternatives is promising, however; we found that a generic

373   disinfectant-coagulant would be as acceptable to consumers as PuR, indicating a potential market

374   for a generic version of this type of HWTS technology.

375   Boiling is the most widely used option within our study population, as it is in other parts of the

376   world (Rosa & Clasen, 2010). It is unclear whether the prevalence of boiling reflects a

377   comparative preference for boiling; our results indicate that this may be the case. Gathering

378   fuelwood and heating water requires time and labor; yet, for a majority of the households, the

379   time savings or other advantages of the retail HWTS products were not enough to induce a WTP

380   that was even close to retail prices. Our findings suggest that boiling, the only HWTS system

381   currently practiced at a global scale, and one with no commercial backing, could be preferred by

382   many communities to several highly-marketed retail products, even when these become more

383   familiar. In all dimensions other than time required, boiling beat PuR, Waterguard and the siphon

384   filter, and it was a strong rival to the pot filter.

385   Because of recontamination during storage, if the Tanzanian government decides to promote

386   boiling water as a health measure, we recommend including a safe storage container at minimal

387   cost. In our study all of the households owned buckets, but not all of these had lids, and none had

388   spigots attached. The retail value of our safe storage container was TZS 8,000; this, too, would

389   require significant subsidies for a national scale up in rural areas.

390   Based on the median bids in our study, we estimate that half of rural households might adopt

391   the pot filter with a storage container if a combination of subsidies and price reductions totaling

392   TZS 42,500 (USD 28) per household were provided. Therefore the initial subsidy needed to

393   create demand sufficient to provide 50% of the rural population with pot filters would equal TZS

394   263 billion, not counting administration costs (SI table S13 shows subsidy estimates for the other

395   HWTS products) [LINK TO SI]. Likewise, if PuR, or a similar coagulant-disinfectant, were to

396   sell for TZS ~50 per packet, then this might be a "sweet spot" where households with turbid

397   source water could afford to regularly purchase it.

398   We find that consumer-approved and efficacious household water treatments exist for rural

399   Tanzania, but the degree to which households are both willing and able to pay for these is modest

400   and will constrain scale-up. The estimation and appropriate targeting of subsidies is a contested

401   topic in the development literature, but many researchers have argued that, without subsidies,

402   universal access to safe drinking water will not be possible (Ahuja et al., 2010; Amrose et al.,

403   2015). We conclude that, for a low-income country looking to improve the health of its citizens

404   through scaling up HWTS, there may be no "low-cost" options to safe drinking water for all.

405   Our study had several limitations. First, the duration of use for each HWTS system – 4 to 6

406   weeks – was arguably short. Our relatively short evaluation period, however, allowed us to

407   include a greater number of HWTS systems. The duration was sufficient for the participants to

408   understand correct use of the HWTS systems and the effort involved therein, as well as to

409   become acquainted with the taste and smell of treated water.

410   Second, we provided the pot filter within a container designed by our research team. In

411   Tanzanian markets the ceramic filter is sold by itself and put inside a 20 liter bucket, but, during

412   pre-survey piloting, we found that the standard bucket had insufficient storage space. Our

413   preference and WTP results thus reference the filter and container together.

414   Third, we provided a locally manufactured efficient stove as part of the boiling treatment;

415   therefore, an expressed preference for boiling could have partly reflected an affinity for the

416   cookstoves. This limitation was an explicit part of our study design, since we decided that we

417   could not recommend, either to our study participants or to policy makers, an HWTS system that

418   might increase the burning of solid fuels but do nothing to mitigate its negative impacts. We note

419   that all participants understood that they could keep the cookstoves whatever their preferences

420   for the various HWTS systems.

421   Fourth, filters and consumables are inherently difficult to compare because the former retain

422   their value despite repeated use. We encouraged households to express their HWTS preferences

423   based on ease of use, taste, aesthetics, perceived effectiveness and time required. We thus tried to

424   elicit user preferences that were based on product characteristics besides resale value. Our results

425   show that even if durability affected preferences, it did not eclipse other product features (such as

426   ease of use) or relevant household characteristics (such as source water turbidity).

427   Fifth, usage rates (reported or observed) are a potential indicator for the frequency of use after

428   adoption. But households may have been influenced by our repeated visits over the course of the

429   study, resulting in a reactivity bias. Therefore our reported rates may overestimate use in the

430   long term. Even if this bias occurred, if it was consistent across HWTS options, it should not

431   have biased the relative differences in user preferences and WTP amongst the HWTS systems.

432   Finally, it is unclear what other challenges exist to making any of these HWTS systems

433   available throughout Tanzania; supply chain constraints were not explicitly addressed in this

434   paper. Further study is warranted on the creation of a reliable supply chain for multiple HWTS

435   systems, in particular for the pot filter, safe storage containers and efficient cookstoves.

436

437   **Supporting Information**

438   Additional information as noted in the text.

439   (WHO/UNICEF, 2014), (Kols, n.d.), (National Bureau of Statistics, n.d.), (Ministry of Finance,

440   United Republic of Tanzania, n.d.), (McFadden & Train, 2000), (Bierlaire, 2003)

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604

Ranking of HWTS Across all Households
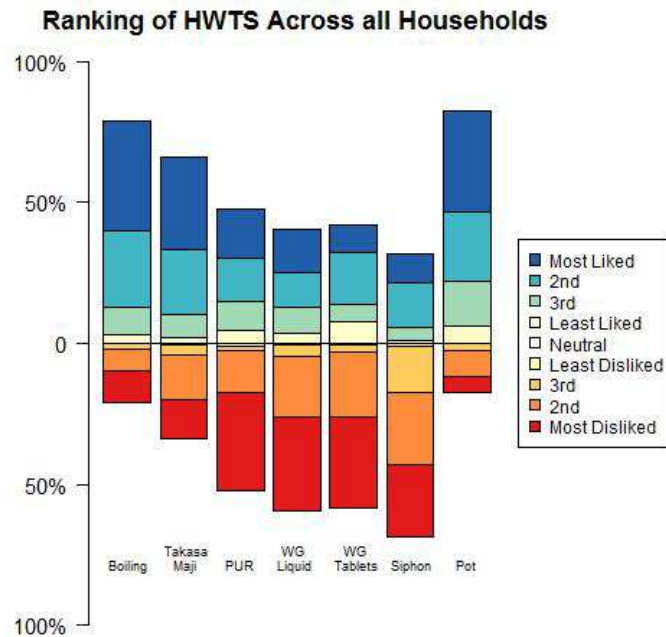

Figure 1: Average Rank of HWTS systems, X-axis lists the HWTS. Y-axis shows the percentage of participants that gave the HWTS system a specific ranking.

Preference for each HWTS by Turbidity of Source Water
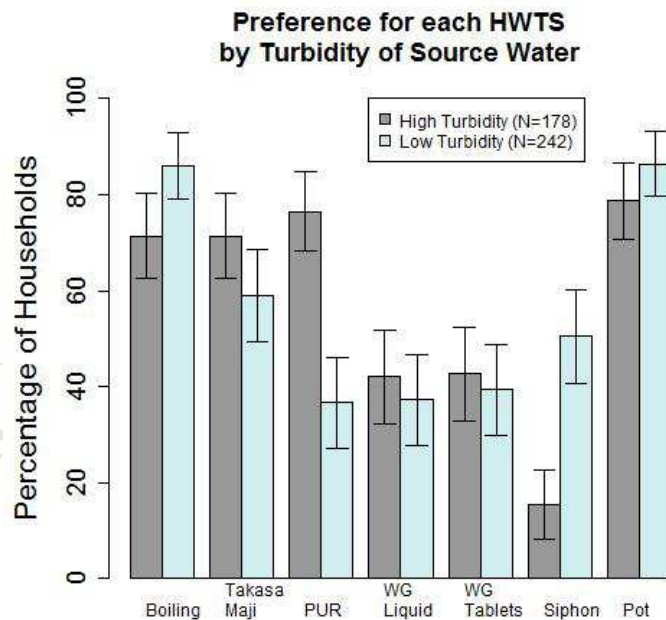
Figure 2: Percentage of participants that liked each HWTS system, separated by high and low source water turbidity. X-axis lists the HWTS system. Y-axis shows the percentage of participants.
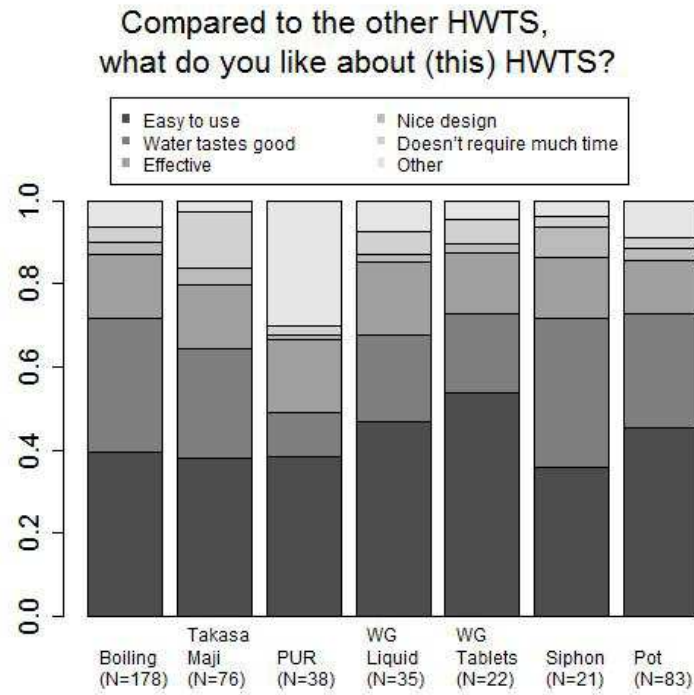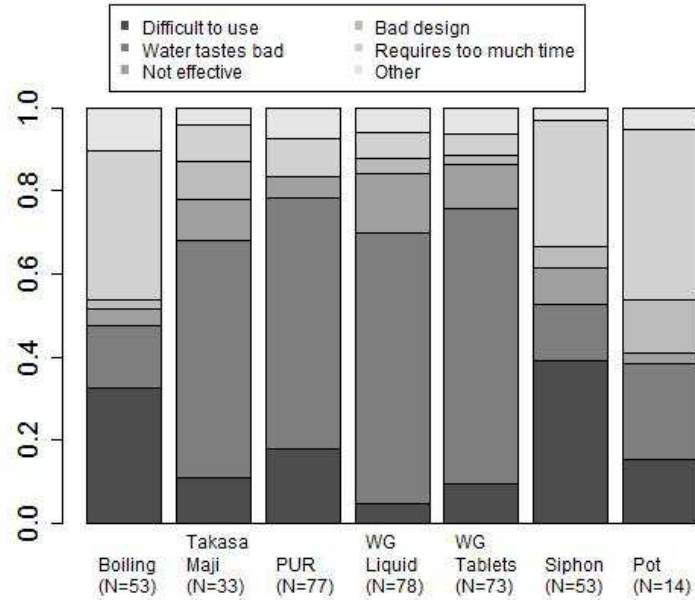
Figure 3: Reasons given for why participants liked their assigned HWTS system when it was ranked most or second-most liked. The attributes reflect the respondents' subjective opinions. X-Axis shows number of responses for each HWTS system. Y-axis shows tally of reasons given for each HWTS system

29

617

Figure 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.

621

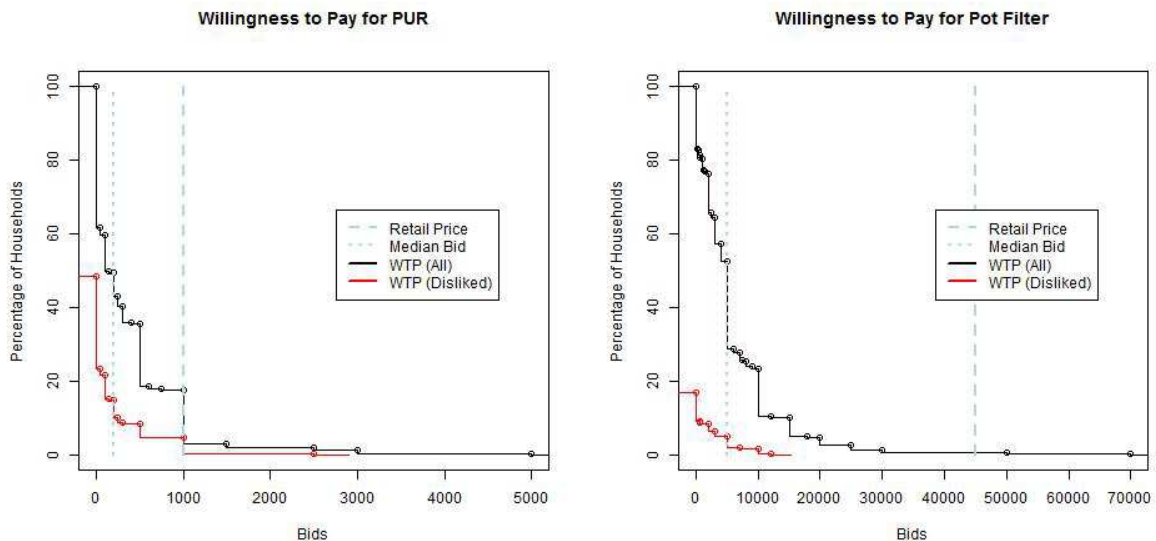**Figure 5**: The Ceramic Pot Filter and PuR Bid Curves (for all households and for households that disliked these HWTS) with Retail Prices and Median Bid Prices. X-Axis shows bid prices. Y-axis shows the percentage of all participants who were willing to pay at each bid price.

625 **Table 1:** WTP bids for HWTS. Mean bids include stated zero bids, including those who refused
626 to participate in the auction. Results with zero bids excluded are found in SI Table S11 [LINK
627 TO SI]. We use means here in order to express confidence intervals – a measure of the scatter or
628 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	1,500
	Geita	443	±88	234	105	
	All	583	±92	435	165	
Water-Guard Tablets (10 Tablets)	Kisarawe	409	±82	201	72	1,000
	Geita	268	±53	234	104	
	All	333	±48	435	176	
PuR (5 Packets)	Kisarawe	600	±134	107	28	1,000
	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	

629

User Preferences and Willingness to Pay for Safe Drinking Water: Experimental

Evidence from Rural Tanzania

Highlights

- Boiling and the ceramic pot filter are the most preferred HWTS systems
- Source turbidity is correlated with stronger / weaker preferences for different HWTS
- Average willingness to pay for all HWTS is more than 0 and less than retail prices
- Willingness to pay may not be a good indicator of future sustained use
- Scale-up will require significant subsidies or significantly cheaper products