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Targeting health subsidies through a non-price mechanism: A randomized controlled trial in Kenya

Pascaline Dupas[1,2,3,*], **Vivian Hoffmann**[4,*], **Michael Kremer**[2,3,5,*], and **Alix Peterson Zwane**[6,*]

[1]Stanford University, Stanford CA, USA

[2]NBER, Cambridge MA, USA

[3]JPAL, Cambridge MA, USA

[4]IFPRI, Washington DC, USA

[5]Harvard University, Cambridge MA, USA

[6]Global Innovation Fund, Washington DC, USA

Abstract

Free provision of preventive health products can dramatically increase access in low income countries. A cost concern about free provision is that some recipients may not use the product, wasting resources (over-inclusion). Yet charging a price to screen out non-users may screen out poor people who need and would use the product (over-exclusion). We report on a randomized controlled trial of a screening mechanism that combines the free provision of chlorine solution for water treatment with a small non-monetary cost (household vouchers that need to be redeemed monthly in order). Relative to a non-voucher free distribution program, this mechanism reduces the quantity of chlorine procured by 60 percentage points, but reduces the share of households whose stored water tests positive for chlorine residual by only one percentage point, dramatically improving the tradeoff between over-inclusion and over-exclusion.

1. Introduction

Policy makers have long debated whether developing countries should charge for health products such as deworming medication, malaria medication, mosquito nets, water treatment solution, and latrines. Multiple studies have found that demand for preventive health goods is highly sensitive to price (1–4). For mosquito nets, usage appears as high among recipients who get them only when they are free or nearly free as among those able to pay a price of USD 1 or more (5, 2, 6–8). However, in the case of water treatment solution, Ashraf, Berry,

*To whom correspondence should be addressed: Dupas pdupas@stanford.edu; Hoffmann: v.hoffmann@cgiar.org; Kremer: mkremer@fas.harvard.edu; Zwane: alix.zwane@globalinnovation.fund.

Supporting Online Material includes the following:
A. Additional Details on Study Methods
B. Characteristics of Study Sample and Randomization Check (Table S1)
C. Determinants of Take-up and Results by Months Since Enrollment (Tables S2–S5)
D. Calculation of Cost per Life and DALY Saved
References 46–56 appear only in the Supplementary Material.

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and Shapiro (9) argue that households with lower willingness to pay for the product when a marketer comes to their doorstep are less likely to use it for its intended health purpose, and more likely to use it for other purposes, such as washing clothes or cleaning toilets. Policymakers may thus be concerned that free distribution of products that only part of the population values for their health purpose can generate wastage.

This paper reports findings from a randomized controlled trial that compares three mechanisms for allocating dilute-chlorine water treatment solution: (1) charging a partially subsidized price; (2) free provision during a clinic visit and a follow-up household visit (10); and (3) combining free provision with a screening mechanism designed to make the water treatment solution available to those willing to expend a small effort (redemption of a month-specific voucher at a local shop) to obtain it. By testing households' stored water for chlorine residual, we assess actual use of the product, and thus compare the extent to which each mechanism generates errors of inclusion (by providing the product to households who will not use it to treat water) or of exclusion (by preventing households who would use the product to treat water from obtaining the product.) We then examine how the optimal choice of mechanism for a policymaker depends on these error rates, the cost of each mechanism, and policymakers' valuation of households' use of the water treatment solution.

We find that combining free provision with a voucher mechanism screens out 88% of those who would accept the product under free provision but not treat their water, thus dramatically reducing errors of inclusion, while creating very few errors of exclusion relative to free provision. Rates of positive residual chlorine tests are almost identical when comparing free distribution and voucher provision. The proportion of households with water testing positive for residual chlorine was 32.9% in the group receiving vouchers, and only 1 percentage point higher, at 33.9%, in the group with free distribution. The difference is not statistically significant. This suggests that the inconvenience of safekeeping and redeeming vouchers screened out very few of those who would have used chlorine solution if given it directly.

We also confirm previous findings that although errors of inclusion are low under cost-sharing, cost-sharing generates many errors of exclusion relative to free treatment. Only 12.4% of households in the cost sharing group had chlorine in their water, many fewer than under either form of free treatment.

2. Setting and Background

Diarrhea is a major cause of child mortality (ages 1–59 months) globally and in Kenya (11). Water is a major channel for the transmission of diarrheal disease. Dilute chlorine solution kills many of the pathogens that cause diarrhea. Arnold and Colford (12) review 21 randomized controlled trials on the impact of point-of-use water treatment with dilute chlorine solution and find that access to point of use chlorination reduces reported child diarrhea by an average of 29% overall (13). Dilute chlorine solution is socially marketed in many countries by the non-governmental organization Population Services International (PSI), which receives donor support.

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The study took place from November 2007 to September 2008 in western Kenya, a region with the second highest prevalence of child diarrhea in Kenya (14). In addition to free government provision during epidemics, the primary approach to distribution of water treatment solution in this area had been social marketing and sales to households through retail shops. PSI began marketing 150 ml bottles of dilute chlorine solution branded as 'WaterGuard' in Kenya in May 2003. These bottles, expected to last a household 30–50 days (15–17), were sold at a price of 20 Kenyan Shillings (Ksh) at the onset of this study, around US$ 0.30 at the exchange rate at that time (18–19). While brand recognition for WaterGuard is high, as is reported understanding of the potential benefits of the technology, take up of water chlorination in rural Western Kenya is low. Kremer et al. (20) report that only 7% of rural households in this part of Kenya were using chlorine to treat their drinking water, a rate typical of many other rural African settings. Point-of-use water treatment requires repeated, proactive behavior on the part of households even when the technology is offered free of charge. Previous work in the region has found that the rate of verified water treatment is around 50% when chlorine solution is provided free but encouragement and reminders are relatively infrequent (20–21). Limited use could be due to a number of factors, including aversion to the taste of chlorine, particularly if dosing is too high or water is consumed too soon after treatment.

3. Methods

Parents of children aged six to twelve months, an age group at high risk for mortality due to diarrheal disease, were recruited from the waiting rooms of four rural maternal and child health clinics in Busia District. Once enrolled, study participants were administered a baseline survey on basic demographics, current water treatment practices, knowledge about waterborne illness and diarrhea prevention, and child health. At the end of the survey, the 1,118 participants in this study sample were randomly assigned to one of three experimental arms by choosing an envelope from a bag full of identical envelopes, each containing a letter corresponding to one of these arms. Once the respondent selected an envelope and revealed the letter, the enumerator offered the corresponding treatment. The Supporting Online Material (SOM) provides additional information on methods and sampling. Table S1 presents baseline characteristics of our study sample, as well as tests of balance across the treatment arms. Note that since the baseline survey was administered in waiting rooms of clinics and not at respondents' homes, no water test could be performed at baseline, and therefore we cannot test for baseline balance on the primary endpoint of interest (presence of chlorine in drinking water at home).

In each of these experimental treatments, participants were offered the opportunity to obtain sufficient water treatment solution to last them much beyond the time of the follow-up survey, which was conducted during a home visit three to five months later. Comparing take up and usage at follow-up across these groups thus allows us to identify the targeting effects of varying the price and effort cost of obtaining the product. The three experimental treatments were as follows:

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COST SHARING treatment

Water treatment solution was made available for immediate purchase at a 50% discount off the retail price. Participants could purchase up to five 150 ml bottles of the solution (enough to last approximately five to eight months), at 10 Kenyan Shillings (Ksh) per bottle.

VOUCHERS treatment

Twelve vouchers, each redeemable for one 150 ml bottle of water treatment solution at either a local shop or the clinic itself were provided. Each voucher was marked for a specific month, for the next 12 consecutive months, and participants were given a calendar to track the expiration of vouchers.

FREE DELIVERY treatment

Two 500 ml bottles of water treatment solution were provided, one immediately and the second given during the follow-up survey conducted at the participant's home, three to five months later (22). At the time they received the first bottle, participants were informed they would receive a second bottle later. This supply of 1,000 ml of water treatment solution was expected to last approximately 7 to 11 months.

A follow-up was conducted at participant's homes three to five months after enrollment. Details on the methods and attrition at follow-up survey are provided in section A of the SOM.

4. Results

Table 1 presents dilute chlorine procurement ("take up") by treatment arm. While take-up in the *FREE DELIVERY* arm was nearly universal (everyone took the first bottle of water treatment solution offered at the clinic, and only about one percent of participants refused to accept the second bottle offered during the follow-up home visit), only 13.4% of the five bottles offered for sale were purchased in the *COST SHARING* group. (Just over half (51.9%) of those in the group purchased a bottle, and few purchased more than one.) (23).

Take-up in the *VOUCHERS* group was higher, with 39.8% of the 12 monthly vouchers redeemed per household (85.3% of households redeemed at least one voucher). Analysis presented in Table S2 of the SOM indicates a positive relationship between household wealth and purchase of water treatment solution in the *COST SHARING* group, but a negative association between wealth and procurement in the *VOUCHERS* group.

Table 2 shows water treatment at follow-up by arm. The first row shows the unconditional proportions of participants in each treatment group with a positive chlorine test among those with stored drinking water at the time of the survey, while the second row shows coefficients and standard errors from a regression of positive chlorine tests on treatment arm and baseline variables from Table S1, stratification variables (clinic and survey wave indicator variables), and time since enrollment. The two sets of results are very similar. We focus our discussion and analysis on the specification conditional on controls.

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Table 2 confirms the earlier literature showing that user fees create substantial exclusion errors relative to free delivery: the proportion of households with a positive chlorine test was only 12.4% in the *COST SHARING* group, 21.5 percentage points lower than in the *FREE DELIVERY* group.

Table 2 also presents the more novel finding that is the main result in this paper: the rates of positive residual chlorine tests in the *FREE DELIVERY* and *VOUCHERS* groups are almost identical. In the *VOUCHERS* group 32.9% of households had water testing positive for residual chlorine. In the *FREE DELIVERY* group 33.9% tested positive, so the point estimate of the difference was only 1.0 percentage point (and this was not statistically significant). The 95% confidence intervals for the *VOUCHERS* and *FREE DELIVERY* groups are [25.3, 40.5] and [26.3, 41.5], respectively. Results are very similar and also do not differ statistically when restricting attention only to those households sampled at 3 or 4 months after enrollment, which collectively account for 80% of the sample: at 3 months, the difference between *FREE DELIVERY* and *VOUCHERS* was 1.4%; at 4 months the difference was 2.7% (see Table S3 in the SOM). This indicates that results are not driven by households in the *FREE DELIVERY* group running out of chlorine. The share of households that report running out in that group at the time of follow-up was 15.1% (13.6% for those surveyed after three months) (24).

While we cannot directly test whether the *same households* who use the water treatment product under *FREE DELIVERY* would also use it under the *VOUCHERS* scheme, we can test whether confirmed users under the two schemes have similar characteristics. We do this in Table S4 of the Supplementary Materials, which shows, for the subsample of individuals in either the *FREE DELIVERY* or *VOUCHERS* groups, the coefficient estimates of a regression of confirmed water usage on baseline characteristics and interactions between baseline characteristics and the *VOUCHERS* treatment. We cannot reject the null that users under the two schemes are selected along identical characteristics, which suggest that those that did not redeem vouchers would likely not have used under *FREE DELIVERY*.

Together, the results so far suggest that imposing the inconvenience of redeeming time-stamped vouchers does not substantially reduce water treatment relative to free distribution. Relative to free distribution, the voucher allocation mechanism reduced errors of inclusion dramatically (by 58 percentage points) and had almost no impact on errors of exclusion. Combining free provision with a voucher mechanism achieves most of the benefits of free treatment, while eliminating most of the downside of potential wastage due to errors of including people who would not use the product to treat water. As discussed more formally in the next section, our point estimates imply that unless a policymaker is willing to accept almost 60 exclusion errors to avoid one inclusion error, the policymaker will prefer a voucher screening mechanism to free delivery.

While the effort required to redeem vouchers was not varied experimentally in the study, we can use variation in the location at which vouchers could be redeemed to generate a measure of the strength of the non-price screen. Specifically, shops where the vouchers could be redeemed were in the nearest market center for 22% of respondents. Table 3 column 1 shows that participants who could redeem vouchers at the nearest market center were 15.3

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percentage points more likely (adjusted p-value: 0.034) to have redeemed a voucher in the month prior to the follow-up interview than those who had to go further out of their way to do so, conditional on stratification variables (wave and clinic), time since enrollment, and baseline covariates. However, these participants were only 4.4 percentage points more likely (adjusted p-value: 0.532) to be using the solution to treat their water, according to chlorine test results (Table 3 column 2) (25). We note that distance to the redemption point was not randomly assigned so it is possibly correlated with characteristics that were not measured at baseline and therefore not controlled for in the analysis. Future work could experimentally vary the location of voucher redemption locations to test the hypothesis that less onerous non-price screening mechanisms generate higher take up, but are less effective at screening out those who do not use a good for its intended purpose.

5. Optimal Policy

To formally examine the optimal choice of mechanism for a policymaker, let V denote the policy maker's valuation of providing water treatment solution to a household that has children at risk of mortality from diarrheal disease and that will actually use the water treatment solution for its intended purpose. The policymaker therefore seeks to maximize total value minus the total cost of the subsidy, or $VN_m – C_mT_m$ where the subscript m denotes the mechanism, N denotes the number of households using water treatment under mechanism m, C_m denotes the subsidy per household obtaining water treatment under mechanism m, and T_m denotes total take-up, i.e., the number of households who obtain chlorine solution under mechanism m. The policymaker will prefer changing from delivery mechanism a to mechanism b that expands take-up relative to mechanism a, if and only if $V(N_b–N_a) > C_bT_b – C_aT_a$, which we can rewrite as follows:

$$V(N_b - N_a) > C_b(T_b - T_a) + (C_b - C_a)T_a. \quad (1)$$

The left hand side of inequality (1) is the value to the policymaker of additional chlorine usage, and the right hand side is the cost to the policymaker of achieving this change, which consists of the cost of reaching marginal consumers, $C_b(T_b – T_a)$, plus the cost of further subsidizing inframarginal consumers who would have obtained water treatment solution in any case, $(C_b – C_a)T_a$. In the special case in which the cost to the policymaker per taker is the same under the two mechanisms ($C_b = C_a = C$), this expression simplifies and can be expressed as $(N_b – N_a)/(T_b–T_a) > C/V$, so that the ratio of new users to new recipients must be greater than the ratio of the subsidy per taker to the policymaker's valuation of health. If the cost per user under method b (which achieves higher take up) is greater, as will typically be the case, then this condition will be necessary (but not sufficient) for method b to be preferred.

Clearly, if policymakers have a low enough valuation of a targeted household treating its water (any value less than the cost of the treatment and extending up to some range above this), they will want a positive price (either no subsidy or a subsidy that does not bring the price to zero). If policymakers have a high enough valuation, they will prefer free household delivery. However, our estimates imply that it is possible to make a product available for free

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with little wastage, and hence that there will be a broad range of valuations over which they will prefer combining a full subsidy with a non-price screening mechanism (26).

Table 4 summarizes the material cost of water treatment solution per additional user reached under the policy changes considered. The first column shows the change in chlorine usage for 100 subsidized doses, and columns 2–5 spell out the components of the two terms on the right-hand side of inequality (1). Column (6) indicates the total material cost per additional user, abstracting from differences in delivery costs. The first row of Table 4 illustrates the binary choice between *COST SHARING* and *FREE DELIVERY*, excluding the option of a voucher screening mechanism. Relative to *COST SHARING*, delivering chlorine free of charge to users increases the proportion of households who obtain it by 86.6 percentage points, from 13.4% to 100% (columns 3 and 7 in Table 1), and increases the proportion of verified chlorine users from 21.5 percentage points, from 12.4% to 33.9% (columns 1 and 3, second row of Table 2). This implies that 4.03 additional doses of water treatment solution have to be delivered for every additional dose used (86.6/21.5) (27). What is more, under free delivery the policymaker fully subsidizes water treatment for the 13.4% of households who would purchase at the cost-sharing price (28). This adds a cost equivalent to 0.31 doses per additional user [(13.4 * 1/2 dose) / 21.5 = 0.31], which brings the total cost to 4.34 doses for every new user (29). If a policymaker has a high value of health, this could be a cost worth bearing to achieve high coverage, but a policymaker with a lower value of health may choose a cost-sharing approach.

Once the possibility of a voucher screening mechanism is introduced, policymakers with a broad range of valuations of health will prefer this approach to either cost sharing or full subsidy via free delivery (30). This result is shown in rows 2 and 3 of Table 4. Moving from cost sharing to a voucher-based screen implies the policymaker must provide 1.7 additional units of treatment solution for every additional chlorine-using household. To see this, note that in the *VOUCHERS* treatment, 41.1% of recipients redeemed a voucher in the month prior to the follow-up visit and 39.8% of total vouchers were redeemed over the twelve-month span of their validity (columns 5 and 6, Table 1). Based on the prior-month redemption figure and the adjusted confirmed usage rate of 32.9% (Table 2, column 2) in this group, the proportion of households obtaining chlorine increases by 27.7 percentage points, relative to cost sharing, while the proportion of users increases by 20.5 percentage points, relative to cost sharing. Thus, moving from cost sharing to a voucher-based screen implies the policymaker must provide 27.7 / 20.5 = 1.35 additional units of treatment solution for every additional household with confirmed chlorine residual. Adding the cost of fully subsidizing those who would use under cost-sharing, as calculated above, brings the full cost of the policy change to 1.68 units per new user.

If the additional value (beyond that of the household itself) that policymakers place on a household treating its water is less than the cost of one dose, then they would not want to fully subsidize treatment. If they value it at between 1 and 1.68 times the cost of a dose, then the wastage associated with a voucher-based approach would lead them to reject such a program. If water treatment is valued above 1.68 times the cost of a dose, voucher programs are potentially attractive.

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Moving from vouchers to universal free delivery, under which 33.9% of households were confirmed to be chlorinating at the follow-up visit, entails providing 58.9 additional units of treatment solution to reach one additional using household (100% take up under free delivery minus 41.1% coupon redemption to achieve an increase of 1% in usage). If the value of reaching that one additional household is extremely high, a policy maker might choose the free delivery mechanism. However, it is easy to see that for a wide range of values placed on the health of this 34th household, the voucher mechanism would be preferred to full subsidy via free delivery, as it is significantly cheaper.

We can be more specific about how policymakers' decisions will depend on their valuation of averting a disability-adjusted life year (DALY) and their expectations about the number of DALYs saved per household chlorinating their water (31). For the purposes of illustration, we use the estimated impact of point-of-use chlorination on diarrheal disease reported by Arnold and Colford (12), and assume that the reduction in child deaths achieved through treatment of drinking water is roughly proportional to diarrhea cases averted. (If policymakers believed that water treatment is half as effective as implied by these assumptions, they would simply require valuations twice as high as those reported here to make each decision.) Using estimates of the total under-five mortality rate and under-five diarrheal mortality rate in Kenya provided by the UN Inter-agency Group for Child Mortality Estimation (32) and Health Epidemiology Reference Group (33) respectively, a policymaker would arrive at estimates of the material costs per DALY and life saved via water treatment shown in columns 7 and 8 of Table 4. Underlying data and assumptions are described in Part C of the SOM.

In this example, setting aside issues of differences in distribution costs between the options, policymakers who value a DALY saved at between $70 and $2,475 (or a statistical life at between $2,134 and $74,921) will prefer the voucher screening approach to the other options. Note that the range of valuations for which the voucher approach is preferred is very wide, encompassing values far below the very stringent standard of $246 per DALY corresponding to the current dollar value of the $150/DALY threshold implicitly suggested by the World Bank in the 1993 World Development Report (34, 35) and extending above the more generous approach taken by the WHO (36, 37) of considering interventions costing less than the GDP per capita of the country (currently $1245 for Kenya) as highly cost effective. Policymakers with valuations below $70/DALY would likely prefer cost sharing, while policymakers with valuations above $2,475/DALY would prefer free distribution.

This analysis considers only the cost of the water treatment itself. Administering a voucher system could generate some additional costs relative to a partial subsidy system without vouchers; the magnitude of these costs is an important question when considering operationalizing such a program. Similarly, free household delivery would be substantially more expensive than a voucher system. While delivering a 500 ml bottle at the clinic is relatively cheap, since children are vulnerable to diarrhea until age five and since dilute chlorine solution has a limited shelf life (18 months from the date of manufacture, so 6 to 12 months given distribution lags), additional bottles would have to be provided later on. Arranging for these to be delivered to households would be very expensive relative to

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vouchers (38). This suggests that only policymakers with a very high valuation of health would prefer free delivery to a voucher system.

6. Discussion

Ashraf et al. (9) report that use of a price mechanism to target a preventive health product – dilute chlorine solution for water treatment – disproportionately targets those who will use it, but also excludes many potential users. The results presented here suggest that combining free provision with a non-price screening mechanism – requiring people to redeem vouchers – can also greatly reduce wastage but without a corresponding increase in the exclusion of those who would use treatment. This paper makes several contributions. First, it extends a literature in economics on "ordeal mechanisms" as targeting mechanisms. Second, the findings demonstrate proof of concept for a novel approach to the distribution of water treatment solution.

An existing literature in economics discusses the effectiveness of "ordeal mechanisms", such as requiring work for welfare, in targeting redistributive transfers to the poor (39,40). For example, some food subsidy programs focus on coarser grains that richer households are less likely to consume in order to reduce errors of inclusion of richer households. This paper takes the idea in a new direction, by examining the extent to which what might be termed "micro-ordeals" can target merit goods (goods for which the policymakers values consumption beyond the value at which the household values consumption) to those who will use them as intended by the policymaker. We provide evidence that time and money costs have different selection properties, and in particular that compared to free delivery, charging selects a richer group of households to obtain water treatment, while a voucher system selects a poorer group of households, consistent with a model in which richer households have a higher value of time. This differential pattern of selection suggests that price-based selection mechanisms are unlikely to be able to duplicate the pattern of selection created by the voucher redemption mechanism. To the extent that poorer households are more likely to experience mortality from diarrheal disease, the voucher system induces a pattern of selection that is likely to yield greater health benefits per person treating their water.

There are several potential reasons why in our context willingness to redeem vouchers predicted usage well while willingness to pay a monetary cost led to many errors of exclusion of those who would use the water treatment solution. Perhaps households with a low valuation of time were more likely both to redeem vouchers and to use water treatment solution. Perhaps households that are motivated and organized enough to safe keep and redeem vouchers were also motivated and organized enough to treat their water, but labor market imperfections made it difficult for these households to convert their time to money that could be used to purchase the product.

Such micro-ordeal screens could potentially be used more broadly. For example, it might be the case that having to fill out application forms to apply for a college scholarship targets students who will later study diligently and thus use the college education most productively. As this example indicates, such judgements will have to be made on a case by case basis

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based on the empirical evidence for that case. In some cases, a micro-ordeal might be insufficient to screen out people who would use a product in a way other than the policymaker intended. For example, in the same area of Kenya, Cohen et al. (41) find that, conditional on having an episode of fever, willingness to pay the effort cost of visiting a local drug shop to redeem a voucher for highly subsidized antimalarial medication is poorly correlated with actual malaria status – specifically, 44% of those redeeming an antimalarial voucher do not have malaria (but think they do). This is due to poor access to accurate malaria diagnosis combined with the very high benefit of appropriately treating malaria when it truly is the underlying cause of the fever. Ma et al. (42) find that 90% of households in China redeem vouchers for free prescription eyeglasses for myopic children, even though less than half of the children end up wearing the eyeglasses regularly. This could be because for such a product, as in water chlorination, users need to try the product out to know the usage cost, and the option value of learning outweighs the redemption cost for most households. Unlike water chlorination, eyeglasses cannot be distributed in monthly doses, so the voucher mechanism cannot be used to screen out, over time, those who have learned the usage costs are too high for them. In other cases, almost everyone who takes a product distributed for free may use it as intended, so there is no need for a micro-ordeal (See, for example, (6) on antimalarial bed nets.)

Because many real-world free distribution programs do not involve in-person free delivery, but instead require those seeking a product to make some effort to obtain the product, our results suggest caution in extrapolating adoption rates from studies in which surveyors visit households and offer highly subsidized or free products, to predict the impact of scaled programs in which households must expend some effort to obtain a subsidized product. Note that the very high uptake rate of dilute chlorine solution in the *FREE DELIVERY* arm is consistent with the hypothesis that respondents who knew they were unlikely to use chlorine solution might have been reluctant to turning down the free gift since this might be perceived as rude or as signaling a lack of commitment to child health. In order to reduce the possibility of experimenter demand effects, it may be better to assess demand for products by examining whether households redeem coupons for products since this does not involve an enumerator directly observing the action of the survey respondent.

A voucher-based subsidy for water treatment solution seems potentially scalable. The NGO PATH and the CDC have explored a similar approach of distributing dilute chlorine through antenatal clinics in Malawi (43), and the Tanzania National Voucher Scheme (44) provides a discount voucher for insecticide-treated mosquito nets to pregnant women and parents of young children through health centers. Vouchers could easily be bundled in safe birthing kits, which are an increasingly common intervention, and could also be implemented electronically using mobile phones.

There are several reasons that a voucher program could be appealing, in addition to avoiding wastage. One advantage of this approach is that it facilitates targeting subsidies to particular populations – in this case, households with young children at risk of diarrheal mortality and morbidity. Also, a voucher-based subsidy complement the existing system of social marketing by generating more business for shops that sell dilute chlorine solution, which may encourage shops to carry the product and avoid stockouts. To the extent that this

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approach leads households to continue using chlorine solution after their children have passed the age at which subsidies are provided it may have broader benefits (45). As discussed further in the Supporting Online Material, vouchers also seem to target the poor whereas richer households are more likely to adopt under cost sharing. Insofar as children from poor households may be at highest risk of diarrheal mortality and other outcomes such as stunting, this represents another advantage of free distribution through vouchers. Note also that such a program, if implemented through the health care system (i.e., vouchers distributed during well-baby checkups), would provide at least some increased incentive for households to bring children into clinics.

We note three limitations of this study. First, we do not report on health outcomes. Self-reported diarrhea in the context of a trial through which recipients were provided free water treatment solution may be subject to bias, and collection of observational data on this outcome was beyond the available budget. Second, the volume of water treatment solution offered to participants differed across treatments for logistical reasons. While analysis of sub-groups by time of follow-up data collection indicates that results were not driven by households differentially running out of water treatment solution across arms, it is possible that larger quantities were interpreted as a signal of lower quality. However, this seems unlikely since all groups were given the same information on the importance of treating water with chlorine and on the potency of the product. Finally, while we are able to show that screening with a voucher mechanism eliminates most of the wastage of water treatment solution associated with free delivery, with very little cost in terms of reduced water treatment, due to budget constraints, we could not examine the full space of potential policies. Given the results we found, it would be of considerable intellectual interest for future work to examine a range of non-price mechanisms, a range of prices, and the space combining price and non-price mechanisms in various combinations (for example by requiring households to both travel to a redemption center to redeem vouchers, and to make a payment), as well as the health consequences of the differential patterns of selection of different mechanisms. Because this space is extensive, fully exploring it would likely require multiple studies.

Future work could also formally examine a range of potential underlying mechanisms. For example, the finding that price and non-price mechanisms have different patterns of heterogeneous effects with assets is consistent with the idea that liquidity constraints play a major role, as shown in previous work on mosquito nets (46). By examining a finer range of subsidy levels between 50% and 100% and by more fully examining heterogeneity among households with different levels of assets, it might be possible to test the hypothesis that a substantial fraction of households are severely credit constrained, with zero or extremely limited liquid assets but with access to labor that cannot easily be transformed into liquid assets, and thus that even if the price were as low as a single Kenyan shilling, rates of water treatment would be substantially lower than under free delivery, and thus that it would not be possible to replicate the pattern of selection induced by the non-price mechanism. Future work could also examine hypotheses from psychology that households may seek to avoid the decision making costs associated with making any choice to spend money or that there may be a discontinuity in behavior around a price of zero. Finally, future work could examine the hypothesis that differential social costs of refusing to accept water treatment solution during

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household visits, visits to clinics, and visits to shops induce different patterns of selection of those who will use water treatment solution.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References and Notes

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14. Kenya National Bureau of Statistics (KNBS) and ICF Macro. Kenya Demographic and Health Survey 2008–09. Calverton, Maryland: KNBS and ICF Macro; 2010.
15. Population Services International states that one 150 ml bottle protects a family of six for one month (16). However, Lantagne et al. (17) estimate, based on the assumption that a family of five to six uses 20 L of high-quality water for drinking and cooking per day, that a bottle lasts 50 days.

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22. We wanted to give respondents in the *FREE DELIVERY* group water treatment solution in a non-easily divisible fashion. Given well documented evidence of informal insurance and sharing in networks in the study area (and in fact we do see evidence of sharing in our study, see Table S5 in the Supplementary Online Material), we feared that if people received 12 small bottles at once they would be more likely to share them with others. The only available “big size” bottle was the 500 ml Aquaguard bottle, so we decided to give two of them over a year. The supply was given in the form of two separate 500 mL bottles due to concerns about chlorine degrading over time *(see Lantagne et al., 2011)*. Water treatment solution offered in 500 mL bottles is labeled as Aquaguard in the study area. This product is chemically equivalent to WaterGuard. We could have given three Aquguard bottles, and given only 10 vouchers, to make the two quantities exactly match across groups, but since we planned to do the follow-up within six months anyway, we did not expect the total quantity to be a very important factor.

23. It is plausible that a substantial proportion of the population face liquidity constraints and that they might have bought more water treatment solution in steady state under a policy in which everyone knew in advance that the solution would be available to parents of young children at half price in clinics. However, a separate study conducted in fall 2006 in the study region provides suggestive evidence that take up levels under the cost sharing treatment would have been similar even if households could have purchased the water treatment solution over time. In that study, 210 households received 12 monthly coupons for a 50% subsidy on Waterguard bottles redeemable at local shops (20). The authors report that approximately 10% of the 2520 coupons distributed were redeemed, a rate comparable to, if slightly lower, than the 13.4% purchase rate found in our study. While the two samples were different (our study sampled parents of young children at clinics whereas Kremer at al. (20) had a representative sample), this nevertheless suggests that take up is low even when households are given a month to find the money. This suggests that the *COST SHARING* treatment yields estimates of take-up that are likely not very far from would have been observed had this discount been offered over an extended period.

24. The follow-up survey recorded whether the initial Aquaguard bottle could be seen on the compound. It could be seen with Aquaguard in it in 72.6% of the compounds. 11.5% of recipients declared having given the bottle away to neighbors. See Table S5 in the SOM.

25. The one clinic that served as a redemption point was not located in a market center, so all of the participants recruited at this clinic are included in the group unable to redeem at the nearest market. Omitting this subsample from the analysis does not affect the pattern or statistical significance of the results.

26. Note that policy makers will not want to choose a negative price if households can freely and unobservably dispose of chlorine solution because then people with no valuation of the water treatment solution will nonetheless obtain it to get the subsidy, but will simply throw it away.

27. We cannot rule out the possibility that some of these additional doses delivered were not “wasted”, but were, for example, given to other households, or used after the period of water testing, but since we assume that the policymaker values water treatment in households with children in the age range at greatest risk of diarrheal mortality, and since dilute chlorine solution expires over time, we will treat the policymaker as valuing verified water treatment.

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28. Note that we thus consider the problem of a health planner, who seeks to maximize health gains with a given fiscal expenditure and who does not value the implicit transfer involved in subsidies to inframarginal households. A social planner who valued household income would place at least some value on the implicit transfer to inframarginal households and would thus focus more on the figures including only the cost of wastage. This slightly reduces the cost of moving from COST SHARING to either of these policies, but does not alter the basic conclusions of this analysis.
29. This analysis considers only the cost of the water treatment solution, valued at 20 Kenyan shillings per 150 mL, the price at which WaterGuard is sold in Kenya. See below for a discussion of how the analysis might be affected by considering full delivery costs from implementing different policies at scale.
30. The time cost to recipients of redeeming vouchers is ignored in this analysis. Taking this cost into consideration reduces the cost-effectiveness of the voucher-based screening mechanism slightly, however under reasonable assumptions on the value of time in this setting, the voucher policy remains preferred over a wide range of valuations on health.
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49. Directions to respondents' place of residence were collected at baseline, and GPS coordinates were obtained at the follow-up visit.

50. Whether the participant walked to the clinic is omitted because walking (as opposed to taking public transit) is highly correlated with household wealth, conditional on the distance from home to clinic.

51. The assets included are beds, sofas, tables, chairs, cook stoves, radios, televisions, mobile phones, landline phones, wall clocks, watches, sewing machines, electric irons, and bicycles. The value of the index ranges from zero to thirteen, with a mean of 6.8 that varies by less than 0.01 and is never statistically different, across treatment groups.

52. The Global Enteric Multicenter Study (GEMS) found that pathogens highly susceptible to chlorine treatment accounted for 79% of moderate to severe diarrhea episodes attributable to a specific pathogen in that trial's western Kenyan study site (53). Across study sites, only pathogens susceptible to chlorination (typical enteropathogenic E. coli and heat-stable toxin enteropathogenic E. coli) were significantly associated with subsequent deaths among children aged 0 to 11 months. One susceptible pathogen (E. histolytica) and one non-susceptible pathogen (Cryptosporidum) were associated with deaths among children aged 12–23 months, with approximately equal adjusted odds ratios. This study also found that 56% of child diarrhea deaths across sites occurred prior to one year of age. Taking the results on pathogen-attributable mortality to imply that all diarrheal deaths among children under a year are due to chlorine-susceptible organisms, and that 50% of diarrheal deaths among older children are due to such organisms, the proportion of deaths that could be averted through chlorine use is 78%. Dividing this by the proportion of diarrhea episodes attributed to chlorine-susceptible organisms (79%) suggests that the reduction in deaths due to chlorine use is approximately proportional to the reduction in cases. GEMS data only includes cases of moderate to severe diarrhea, whereas Arnold and Colford (12) consider the reduction in all diarrhea cases. The translation of total averted diarrhea cases to averted child mortality may not be proportional, but given the available evidence, proportionality seems as reasonable an assumption as any.

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Table 1

Take-Up by Treatment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	COST SHARING			***VOUCHERS***			***FREE DELIVERY***
	Purchased at least one bottle at clinic	**Purchased at least two bottles**	**Proportion of five bottles purchased**	**Redeemed at least one voucher**	**Redeemed voucher month before follow-up**	**Proportion of 12 vouchers redeemed**	**Accepted water treatment solution at baseline**
Mean	0.519	0.120	0.134	0.853	0.411	0.398	1.000
Observations	351	351	351	382	350	382	385

Sources: Records from baseline survey (cols 1–3, 7); redemption data collected from participating retailers (cols 4–6).

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Table 2

Positive Chlorine Test at Follow-up (3–5 months after intervention)

	(1)	(2)	(3)
	COST SHARING	***VOUCHERS***	***FREE DELIVERY***
Raw means	0.124 (0.019)	0.345 (0.026)	0.344 (0.026)
Adjusting for baseline controls	0.124 (0.019)	0.329 (0.039)	0.340 (0.039)

Notes: Adjusted differences are computed from coefficients in a linear regression of the outcome (positive chlorine test at follow-up) on treatment indicators, controlling for clinic, recruitment wave, time since interview, and baseline controls shown in Table S1. Standard errors in parentheses.

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Table 3

Take up and Usage by Distance to Redemption Point

	(1)	(2)
	Proportion redeemed voucher month of survey	**Proportion with positive chlorine test**
Vouchers redeemable at nearest market	0.507 (0.060)	0.368 (0.059)
Observations	71	68
Not redeemable at nearest market	0.383 (0.031)	0.331 (0.030)
Observations	253	248
Difference of means	0.124	0.037
P-value, unadjusted difference of means	0.062	0.569
Difference of adjusted means	0.153	0.044
P-value, difference of adjusted means	0.034	0.532

Notes: Standard errors in parentheses. Data is from participants in the *VOUCHERS* treatment whose chlorine use was observed at the follow-up interview (data on location of home is not available for attriters; chlorine test results not available for those without stored water at time of survey). Adjusted differences are computed from coefficients in a linear regression of each outcome on treatment indicators, controlling for clinic, enrollment wave, time since interview, and baseline controls shown in Table S1.

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Table 4

Policy Comparisons

	(1) Additional verified users for 100 doses subsidized (*Nb-Na*)	(2) Additional takers for 100 doses subsidized (*Tb-Ta*)	(3) Doses fully subsidized per marginal user col (1)/ col (2)	(4) Full-dose equivalent for inframarginal users (Table 1 col(3) × 1/2)	(5) Full-dose equivalent subsidy for inframarginal users, per marginal user col (4)/ col (2)	(6) Total additional doses provided per new user col (3) + col (5)	(7) Cost per addi-tional DALY saved, USD*	(8) Cost per addi-tional life saved, USD*
Policy change considered:								
1. Cost-sharing to free delivery	21.5	86.6	4.03	6.70	0.31	4.34	182	5,520
2. Cost-sharing to vouchers	20.5	27.7	1.35	6.70	0.33	1.68	70	2,134
3. Vouchers to free delivery	1.00	58.9	58.9	0	0	58.9	2,475	74,921

Notes: Calculations reflect material cost of water treatment solution only; differences in delivery costs are not included. What we call a dose is a yearly dose (12 bottles of 150mL). At the time of writing the exchange rate is Ksh 103 to USD 1, thus a yearly dose costs 12×20 / 103 = USD 2.33.

* See Supplementary Materials for assumptions used in calculations of costs per DALY and cost per life saved.