Environmental Science & Technology

Article

pubs.acs.org/est

Supply and Demand for Improved Sanitation: Results from Randomized Pricing Experiments in Rural Tanzania

Rachel Peletz,*[,†] Alicea Cock-Esteb,[†] Dorothea Ysenburg,[‡] Salim Haji,[§] Ranjiv Khush,[§] and Pascaline Dupas[∥]

[†]The Aquaya Institute, PO Box 21862−00505, Nairobi, Kenya

[‡]Oliver Wyman, Berlin 10117, Germany

[§]The Aquaya Institute, 12 E Sir Francis Drake Blvd Suite E, Larkspur, California 94939 United States

[∥]Department of Economics, Stanford University, Stanford, California 94305, United States

Supporting Information

ABSTRACT: Improving access to sanitation is a global public health priority. Sufficient consumer demand is required for sanitation coverage to expand through private provision. To measure consumer demand for hygienic latrine platform products in rural Tanzania, we conducted a randomized, voucher-based real-money sales trial with 1638 households with unimproved latrines. We also evaluated multiple supply chain options to determine the costs of supplying latrine platform products to rural households. For concrete latrine SanPlats, 60% of households were willing to pay US$0.48 and 10% of households were willing to pay US$4.05, yet the average cost of supplying the SanPlat to households was US $7.51. Similarly, for plastic sanitary platforms, willingness-to-pay (WTP) dropped from almost 60% at a price of US$1.43 to 5% at a price of US$12.29, compared to an average supply cost of US$23.28. WTP was not significantly different between villages that had participated in the National Sanitation Campaign and those that had not. Randomized informational interventions, including hygiene data-sharing and peer-based exposure to latrine platform products, had minimal effects on WTP. In conclusion, current household demand for latrine platform products is too low to achieve national goals for improved sanitation coverage through fully commercial distribution.

INTRODUCTION

Globally, over 2.4 billion people lacked access to an improved sanitation facility in 2015.[1] Poor sanitation is associated with diarrhea, helminth infection, and other infectious diseases,[2,3] in addition to environmental enteric dysfunction[4] and child growth faltering.[5] Despite challenges in quantifying the health impacts of sanitation interventions,[6] the World Health Organization estimates that inadequate sanitation alone results in 280 000 deaths every year.[7] Improved sanitation also has social and economic benefits; returns on sanitation investments are estimated to be at least 5-fold.[8,9]

In Tanzania, open defecation levels are relatively low, and approximately 83% of rural residents have access to simple pit latrines.[1] Most of these pit latrines, however, do not meet the UNICEF-WHO Joint Monitoring Programme specifications for improved sanitation facilities, which should hygienically separate human excreta from human contact. Improved sanitation facilities include: (1) flush or pour flush toilets connected to either sewer systems, septic tanks, or latrine pits; (2) ventilated improved pit latrines; (3) pit latrines with a sanitary surface; and (4) composting toilets.[10,11] According to the 2015 UNICEF-WHO Joint Monitoring Programme estimates, only 12% of Tanzania's rural population uses improved latrine facilities.[1] This low coverage is believed to compromise public health and, thereby, impede economic growth. The World Bank estimates that limited access to improved sanitation costs Tanzania almost 1% of its Gross Domestic Product and that these costs are disproportionally borne by the poor.[12]

The Government of Tanzania and development agencies have implemented multiple programs to increase the coverage of improved sanitation. Many of these have emphasized local manufacturing of nonstructural concrete latrine sanitary platforms (sized at approximately 2 foot-by-2 foot), also known as SanPlats.[13] By providing a smooth, easily cleaned, and safe squat hole opening, sanitary platforms are often proposed as a simple option for upgrading pit latrines (photos of traditional pit latrines are included in Figure S1 and photos of installed platforms are included in Figure S2 of the

Received: August 1, 2016
Revised: May 22, 2017
Accepted: May 30, 2017
Published: May 31, 2017

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

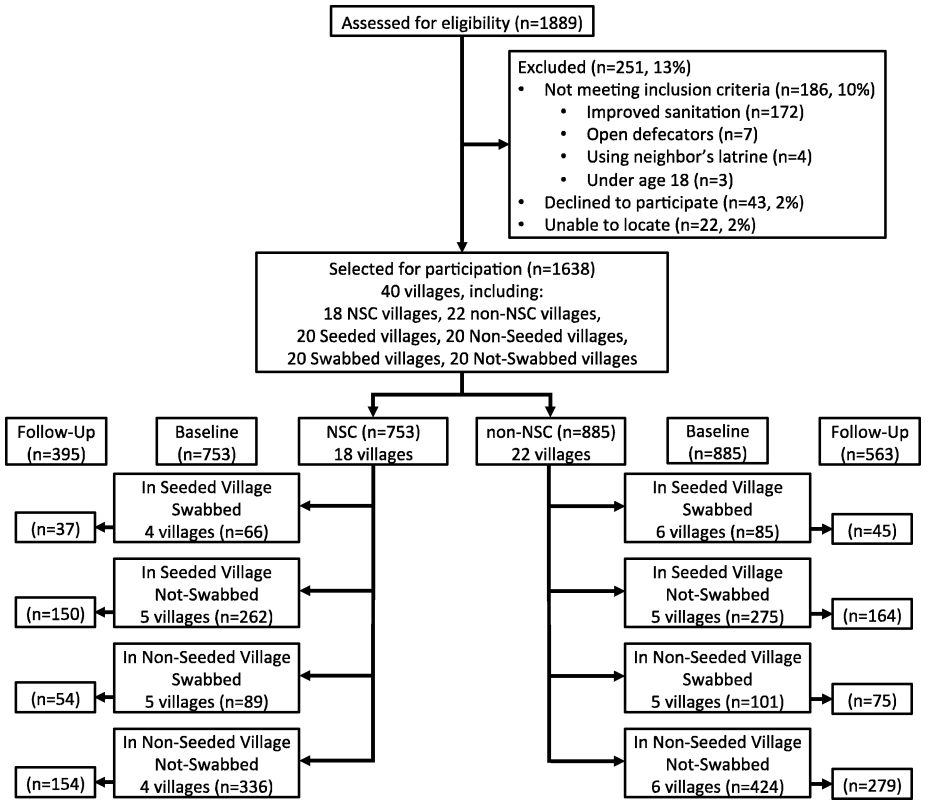

Figure 1. Study design. Village selection was stratified by prior participation of the National Sanitation Campaign (NSC). Additional randomization of villages for swabbing and seeding was stratified by NSC status; randomization of village swabbing was also stratified by village seeding. In each village selected for swabbing, approximately half of the surveyed households were randomly selected for swabbing.

Supporting Information, SI). They also comply with the UNICEF-WHO Joint Monitoring Programme and Government of Tanzania definitions for improved sanitation.[1,14] Concrete SanPlats were introduced in Tanzania through UNICEF-funded programs in the mid-1990s.[15] Subsequently, multiple programs, including the World Bank Rural Water Supply and Sanitation project (2002−2007) and the World Bank Water and Sanitation Program's Total Sanitation and Sanitation Marketing (WSP-TSSM) initiative (2007−2010) promoted concrete SanPlat manufacturing and business development by local village masons.[16] The Government of Tanzania's National Sanitation Campaign (NSC), which began in 2011, continues to promote concrete SanPlats as an appropriate technology for improving rural household sanitation conditions.[16,17]

Despite the attention placed on concrete SanPlats, their production and sales in Tanzania remain low.[18] Proposed explanations for the lack of market development include low consumer demand, limited business skills and working capital among village masons, sparsely distributed populations and high transportation costs, and a shortage of SanPlat molds.[15,16,18,19] To evaluate some of the supply constraints, WSP-TSSM and the Tanzanian Ministry of Health and Social Welfare provided concrete SanPlat molds to local government officials and hardware dealers in selected districts and engaged a marketing firm to coordinate between government officials, hardware dealers, and masons.[19] The hardware dealers took SanPlat orders and commissioned their production by masons. The targeted districts reported an increase in SanPlat sales from 545 in April − July 2010 (before the hardware dealer exercise was initiated) to 6107 over the same period in 2011.[19] These findings prompted further proposals for overcoming concrete SanPlat supply challenges in rural Tanzania.[20]

However, information on whether consumer demand for concrete SanPlats is sufficient to both support market development and greatly increase improved sanitation coverage in rural Tanzania remains largely anecdotal. To address this knowledge gap with experimental data, we first assessed multiple supply chain options and evaluated corresponding costs by stocking rural village retailers with three alternative hygienic platform products: concrete SanPlats, a newly developed plastic sanitary platform (sized at approximately 2 foot-by-2 foot),[21] and ceramic pour-flush latrine pans. We then measured the household redemption of randomly distributed discount vouchers for concrete and plastic sanitary platforms to establish their willingness-to-pay (WTP) at different price points.

We also evaluated consumer preferences between latrine platform products by providing a randomly selected subset of the households with discount vouchers that allowed them to purchase either the concrete SanPlat, plastic sanitary platform, or ceramic pan. Because incomplete information may influence take-up of improved latrine platform products, we also included two interventions to estimate the impacts of information on WTP: (1) we provided a random subset of households with measurements of fecal contamination in their latrines to determine if hygiene messages including contamination levels influenced WTP; and (2) we installed concrete and plastic sanitary platforms (two of each) in randomly selected villages to determine if peer-based information sharing influenced WTP (Figure 1). Finally, we included both villages that had and had not received the NSC to estimate WTP under both situations.

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

METHODS

Study Sites and Participants. We conducted our research in two districts of Tanzania: Kilosa District in the central Morogoro Region and Ludewa District in the southern Njombe Region. Our initial assessment determined that baseline levels of improved sanitation coverage were 19% in Kilosa and 3% in Ludewa. We selected these districts based on their suitability for pit latrines (i.e., avoidance of flood plains), their rural settings, and our ability to identify villages that had and had not participated in NSC activities. Within these two districts, we randomly selected 13 out of 19 eligible wards; 23 additional wards were ineligible because they were inaccessible by road and one ward was ineligible because it had selected pour-flush latrines as the only sanitation technology to be promoted as part of the NSC. Within the selected 13 wards, 40 out of 43 eligible villages were randomly selected, after stratifying by their prior NSC participation (four additional villages were ineligible because they were inaccessible and one village was ineligible because most households were practicing open defecation).

The NSC included a combination of Community Led Total Sanitation (CLTS), social marketing and behavior change communication.[17] It is important to note that the NSC implementation was not randomized; NSC village selection was based on: (i) low sanitation coverage before the campaign, (ii) existence of water supply scheme, (iii) high prevalence of diarrheal disease in the area, and (iv) readiness of the particular community to take part in sanitation and hygiene issues (Ministry of Health and Social Welfare, personal communication, 15 Oct 2015).

We collaborated with the main retail outlet of each village, as identified by the village leader, to stock the three latrine sanitary platforms. We hired local masons to produce concrete SanPlats in each district using molds rented from the Kilosa District Health Office. We purchased plastic sanitary platforms from the regional supplier, SilAfrica Tanzania Ltd. (the plastic sanitary platforms were manufactured by SilAfrica in Nairobi, Kenya). We purchased the ceramic pans, which are manufactured in India and China, from retailers in Dar es Salaam (for Kilosa District) and Njombe Town (for Ludewa District).

Voucher-Based Sales Trials. Village households were eligible to participate in our study if they (i) permanently resided in the selected villages, (ii) had an unimproved latrine at the time of the study, (iii) had a male or female household head that was at least 18 years old, and (iv) did not share their latrine with another household already included in the study. To measure household WTP for the latrine platform products, we used a randomized voucher-based sales trial.[22] Each participating household received a randomly selected discount voucher that specified a price reduction of approximately 15%, 30%, 45%, 60%, 75%, or 90% (from the estimated retail price) for one of the following options: (i) a concrete sanitary platform (SanPlat), (ii) a plastic sanitary platform, or (iii) a choice of either of the concrete or plastic sanitary platforms or the ceramic pan, each at the specified price reduction (additional details on voucher allocatation are provided in Table S1). The vouchers included an identification number, an expiration date (approximately 2 to 4.5 months after voucher distribution), the location of the local retailer were the vouchers could be redeemed in each village, a purchase price, and the estimated retail price for the specified latrine platform option. Though it was possible to transfer vouchers to other households, < 1% of vouchers were sold or given away (reported during household surveys and verified with retailer records). The sales trials were conducted from January–July 2015. Households that redeemed their vouchers were responsible for installing the purchased platform products.

Informational Interventions. We cross-cut the price randomization with the following interventions to determine the effects of information on WTP (Figure 1).[22,23]

Village Seeding. To determine whether peer-based information sharing influenced WTP, we "seeded" 20 randomly selected villages prior to voucher distribution by installing two concrete SanPlats and two plastic sanitary platforms for free in randomly selected, consenting households (four households per village). We stratified the randomization of villages for seeding by NSC status (Figure 1). The village seedings took place at the same time as household baseline surveys and voucher distribution, from January to March 2015.

Household Swabbing and Hygiene Information Messaging. To determine whether information on fecal contamination influenced demand, we randomly selected 20 villages for hygiene informational messaging and measurements of fecal indicator bacteria on latrine floors (i.e., swabbing latrine floors). We hypothesized that the hygiene information messaging would increase WTP; previous evidence has found that fecal contamination information has influenced behavior.[24,25] Randomization of villages for swabbing was stratified by NSC status and seeding of villages (Figure 1). In each selected village, approximately half of the surveyed households were randomly selected for swabbing. Additional details of the household swabbing are provided in the Methods of the SI.

Within 10 days of swabbing, we sent the swabbed households a text message that included the fecal contamination level of their latrine, the health risks associated with fecal contamination, and a recommendation to improve their latrines; the health risks and latrine improvement recommendation were included in the text message regardless of the fecal contamination level.

Supply Chain Analysis. To estimate the financial requirements for distributing and installing improved latrine platform products in rural Tanzania through commercial channels, we modeled multiple options for supplying each platform product to village households. We interviewed retailers, large/national suppliers, and village health officers to obtain information on available materials, current supply chain structures, and costs. Interviews were conducted until saturation (47 for rural retailers, two for large/national suppliers, and two for village health officers). We developed supply models for the three latrine platform products and calculated the cost per channel segment to develop total costs for each supply chain. These cost estimates incorporated raw material costs, transportation costs, appropriate mark-ups (including storage costs), and breakage rates. We verified our cost estimates with our expenditures for stocking village retailers with the latrine platform products.

Sample Size and Sampling. We estimated at least 1440 households (36 households from each of 40 villages) randomly allocated to high subsidy levels with twice the odds of being allocated to low subsidy levels would allow us to measure WTP at six price points and to detect a differential in take-up rate across the two lower price points of at least 10 percentage points and across the middle and higher price points of at least 25 percentage points (with a statistical power of 0.9 and a significance level of 5%). For interventions implemented at the village level (experimental seeding and NSC), given the

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

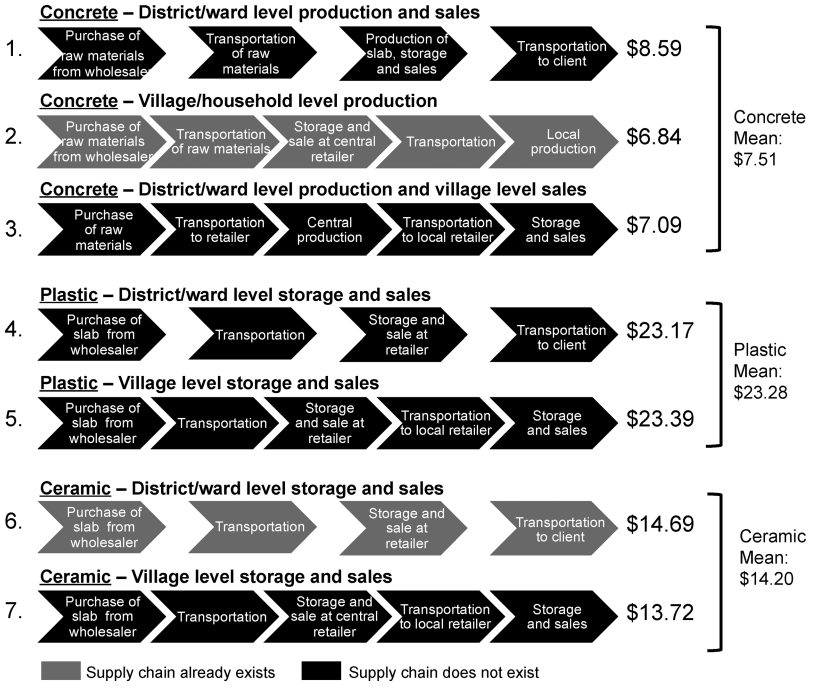

Figure 2. Supply chains and corresponding costs. Costs (in US Dollars) for each supply chain include raw material costs, transportation costs, retailer mark-ups (including storage costs), and breakage rates. These totals do not include installation costs, which were calculated to be an average of US$9.53 for ceramics, and no additional cost for plastic and concrete based on feedback from household surveys. Supply chains that currently exist are represented in gray, and supply chains that were identified but do not currently exist are in black.

observed intracluster correlation of 0.032 in take-up, the sample of 20 villages in each arm with 36 households per village allowed us to detect differences in take-up across intervention arms of at least 11 percentage points with a statistical power of 0.8 and a significance level of 5%.

To select households, we used village household registers (generated in 2014 for the national elections in 2015) and a random number generator to pick an initial household for each enumerator in each village to assess for eligibility and recruitment; enumerators then continued with systematic sampling (every n^{th} household). If households were not home after being visited three times, then a randomly selected discount voucher and brochure were left in a sealed envelope at the household, and explained to a neighbor if available. This occurred for 10.8% of the sample.

In total, we distributed discount vouchers to 1461 households that were eligible and consented to participate in the sales trial and left an additional 177 vouchers for households where no one was home during the survey visits. Of our total distribution of 1638 discount vouchers, 36% (585) were for concrete SanPlats, 34% (560) were for plastic sanitary platforms, and 29% (471) offered a choice between the three latrine platform products (voucher type information was missing for 1.34% (22) of the households). Approximately half of the households were in seeded villages and one-quarter of the households were swabbed for microbial contamination (Figure 1). Finally, we engaged 39 retailers across the 40 villages (2 villages shared the same retailer).

Data Collection. *Baseline Household Survey.* Enumerators administered household baseline surveys to the female and/or male head of eligible, consenting households from January to March 2015. The surveys collected data on household demographics, socioeconomic status, hygiene practices, water access, and sanitation. When applicable, swabbing took place at the end of the baseline survey. At the end of the baseline survey, enumerators gave randomly selected vouchers to the sampled households and verbally explained the voucher details. For absent households that received vouchers, we collected data on time-invariant baseline characteristics during follow-up when possible.

Follow-Up Household Survey. Enumerators conducted follow-up surveys from June − July 2015 (approximately 3.5−5.5 months after discount voucher distribution) with all participating households in 70% (28/40) of villages that were randomly selected for follow-up; not all villages could be sampled for follow-up due to budget constraints. The follow-up survey included questions regarding discount voucher redemption behaviors and latrine platform installation and usage. Observations were also included to confirm the presence and use of purchased products. In addition, enumerators reswabbed latrines in households that had been swabbed during the baseline survey.

Retailers. Retailers documented purchases by saving redeemed vouchers and recording the voucher redemption information (identification numbers, the voucher redemption date, and the identity of the purchaser). We also gave retailers the option of buying surplus latrine platform products at a reduced price of 50% of the market value; the retailer purchases are described in the Results of the SI.

All surveys were conducted on electronic tablets (Samsung Galaxy Tab 4 Sm-T235, Seoul, South Korea) using the CommCare survey and data management application (DiMagi Inc., Cambridge, MA U.S.A.).

Data Analysis. We classified the participating households into socio-economic status quintiles, relative to the entire Tanzania population using Demographic Health Survey categories that include factors such as number of people per

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

sleeping rooms, type of fuel for cooking/lighting, and owned possessions.[26]

The exchange rate used for the analysis was 1776.85 TZS to US$1.00 (28 January 2015, oanda.com).

Data analysis was performed using the statistical package Stata 13. Linear probability models were used, and the standard errors were adjusted for clustering at the village level to account for the fact that the NSC participation and seeding were village-level interventions. Analysis was done both without adjusting for any controls besides stratification variables (district) and adjusting for controls for major baseline characteristics.

Research Approvals and Ethical Reviews. This study was approved by the National Institute for Medical Research in Tanzania (NIMR/HQ/R.8a/Vol. IX/1916), the Tanzania Commission for Science and Technology (No. 2015-172-NA-201573), and the Stanford University, U.S.A., Internal Review Board (Protocol ID 32426, IRB 346). The trial is also registered with www.socialscienceregistry.org (AEARCTR-0001242).

The village executive officers gave verbal consent for village participation. Participants were provided with verbal and printed details of the study in the local language; informed, written consent was obtained from all participating households.

RESULTS

Study Population. We collected demographic information from 92% (1515/1638) of the households that received vouchers (Table S2). The majority of households grew crops (96%, 1449/1515) and most heads of households had not progressed beyond primary school (94%, 1422/1515). Households in Kilosa District were poorer than those in Ludewa District: 35% of Kilosa households were in the bottom two wealth quintiles, compared to 15% in Ludewa. In Kilosa, an average of 19% of interviewed households had improved sanitation facilities (24% in NSC villages vs 14% non-NSC villages) compared to 3% in Ludewa (1% in NSC villages vs 5% in non-NSC villages). Additional demographic details are provided in Table S2.

Latrine Platform Product Supply Chain Analysis. We compared the costs of three supply alternatives for concrete SanPlats (Figure 2). In supply chain 1, raw materials (i.e., cement and metal rebar) were transported from large cities to rural urban centers where concrete SanPlat suppliers produced and sold the SanPlats. In supply chain 2, raw materials were transported to rural villages where masons produced and sold the SanPlats in collaboration with village retailers. In supply chain 3, SanPlats produced in urban centers were transported to villages and sold by village retailers. Our cost estimates for these supply options averaged US$7.51 (Figure 2). We found that there were limited opportunities for economies of scale due to low fixed costs for concrete SanPlats and international importation of plastic and ceramic platform products.

The supply options for plastic sanitary platforms and ceramic pans were similar because both were imported into Tanzania: plastic sanitary platforms were manufactured in Kenya and ceramic pans were manufactured in India and China (Figure 2). In supply chains 4 and 6, the two latrine platform products were transported from Tanzania's major city, Dar es Salaam, to rural urban centers for storage and sales. In supply chains 5 and 7, the two latrine platform products were transported from Dar es Salaam to villages and sold by village retailers. Our cost estimates for these supply options averaged US$23.28 for plastic sanitary platforms and US$14.20 for ceramic pans (Figure 2).

Willingness-to-Pay for Latrine Platform Products. Of the 1638 households that were given discount vouchers, 36% (593) redeemed their vouchers for improved latrine platform products. Take-up of concrete SanPlats dropped from 60% among households that were offered a discounted price of US $0.48 (90% subsidy) to 10% among households that were offered a discounted price of US$4.05 (15% subsidy) (Figure 3). Similarly, take-up of plastic sanitary platforms dropped from

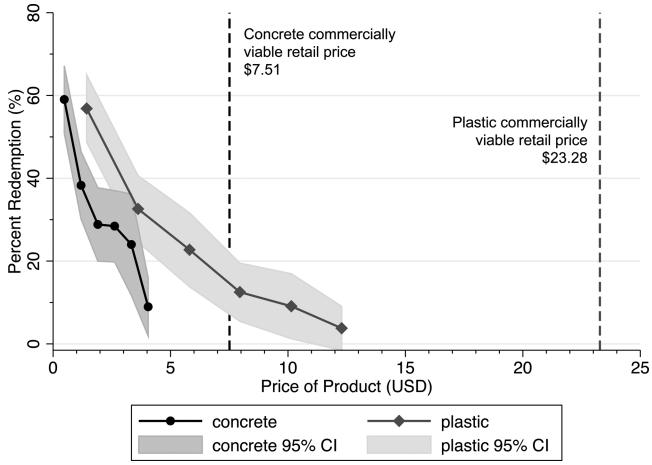

Figure 3. Gaps in willingness-to-pay and the costs of supplying concrete and plastic sanitary platforms to rural households. Supply costs (dotted lines) are averages (means) of the different supply chains for each latrine platform product. Shaded areas represent 95% confidence intervals for willingness-to-pay, or household redemption of vouchers.

almost 60% among households offered a discounted price of US$1.43 (90% subsidy) to 5% of households offered a discounted price of US$12.29 (15% subsidy) (Figure 3). Using multivariate regression models, we found that concrete SanPlat voucher redemption was positively correlated with age of the household head (increasing redemption by 1.3% for every year in age, $p < 0.01$) and presence of soap in the house at baseline (increasing redemption by 56%, $p < 0.01$) (Table 1). Plastic sanitary platform voucher redemption was positively correlated with household wealth (increasing redemption by 92% for each wealth quintile, $p < 0.01$), proximity to a retailer (increasing redemption by 6.6% for every 10 min closer to the retailer, $p < 0.01$), and baseline respondent being male (increasing redemption by 29%, $p < 0.05$) (Table 1). At the time of follow-up visits, which took place 3.5−5 months after discount voucher distribution, 73% (386/527) of households interviewed that did not redeem their discount voucher cited a "lack of cash" as their constraint (it is important to note that harvest season was delayed in 2015).

Preferences for Latrine Platform Products. Households were more likely to redeem a discount voucher that allowed them to choose between concrete SanPlats, plastic sanitary platforms, or ceramic pans if the respondent of the baseline survey was older (increasing redemption by 1.1% for every year in age, $p < 0.01$), households were wealthier (increasing redemption by 39% for each wealth quintile, $p < 0.05$), vouchers were delivered directly to household head (increasing redemption by 92%, $p < 0.01$), or the respondent of the baseline survey was educated (increasing redemption by 26%, p

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

Table 1. Voucher Redemption Multivariate Models[a]

	all voucher recipients	voucher recipients with baseline data			
independent variables	redeemed voucher	redeemed voucher	redeemed concrete voucher	redeemed plastic voucher	redeemed choice voucher
product price in USD	−0.053	−0.061	−0.116	−0.048	−0.119
	(0.004)***	(0.004)***	(0.014)***	(0.005)***	(0.014)***
plastic sanitary platform voucher	0.126	0.138			
	(0.038)***	(0.042)***			
choice voucher	0.051	0.066			
	(0.027)*	(0.027)**			
sampled for swabbing at baseline	−0.033	−0.055	−0.078	−0.021	−0.081
	(0.031)	(0.028)*	(0.035)**	(0.040)	(0.080)
village sampled for "seeding"	0.011	0.034	0.025	0.042	0.028
	(0.030)	(0.030)	(0.046)	(0.028)	(0.059)
village participated in NSC	−0.015	−0.03	−0.069	0.041	−0.042
	(0.030)	(0.030)	(0.052)	(0.032)	(0.051)
Kilosa district	−0.121	−0.021	−0.036	−0.024	0.005
	(0.031)***	(0.039)	(0.062)	(0.050)	(0.054)
voucher delivered directly to household head[b]	0.228	0.157	0.038	0.05	0.404
	(0.026)***	(0.079)*	(0.150)	(0.155)	(0.116)***
baseline respondent is male		0.068	0.091	0.083	−0.013
		(0.024)***	(0.048)*	(0.031)**	(0.039)
age of baseline respondent		0.004	0.005	0.002	0.005
		(0.001)***	(0.001)***	(0.001)	(0.002)***
baseline respondent has no education		−0.048	−0.011	−0.045	−0.116
		(0.031)	(0.052)	(0.059)	(0.053)**
socioeconomic status		0.174	0.075	0.267	0.17
		(0.033)***	(0.059)	(0.047)***	(0.071)**
number of children <5 years in the household		−0.017	−0.004	−0.012	−0.03
		(0.014)	(0.026)	(0.032)	(0.023)
homeowner		0.039	0.06	0.009	0.036
		(0.043)	(0.082)	(0.081)	(0.070)
soap present at handwashing station		0.142	0.213	0.063	0.051
		(0.045)***	(0.062)***	(0.069)	(0.087)
household has private pit latrine		0.064	0.04	0.061	0.096
		(0.035)*	(0.060)	(0.040)	(0.076)
pit latrine covered		0.037	0.078	−0.032	0.064
		(0.028)	(0.042)*	(0.051)	(0.051)
plans to build a new latrine		−0.007	−0.027	−0.045	0.067
		(0.031)	(0.060)	(0.054)	(0.063)
plans to install pour-flush toilet		0.03	0.021	−0.004	0.075
		(0.043)	(0.068)	(0.067)	(0.082)
plans other change to latrine (e.g., build roof, wall, door)		0.032	0.019	0.054	0.006
		(0.035)	(0.061)	(0.049)	(0.082)
log (minutes to collect water from main drinking water source, round-trip)		−0.005	−0.032	0.006	0.022
		(0.015)	(0.022)	(0.020)	(0.030)
water is always available at main drinking water source		−0.044	−0.081	−0.059	0.039
		(0.034)	(0.062)	(0.049)	(0.065)
time to retailer (in 10 s of minutes)		−0.011	−0.005	−0.019	−0.015
		(0.004)***	(0.006)	(0.006)***	(0.010)
number of 90% discount choice voucher recipients within 300 m radius		−0.001	0.029	−0.017	−0.012
		(0.012)	(0.018)	(0.017)	(0.028)
total number of voucher recipients within 300 m radius		−0.002	−0.005	0.002	−0.008
		(0.005)	(0.005)	(0.006)	(0.009)
observations	**1596**	**1421**	**531**	**487**	**403**
R-squared	**0.139**	**0.195**	**0.205**	**0.269**	**0.21**
dependent variable mean	**0.36**	**0.362**	**0.383**	**0.289**	**0.439**

[a]Each column corresponds to a linear probability model regression. Robust standard errors clustered by village (the unit of randomization for the seeding treatment) are given in parentheses below values in all specifications. Data on household characteristics are from the baseline survey. Not all voucher recipients had baseline data available because 10.8% of household head(s) were not home after being visited three times; in this case, vouchers and study brochures were left in a sealed envelope and explained to a neighbor if available. [b]In 10.8% of the cases, the voucher was left because the household head(s) were absent, with a neighbor if available.

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

< 0.05) (Table 1). The redemption patterns suggested that households that were given a choice voucher were more likely to complete a purchase than households that received a discount voucher for only a concrete SanPlat or only a plastic sanitary platform (though this trend was not significant at p < 0.1). For example, 84% of households that received a voucher that offered the greatest discount (90%) for any of the three latrine platform products completed a purchase; in contrast, approximately 60% of households that received vouchers offering the same discount level for only a concrete SanPlat or only a plastic sanitary platform completed a purchase (Figures 3 and 4). Households that redeemed choice vouchers

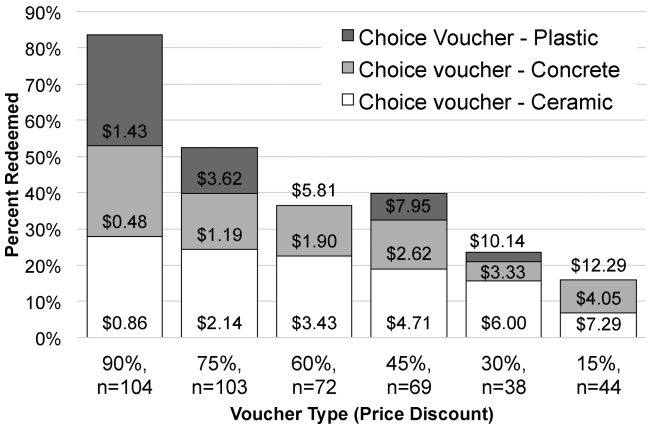

Figure 4. Percentages of households purchasing improved latrine platform products (plastic, cement, and ceramic) using choice discount vouchers (Figure S3 is by district). Financial values in each bar specify the product price, in US Dollars, at different discount levels.

that offered the highest discount level purchased the three products in similar proportions: 31% purchased plastic sanitary platforms, 28% purchased ceramic pans, and 25% purchased concrete SanPlats (Figure 4). At lower discount levels, households were more likely to purchase the cheaper concrete SanPlats or ceramic pans (Figure 4). However, there were differences in product choice between the two districts. In the wealthier Ludewa District, 57% of households that redeemed choice vouchers purchased ceramic pans versus only 22% in Kilosa District (Figure S3a,b). Furthermore, in Ludewa District, ceramic pans were the preferred choice across all discount levels, and in Kilosa District, concrete SanPlats were the preferred choice across all discount levels (Figure S3a,b).

Informational Interventions. The impacts of both peer-based information sharing (seeding villages with concrete or plastic sanitary platforms) and latrine hygiene information (swabbing of latrines to measure fecal contamination) on household WTP for improved latrine platform products were minimal (Table 1). After controlling for baseline variables, we found that seeding villages did not influence voucher redemption (p > 0.1). We also found that sharing latrine hygiene information decreased voucher redemption for concrete SanPlats (by 20%, p < 0.05) (Table 1). WTP was similar between NSC and non-NSC villages (p > 0.1) (Table 1); however, we were not able to evaluate the actual impact of the NSC since NSC village selection was not random (see Methods).

Latrine Platform Product Installation. The majority of households that redeemed their vouchers had not installed their purchased latrine platforms; installation rates were 44% (86/196) for concrete SanPlats, 34% (46/135) for plastic sanitary platform, and 5% (3/62) for ceramic pans. One-quarter of households (34/134) that had installed latrine platform products had rebuilt or upgraded their latrine prior to installation; most households that had not installed their latrine platform products stated that they were waiting to build a new latrine (69%, 162/234) or upgrade their entire latrine facility (16%, 37/234). Installation rates were not associated with voucher discount levels (p > 0.1).

Fecal Contamination Results of Household Latrines. We measured *E. coli* bacteria levels on 25 cm^2 of the footrest surface inside the unimproved pit latrines in 304 study households during the baseline survey. We detected *E. coli* in 53% (161/304) of the unimproved latrines, and 12% (35/304) of the unimproved latrines were contaminated with over 100 *E. coli* colony forming units (CFU)/25 cm^2. During the follow-up surveys, we re-examined *E. coli* contamination in 177 of these households (all households were not visited due to resource constraints). Of these 177 households, 33 had installed a latrine platform product and 144 had not installed a latrine platform product. We detected *E. coli* in 18% (6/33) of the latrines with installed platforms and in 33% (47/144) of the latrines without installed platforms, though this trend was not statistically significant (p = 0.10). There was no significant difference between *E. coli* contamination levels among latrines with installed platforms and latrines without installed platforms (geometric mean 7.5 vs 3.3 CFU/25 cm^2, p = 0.38).

DISCUSSION

Well-functioning sanitation markets can facilitate the delivery of products for the construction of improved latrines that promote hygienic sanitation and, ostensibly, improve public health. Despite extensive analysis of the public and private sector requirements for supporting sanitation improvements in low-income countries,[16,27] sanitation markets that serve the rural poor are virtually nonexistent.[28] Through a randomized evaluation of consumer demand for improved latrine platform products in rural Tanzania, we identified substantial gaps between household WTP for specific latrine platform products and their supply costs. Nevertheless, household purchase of the latrine platform products was high: up to 60% of households that were offered significant discounts (approximately 90%) for concrete and plastic sanitary platforms completed purchases (Figure 3). As latrine platform prices approached actual market costs, however, purchase rates dropped to less than 10%, indicating a low WTP (Figure 3).

Most households cited a lack of cash as their reason for not completing purchases, which could be interpreted as a general constraint of low income: among the lowest wealth quintile of the rural Tanzanian households, a concrete SanPlat represents over 100%, and a plastic sanitary platform over 300%, of average reported monthly income. Financial constraints were further illustrated by higher WTP for both concrete and plastic sanitary platforms among households in higher wealth quintiles. Interest in latrine rebuilding or upgrades also contributed to the low installation rates of all latrine platform products; it is possible that upgrades were also necessary prior to installation for poorly built or older latrines with weak floors that were at risk of collapse. Other studies in rural Tanzania and Cambodia have also shown that households prefer rebuilt latrines structures to simple upgrades.[29,30] Furthermore, the low installation rates of the ceramic pour-flush latrine pans may be due to the additional required investments prior to

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

installation (u-bend pipe, concrete, and hiring a mason), costing an average of US$9.53 according to our supply cost estimates.

We cannot say with certainty why the various informational interventions (NSC, seeding, swabbing), did not significantly influence WTP. It is possible that the NSC prompted some uptake of improved sanitation prior to our demand study and thus the remaining households without improved sanitation were those households resistant to improving their sanitation conditions; however, improved sanitation coverage was low at baseline (10% on average for NSC villages and 7% for non-NSC villages). Seeding might not have had an influence among households because sanitation challenges (or lack thereof) are not something that households discuss much with each other.[31,32] It is possible that seeding may have influenced household expectations for free products; however, previous evidence found that household subsidies (using household vouchers) increased latrine ownership among unsubsidized neighbors.[33] Hygiene information from the swabbing exercises may not have been well understood by households, since it was communicated by SMS rather than in person, and we cannot ascertain that households in fact received or read the SMS. The limited WTP for improved latrine platform products in rural Tanzania, and a preference for incorporating upgrades into comprehensive latrine structure improvements, may underlie both the minimal influences of peer effects and hygiene information on demand for latrine platform products, and the inability of the NSC to build significant demand (Table 1).

These results are consistent with findings from other studies, which show that consumer demand for health-related products in low-income settings is sensitive to price and is correlated with household wealth.[22,30,34−37] Furthermore, the WTP trends that we identified for latrine platform products are comparable to those for other health-related products such as vitamins, soap, bednets, and water treatment technologies.[38] In Bangladesh, a community motivation and information intervention was found to have no impact on sanitation demand;[33] similarly, in Kenya, neither additional health information nor peer effects influenced household purchases of children's rubber shoes that can help prevent worm infection.[23] A randomized, controlled evaluation of a previous sanitation campaign in Tanzania also found that SanPlat use remained low after the campaign, despite a significant increase from 1.4% in the control areas to 7% in the WSP-TSSM areas.[29] In addition, the campaign did not lead to higher household investment in latrines.[39]

Despite extensive efforts to develop improved latrine components, such as concrete and plastic sanitary platforms, and promote demand in rural Tanzania, WTP remains too low to support commercial supply models that will reach poor households, if our results generalize to the greater population. Given household preferences for latrine rebuilding or upgrades, demand for platform products may increase if they are embedded in a complete latrine rebuilding or upgrading package. Additionally, we measured WTP for a single lump sum payment, and it is possible that demand may increase with retailer or household access to financial products. Retail credit products from local financial institutions may promote higher retail inventories of improved latrine platform products and encourage retailers to offer consumer credit and installment plans.[28] Similarly, household microfinance loans for improving latrine facilities may address low WTP.[30] As far as we know, however, formal credit for rural retailers is limited in Tanzania, and financial institutions generally do not provide sanitation microfinance products.[40]

Additionally, the efforts to date to increase the coverage of improved sanitation in Tanzania have been largely funded through government and donor programs (including the present NSC and former demand campaigns, and activities to strengthen supply chains, such as provision of molds and training of masons). The costs of these "software" support activities have not been incorporated into our supply chain estimates, which would presumably increase if the private sector were responsible for market development.

Currently, the NSC has adopted a no-hardware-subsidy approach for households, based on the principals of Community Led Total Sanitation (CLTS) programming.[41] This policy may also reflect earlier poorly designed and administered subsidy programs with limited sustainability;[42] in some settings, heavy subsidies or the provision of latrines have resulted in limited latrine use.[43] However, some level of public finance of sanitation can be justified by its inherent externalities; using a latrine protects the surrounding community at least as much as it protects the users themselves.[42] In addition, recent comparisons of strategies to improve sanitation for poor rural families in Bangladesh showed that combining sanitation campaigns with household subsidies (using household vouchers) was an effective intervention to increase hygienic latrine ownership; similar effects were observed for combining sanitation campaigns, household subsidies (vouchers), and supply side market development interventions, though the sanitation campaign or supply side market development interventions alone did not improve latrine coverage.[33] Similarly, an assessment of six case studies on sanitation financing found that partial public funding could substantially increase household sanitation by 20−70%.[42] Studies also show that subsidies effectively promote the purchase of other essential health products by poor households.[37,44]

This study has several limitations. First, some retailers ran out of the latrine platform products and could not be immediately restocked because of rains (ten retailers ran out of concrete and/or plastic for 2−4 weeks). Though we extended voucher expiration dates in these villages accordingly, it is possible that the lack of latrine platform products would have reduced voucher redemption. Second, the harvest season was delayed in 2015 and the lack of harvest income could have reduced voucher redemption. Third, two villages that were randomly allocated for seeding were actually not seeded; therefore, we performed an intention-to-treat analysis, but it is possible that this underestimated the effect of seeding. Fourth, for households that were not home during the baseline, we left vouchers; however, it is possible that this decreased voucher redemption if they did not fully understand how or where to utilize them. Fifth, our sample size for comparing bacteriological contamination of latrines was limited by low installation rates. Sixth, our study was limited to accessible communities within two districts in Tanzania and may not represent all national contexts. Seventh, we excluded households that did not have a latrine; demand for latrine platform products among these excluded households may differ from our study population. Lastly, the (pre-existing, government-led) NSC was not randomly allocated; NSC villages were selected based on specific criteria so we cannot attribute WTP differences to the presence or absence of the NSC.

Overall, the sales trials of concrete SanPlats, plastic sanitary platforms and ceramic pour-flush latrine pans suggests that the

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

commercial costs of supplying latrine platform products in rural Tanzania, even at scale, are too high to achieve significant market-based penetration among village households: the differences between supply costs and WTP are too large. They also call into question the effectiveness of sanitation marketing campaigns that are designed around supply and marketing of these stand-alone components in Tanzania.[16] We did not find evidence for major supply side constraints that can be addressed to drive down supply costs. Prefabricated concrete manufacturing is a thriving industry in Tanzania that is well-positioned to supply retailers with concrete SanPlats. Similarly, functioning supply networks for plastic goods and ceramic latrines are well established. Consequently, if our results are generalizable to the greater population, efforts to expand the market-based uptake of latrine platform products must confront the low demand.

The supply demand gaps for latrine platform products that we have identified in rural Tanzania and the emerging evidence for including hardware subsidies in sanitation campaigns, together, indicate that the NSC's no-hardware-subsidy approach should be reconsidered, if the private sector is to play a significant role in supplying rural households with latrine platform products. However, to warrant public financing of upgrading latrine platforms, evidence is needed for their reduced pathogen exposure for users and subsequent health benefits. Ongoing randomized, controlled trials in Kenya are evaluating the impacts of latrine platform products on diarrhea disease, helminth infection, and child growth.[45,46] Alternatively, given the household preferences for latrine rebuilding and upgrades, other improved latrine solutions should be considered.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.6b03846.

Details on voucher allocation are in Table S1 and on baseline characteristics are in Table S2, photos of traditional latrines are in Figure S1, photos of installed platforms are in Figure S2, and choice voucher redemption results by district are in Figure S3. The procedure for swabbing is in the SI Methods. Details on retailer purchasing are included in SI Results (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*Phone: +254 701178714; fax: +1 415-306-7594; e-mail: rachel@aquaya.org (R.P.).

ORCID

Rachel Peletz: 0000-0002-9256-0800

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This research was funded through a consulting agreement between the Water & Sanitation Program of the World Bank and The Aquaya Institute. The rural sanitation sales trials were implemented in collaboration with MSABI (Maji Safi kwa Afya Bora Ifakara!). Dr. Emily Kumpel (Aquaya) helped establish and manage electronic data collection systems and reviewed the paper prior to submission. Mr. Alpesh Patel (SilAfrica, Tanzania, Ltd.) provided information on the manufacturing and supply of plastic sanitary platforms. We thank the Water and Sanitation Program of the World Bank for support and feedback throughout the project.

■ REFERENCES

(1) WHO/UNICEF. *Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment*; 2015.

(2) Prüss-Ustün, A.; Bartram, J.; Clasen, T.; Colford, J. M.; Cumming, O.; Curtis, V.; Bonjour, S.; Dangour, A. D.; De France, J.; Fewtrell, L.; et al. 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* **2014**, *19* (8), 894−905.

(3) Mara, D.; Lane, J.; Scott, B.; Trouba, D. Sanitation and Health. *PLoS Med.* **2010**, *7* (11), e1000363.

(4) Lin, A.; Arnold, B. F.; Afreen, S.; Goto, R.; Huda, T. M. N.; Haque, R.; Raqib, R.; Unicomb, L.; Ahmed, T.; Colford, J. M.; Luby, S.; et al. Household Environmental Conditions Are Associated with Enteropathy and Impaired Growth in Rural Bangladesh. *Am. J. Trop. Med. Hyg.* **2013**, *89* (1), 130−137.

(5) Spears, D.; Ghosh, A.; Cumming, O. Open Defecation and Childhood Stunting in India: An Ecological Analysis of New Data from 112 Districts. *PLoS One* **2013**, *8* (9), 1−9.

(6) Schmidt, W.-P. The elusive effect of water and sanitation on the global burden of disease. *Trop. Med. Int. Health* **2014**, *19* (5), 522−527.

(7) WHO. *Preventing Diarrhoea through Better Water, Sanitation and Hygiene*; Geneva, Switzerland, 2014.

(8) Hutton, G.; Haller, L.; Bartram, J. Global cost-benefit analysis of water supply and sanitation interventions. *J. Water Health* **2007**, *5* (4), 481−501.

(9) WHO. *Global Costs and Benefits of Drinking-Water Supply and Sanitation Interventions to Reach the MDG Target and Universal Coverage*; Geneva, Switzerland, 2012; Vol. *11*.

(10) Yu, W.; Wardrop, N. A.; Bain, R. E. S.; Lin, Y.; Zhang, C.; Wright, A. A Global Perspective on Drinking-Water and Sanitation Classification: An Evaluation of Census Content. *PLoS One* **2016**, *11* (3), 1−17.

(11) WHO/UNICEF. *JMP Green Paper: Global Monitoring of Water, Sanitation and Hygiene Post-2015*; 2015.

(12) WSP. *Economic Impacts of Poor Sanitation in Africa*; 2012; Vol. *381*.

(13) Brandberg, B. Latrine building: a handbook for implementation of the SanPlat system. *Intermed. Technol. Publ.* **1997**, Viii−1.

(14) Thomas, J.; Holbro, N.; Young, D. *A Review of Sanitation and Hygiene in Tanzania*; Dar es Salaam, Tanzania, 2013.

(15) Shayo, A. J.; Chaggu, E. J. Private Sector Participation (PSP) in Peri-Urban and Rural Sanitation A Case Study of "SanPlat Promotion in Tanzania. *Int. Water Sanit. Cent.* **2004**, 1−10.

(16) Robinson, A. *Enabling Environment Endline Assessment: Tanzania* ; Washington DC, 2011.

(17) Roma, E.; Rheingans, R.; Stich, A.; Antwi Agyei, P.; Seleman, A.; Mwakitalima, A.; Kiberiti, S.; Tenu, F.; Meku, S.; Cardosi, J. *Process Evaluation of the National Sanitation Campaign of Tanzania*; 2016.

(18) Rosensweig, B. F.; Perez, E.; Robinson, A. *Policy and Sector Reform to Accelerate Access to Improved Rural Sanitation*; Washington DC, 2012.

(19) Cardosi, J.; Mwambuli, K. *How to Sell Concrete Latrine Slabs: Lessons from Rural Tanzania*; Water and Sanitation Program, World Bank: Dar es Salaam, 2013.

(20) Momanyi, M. *Supply Chain Analysis for Improved Sanitation Solutions (SanPlat − Sungura Slabs) in Rural Tanzania: Inception Report*; Water and Sanitation Program, World Bank: Dar es Salaam, 2013.

(21) WSP; IFC; MOPHS. *Selling Sanitation: Catalyzing the Market for Household Sanitation in East Africa*; Nairobi, Kenya, 2013.

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

(22) Dupas, P. What Matters (and What Does Not) in Households' Decision to Invest in Malaria Prevention? *Am. Econ. Rev. Pap. Proc.* **2009**, *99* (2), 224−230.
(23) Meredith, J.; Robinson, J.; Walker, S.; Wydick, B. *Keeping the Doctor Away: Experimental Evidence on Investment in Preventative Health Products*; CEGA Working Paper Series No. WPS-009; Berkeley, 2012.
(24) Lucas, P. J.; Cabral, C.; Colford, J. M. Dissemination of drinking water contamination data to consumers: A systematic review of impact on consumer behaviors. *PLoS One* **2011**, *6* (6), e2109810.1371/journal.pone.0021098
(25) Brown, J.; Hamoudi, A.; Jeuland, M.; Turrini, G. Seeing, believing, and behaving: Heterogeneous effects of an information intervention on household water treatment. *J. Environ. Econ. Manage.* **2016**, DOI: 10.1016/j.jeem.2016.08.005.
(26) National Bureau of Statistics (NBS) [Tanzania] and ICF Macro. *Tanzania Demographic and Health Survey 2010*; Dar es Salaam, Tanzania, 2011.
(27) Perez, E.; Cardosi, J.; Coombes, Y.; Devine, J.; Grossman, A.; Kullmann, C.; Kumar, C. A.; Mukherjee, N.; Prakash, M.; Robiarto, A.; et al. *What Does It Take to Scale up Rural Sanitation?* 2012.
(28) Dumpert, J.; Perez, E. Going beyond mason training: enabling, facilitating, and engaging rural sanitation markets for the base of the pyramid. *Waterlines* **2015**, *34* (3), 210−226.
(29) Briceño, B.; Coville, A.; Martinez, S. *Promoting Handwashing and Sanitation Evidence: From a Large-Scale Randomized Trial in Rural Tanzania*; Washington DC, 2015.
(30) Shah, N. B.; Shirrell, S.; Fraker, A.; Wang, P.; Wang, E. *Understanding Willingness to Pay for Sanitary Latrines in Rural Cambodia: Findings from Four Field Experiments of iDE Cambodia's Sanitation Marketing Program*; 2013.
(31) Sim, J. In the market for proper sanitation. *Bull. World Health Organ.* **2010**, *88*, 167−168.
(32) Black, M.; Fawcett, B. *The Last Taboo: Opening the Door on the Global Sanitation Crisis*; Taylor & Francis: New Yrok, 2008.
(33) Guiteras, R.; Levinsohn, J.; Mushfiq, A. Encouraging sanitation investment in the developing world: A cluster-randomized trial. *Science (Washington, DC, U. S.)* **2015**, *348* (6237), 903−906.
(34) Onwujekwe, O.; Hanson, K.; Fox-rushby, J. Inequalities in purchase of mosquito nets and willingness to pay for insecticide-treated nets in Nigeria: Challenges for malaria control interventions. *BioMed. Cent.* **2006**, *3* (6), 1−8.
(35) Ashraf, B. N.; Berry, J.; Shapiro, J. M. Can Higher Prices Stimulate Product Use? Evidence from a Field Experiment in Zambia. *Am. Econ. Rev.* **2010**, *100* (5), 2383−2413.
(36) Blum, A. G.; Null, C.; Hoffmann, V. Marketing Household Water Treatment: Willingness to Pay Results from an Experiment in Rural Kenya. *Water* **2014**, *6*, 1873−1886.
(37) Dupas, P. Getting essential health products to their end users: Subsidize, but how much? *Science (Washington, DC, U. S.)* **2014**, *345* (6202), 1279−1281.
(38) Dupas, P.; Miguel, E. *Handbook of Impacts and Determinants of Health Levels in Low-Income Countries*; In press, 2016.
(39) Briceño, B.; Chase, C. Cost-efficiency of rural sanitation promotion: activity-based costing and experimental evidence from Tanzania. *J. Dev. Eff.* **2015**, *7* (4), 423−434.
(40) Trémolet, S.; Mansour, G.; Muruka, G. *Developing Microfinance for Sanitation in Tanzania*; 2015.
(41) Kar, K.; Chambers, R. *Handbook on Community-Led Total Sanitation*; London, UK, 2008.
(42) Trémolet, S.; Kolsky, P.; Perez, E. *Financing On-Site Sanitation for the Poor: A Six Country Comparative Review*; Washington DC, 2010.
(43) Barnard, S.; Routray, P.; Majorin, F.; Peletz, R.; Boisson, S.; Sinha, A.; Clasen, T. Impact of Indian Total Sanitation Campaign on latrine coverage and use: a cross-sectional study in Orissa three years following programme implementation. *PLoS One* **2013**, *8* (8), e71438.
(44) Dupas, P. Short-Run Subsidies and Long-Run Adoption of New Health Products: Evidence from a Field Experiment. *Econometrica* **2010**, *82* (1), 192−228.
(45) Water Global Practice. *Health Impact and Effectiveness of Distribution Models for Plastic Latrine Slabs in Kenya*; Knowledge Brief; Washington D.C., 2017.
(46) Arnold, B. F.; Null, C.; Luby, S. P.; Unicomb, L.; Stewart, C. P.; Dewey, K. G.; Ahmed, T.; Ashraf, S.; Christensen, G.; Clasen, T.; et al. Cluster-randomised controlled trials of individual and combined water, sanitation, hygiene and nutritional interventions in rural Bangladesh and Kenya: the WASH Benefits study design and rationale. *BMJ. Open* **2013**, *3* (8), e003476.

DOI: 10.1021/acs.est.6b03846
Environ. Sci. Technol. XXXX, XXX, XXX−XXX