Providing Safe Water: Evidence from Randomized Evaluations*

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Each year, 1.6 million children die from diarrheal diseases; unsafe drinking water is a major cause. This paper reviews evidence from randomized trials on domestic water access and quality in developing countries, interpreting the results through a public economics framework. It argues that subsidies for water treatment are likely warranted, while more evidence is needed to assess the case for subsidizing programs to improve access to water. Multiple randomized trials show that water treatment can cost-effectively reduce reported diarrhea. However, many consumers have low willingness to pay for cleaner water, with less than 10% of households purchasing household water treatment under existing retail models. Provision of information on water quality can increase demand, but only modestly. Free point of collection water treatment systems designed to make water treatment convenient, salient, and public, combined with a local promoter, can generate take up of more than 60 percent. The projected cost is as low as $20 per year of life saved, comparable to vaccines. In contrast, the limited existing evidence suggests many consumers are willing to pay for better access to water, but it does not yet demonstrate that this improves health. Randomized impact evaluations have also generated a number of methodological insights, suggesting that: at least in some contexts, merely surveying households can lead them to change their behavior; separately randomizing offer and transaction prices does not yield evidence of sunk cost effects; revealed preference measures of clean water valuation are much lower than contingent valuation estimates; and randomized evaluations can be used to estimate parameters for structural policy simulations.

Keywords: water quality, water quantity, survey effects, revealed preference, cost recovery, field experiments, local public goods

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1 Introduction

Some 1.6 million children die each year from diarrhea and other gastrointestinal diseases for which contaminated drinking water is a leading cause (Wardlaw et al. forthcoming). The sole quantitative environmental target in the United Nations Millennium Development Goals is the call to "reduce by half the proportion of people without sustainable access to safe drinking water." Efforts to meet this goal have translated into increased donor and national government funding for building local public goods like wells and standpipes, yet it is not clear that this is the most effective approach. This paper critically reviews experimental work on the provision of water for domestic use in developing countries, discussing both policy implications and methodological lessons.[1] We focus on rural service provision, on the poorest countries, and on biological, rather than other, sources of contamination, since the intersection of these characteristics accounts for the bulk of the drinking water-related diarrheal disease burden.

Policymakers in many infrastructure sectors typically seek user-financed cost recovery for at least maintenance and recurrent costs of investments. In contrast, policymakers in health have long seen investments in prevention of communicable diseases as warranting public subsidies; vaccines, for example, are provided for free as a matter of course. In this article we seek to reconcile these approaches for the case of rural water supply in developing countries. To do this, we interpret some recent findings

[1] Earlier work reviewed research using non-randomized approaches (Zwane and Kremer 2007). Holla and Kremer (2008) provide a summary of the literature on randomized evaluations related to pricing and access in health and education and Kremer et. al. (2009d) provide a review of randomized evaluations of willingness to pay for water treatment. Cardenas (2009), Pattanayak and Pfaff (2009), and Timmins and Schlenker (2009) provide reviews on related issues. Recent calls for investment in experiments in environmental economics include Greenstone and Gayer (2009), and Bennear and Coglianese (2005).

on randomized trials on water through the lens of standard public finance concepts, drawing a distinction between the findings on water quality and those on convenient access to water.

To the extent that a consumer is a sole beneficiary of consuming a good, standard economic principles suggest setting the price of a good equal to the cost of provision and/or its value in alternative uses. Public finance theory suggests that subsidies may be appropriate to promote use of goods that have positive externalities, such as health externalities from reductions in infectious disease. Redistribution can typically best be accomplished by transferring cash, rather than subsidizing particular goods. If the target of redistribution has limited power within the household, however, there may be a role for subsidizing goods particularly important for their welfare. Young children are most at risk of death from unsafe water, and women and children are typically responsible for most water collection. Households may also be subject to various behavioral biases that prevent them from making decisions that maximize their welfare.

It is important to bear in mind that market failures may create a potential case for government intervention. These must be assessed against the reality that governments too are subject to many failures. Moreover, a case for subsidies is not necessarily a case for subsidies from national or international sources. Decisions by locally-elected authorities may better reflect residents' preferences and weigh competing local priorities than decisions by national authorities or international donors. Hence, in the absence of cross-jurisdictional externalities or a desire to redistribute to people with low weight within a jurisdiction, transfers to local jurisdictions may be more appropriate than programs specifically targeted to water.

We argue below there is strong evidence from randomized evaluations that improved water quality can reduce communicable disease, many consumers do not value the private benefits of water quality enough to purchase it, and the young children who stand to benefit most from clean water do not receive a lot of weight in household decisions on water. There is also suggestive evidence that household decision-making on water is subject to behavioral biases. This creates a strong prima facie case for subsidies, but this must be weighed against problems stemming from government failures. More evidence is needed to gauge the case for increasing national and international funding for reducing the cost of water access, although it is plausible that this is warranted at least in some cases.

Randomized impact evaluations have also provided evidence on the determinants of uptake of water quality improvements and are helping in the design of new approaches to supporting clean water use. Such evaluations have demonstrated that the demand curve for water quality can be shifted outward by providing information and making treatment easy and convenient, as well as by local promotion of on-going use. This evidence may be combined with the finding of low average willingness to pay for water quality to yield new ideas for service delivery. In particular, providing dilute chlorine solution free at the point of water collection, together with a local promoter, can increase take up of water treatment from less than 10 percent to more than 60 percent.

The limited evidence available from randomized studies suggests that consumers realize substantial non-health benefits from convenient access to water and are willing to pay for this. At this point, however, it does not yet demonstrate that increasing access to water without changing its quality reduces diarrhea incidence.

A key challenge for future research will be determining what institutional arrangements can best to promote ongoing provision of water services. Non-experimental studies suggest substantial benefits of private contracting for urban water provision in Argentina (Galiani et al. 2005). Experimental evidence from Kenya suggests that combining contracting out of maintenance with government supervision and outside funding led to better service quality and maintenance outcomes than community-based voluntary arrangements. Evidence from India suggests that political reservations for women at the local level increase spending on water but the evidence from Kenya suggests little effect of efforts to encourage selection of female user committee chairs on quality of water infrastructure maintenance (Kremer et al. 2009b).

Methodologically, randomized evaluations provide evidence that the process of collecting data through surveys can itself affect behavior and that revealed preference estimates of willingness to pay for environmental interventions in developing countries are far smaller than stated preference estimates. Recent work also marries randomized evaluations with structural modeling to provide guidance on the potential impact of alternative policies and social norms.

The remainder of the paper is structured as follows: Section 2 documents that the evidence that increased access to water improves health is still limited. Section 3 discusses the strong evidence that water treatment can cost effectively improve health, but also notes that take up of water quality interventions is highly sensitive to price. Section 4 indicates that personal contact, psychological factors like salience and convenience, and potentially having public information about water treatment can boost take up. Section 5 discusses cost effective and potentially scalable approaches to improving water quality, drawing on the lessons of sections 2, 3, and 4. Section 6 reviews the evidence on the impact of institutional arrangements to support maintenance of water infrastructure, and argues for additional research in this area. Section 7 reviews methodological contributions from randomized evaluations of domestic water interventions. Section 8 concludes.

2 Water quantity

Separately identifying how water quantity and quality affect health is important because different water interventions affect water quality and quantity asymmetrically. For example, adding chlorine to water affects quality but not quantity. On the other hand, providing household connections to municipal water supplies to households that currently use standpipes is likely to have a bigger effect on the convenience of obtaining water, and thus on the quantity of water consumed, than on water quality.

Much of the most convincing non-experimental evidence on the health impact of water and sanitation makes it difficult to separate the impact of quantity and quality (Cutler and Miller 2005; Watson 2006; Galiani et al. 2005; Gamper-Rabindran et al. 2009) because the interventions studied both reduced the cost of collection and improved quality, making it unclear which route of disease transmission matters the most in practice.

In the 1980's and 1990's, non-randomized studies were frequently cited as evidence that water quantity was more important for health impacts than water quality (Esrey 1996, Esrey et al. 1991). Some argued that these results could be explained because increased availability and convenience of water facilitates more frequent washing of hands, dishes, bodies and clothes, thus reducing disease transmission (Esrey

1996, Esrey et al. 1991, Curtis et al. 2000). There is indeed strong evidence that hand washing is important for health.[2] However, it is difficult to asses the causal impact of water quantity on hand washing in the absence of randomized evaluations or other convincing identification. We discuss in section 3 the numerous randomized evaluations that have shown impacts of improved water quality on health.

Although impacts may be heterogeneous across settings, and caution is warranted in drawing general conclusions, the one available randomized evaluation found that increasing the quantity of water while maintaining unchanged quality did not lead to significant health improvements. Deveto et al. (2009) examines provision of piped connections to homes in urban Morocco previously served by public taps. This increased the quantity of water used by the household, but did not improve water quality, since the alternative, chlorinated water from communal taps, was of similar quality to the water received at home.

As part of a planned piped water service extension in Tangiers, Morocco the authors randomly selected half the households eligible for a first connection to receive information about and an offer of credit toward a new connection, and administrative assistance in applying for credit. Take up was 69 percent (as compared to 10 percent in the control group).

The authors compare outcomes of those who received this treatment to those for households in the control group. They find that piped water provision in this urban Moroccan context had few health benefits. There is no evidence for an impact of

[2] A meta-analysis by Curtis and Cairncross (2003) of seven hand washing intervention studies indicates a 50 percent reduction in diarrheal diseases. Rabie and Curtis (2007) report a 24 percent reduction in respiratory infection in a review of eight hand washing interventions. Randomized evidence on this question is provided by several authors (Luby et al. 2004; Khan 1982; Han and Hlaing 1989)

treatment on a subjective ranking of health of the family or on diarrhea in children under age six (though baseline rates were relatively low, with the average child in the control group experiencing 0.27 days of diarrhea in the past week). Households in the treatment group report increasing their frequency of baths and showers: the number of times respondents in the treatment group washed themselves (baths, showers) during the last seven days is 25 percent higher than in the control group. However, hygiene practices that require less water, such as hand washing, were not affected, according to self-reports.

We would not conclude that increased water quantity never yields health benefits. The benefits of increased water quantity may be context specific and require further research to fully understand. In particular, understanding when and how increased access to water leads to more hand washing is a research priority.

Having a piped water connection had substantial private benefits, despite the lack of impacts on self-reported diarrhea, consistent with the evidence that most households which received information and an offer of credit towards a new connection were willing to pay for it. In particular, it saved time, which was used for leisure and social activities. Measures of social integration and overall welfare improved. One year into the program, not only had the encouragement design resulted in high rates of take up in the treatment group, but for these households their average monthly water bill more than doubled, from 73 to 192 Moroccan dirhams (MAD), or US$ 9 to $24 a month (the previous cost came from households who took water from their neighbors). Other authors have also noted evidence of substantial willingness to pay for water quantity in observational studies (see e.g., Whittington 2010).

Its worth noting that the benefits of water quantity may flow particularly to women (Chattopadhyay and Duflo 2004), suggesting a distributional case for distributing water quantity.

In summary, the health impact of water quantity interventions requires further investigation. Increasing availability of water, even leaving quality unchanged, brings major non-health benefits; yet, insofar as these seem unlikely to create externalities beyond the household, let alone cross-jurisdictional externalities, individual households or local governments may be the proper institution for allocating budgets between water and other public goods. There may, however, be a distributional case for national or supranational investments in improving water access as a way of redistributing toward women.

3 Water quality

3.1 Health impacts

A number of randomized evaluations find that improvements in water quality reduced reported diarrhea. One study examines source water quality improvements. Kremer et al. (2009a), estimate that protecting springs reduced fecal contamination as measured by the presence of *E. coli* bacteria by two-thirds in water at the source, but only by 25 percent for water stored at home. This is likely due in large part to recontamination in transport and storage within the household (Wright et al. 2004). Despite the incomplete pass through of the water quality improvement, mothers reported about 25 percent less child diarrhea in the treatment group. The importance of recontamination suggests either treating water at the point of use, close to the time of use, or treating it in a way that provides residual protection, for example with chlorine at a sufficiently high dose to remain at levels that provide disinfection for at least 24 hours.

Household water treatment at the point of use, for example with filtration or chlorine treatment also reduces child diarrhea. The bulk of the evidence suggests that, with take-up rates on the order of 70 percent (achieved via frequent visits and reminders to subjects), household water treatment reduces child diarrhea by 20-40 percent. There are multiple comprehensive reviews of this literature (Clasen et al. 2006; Arnold and Colford 2007; Fewtrell et al. 2005; Waddington and Snilvsteit 2009). Schmidt and Cairncross (2009) question the strength of this literature because the outcome measure in these studies is typically mothers' reports of child diarrhea. Studies with objective outcomes, infrequently measured, would be preferable. However, the extent of reporting bias in treatment groups would have to be very large to explain the reported reductions in diarrhea associated with cleaner water. To the extent that reporting bias lowers estimates of diarrhea in both the treatment and comparison groups, it may in fact make it harder to statistically detect reductions in diarrhea. If the reductions in diarrhea are even a fraction as large as those estimated, water treatment would still be very cost effective.

Because water treatment can be extremely cheap, even a 20-40 percent reduction in diarrhea makes water treatment very cost-effective. To get a sense for how cheap it is to treat water, note that a 1.42 gallon generic bottle of bleach with approximately six percent sodium hypochlorite concentration sold in Wal-Mart for $2.54 as of December 2009 has enough chlorine to treat 163,400 liters of water. This corresponds to a price of $0.00002 per liter of water treated. Actual costs of treatment with chlorine are higher because chlorine used for treatment is normally at lower concentrations and the concentration quality has to be made more consistent. Nonetheless, under the assumptions that chlorination reduces diarrhea by 20-40 %, and that mortality reductions are proportional to reported morbidity reductions, the cost per DALY of chlorine provision using the traditional social marketing approach is under $40[3], well below the benchmark of $100-150 per DALY saved that is typically used in health planning in low income countries.

3.2 Valuation

Despite the evidence of health benefits associated with water quality, a number of papers suggest many households are not willing to pay much for improved water quality. Moreover, there is little evidence that households with young children place substantial additional value on clean water, suggesting low valuation of child health.

Kremer et al. (2009b) exploit exogenous changes in the trade-off that households face when choosing between multiple water sources, some of which are close but contaminated and others of which are further but cleaner using a travel cost model. This variation in the distance / water quality trade-off is generated by the spring protection intervention discussed above that was randomly phased in to almost 200 communities in rural Kenya.[4] They estimate that households' willingness to pay for child health is considerably below the benchmark of $100-150 of DALY saved is typically used in health planning in low income countries.

Kremer et al. (2009a) use randomly assigned discounts to investigate willingness to pay for dilute chlorine. They describe behavior consistent with a low willingness to pay for water treatment and find no evidence of higher valuation among households with

[3] In Zambia, the CDC estimated that the ongoing cost of providing a month's supply of chlorine per family was approximately $0.37 (Lantagne et al. 2007). This translates to a cost per DALY saved of less than $40. Costs are in the same range in Kenya. The retail price is approximately $0.3, but this does not account for marketing and management costs.

[4] Spring protection reduces contamination by sealing off the eye of the spring so that it is no longer vulnerable to surface-water runoff.

vulnerable young children. In a set of impact evaluations that tested both price and non-price interventions to increase take-up of chlorine, households were randomly assigned to either a comparison group or to treatment arms in which they received a free supply of individually-packaged chlorine or coupons for half-priced chlorine that could be redeemed at local shops. Comparison households could buy WaterGuard through normal retail channels, at about $0.30 for a one-month supply (roughly a quarter of the agricultural daily wage).

Although 70-90 percent of households in the study region had heard of the local brand of point-of-use chlorine and roughly 70 percent volunteered that drinking "dirty" water is a cause of diarrhea, only five to ten percent of households reported that their main supply of drinking water was chlorinated prior to the interventions. Almost 60 percent of people used chlorine when a field worker delivered it free to their house. Demand for chlorine with coupons for a 50 percent discount was very similar to that when people had to pay the full price. The point estimate for take-up under the discount coupons treatment suggests a four percentage point increase relative to the comparison group, but this is not statistically significant. This is evidence for very elastic demand going from a zero price to a low positive price and inelastic demand as the price increases further.[5]

Households with young children did not behave differently from other households (*p* value of 0.85 on the test of equality of means). The low willingness to pay for water quality among households with young children could indicate a low valuation of child

[5] The positive price group received coupons while the zero price group received home delivery of chlorine; there is evidence that the requirement to actively redeem coupons may deter some people from taking up the product.

health or lack of full awareness of the grave consequences that diarrhea can have in infants. Either way, it suggests a potential rationale for subsidizing water treatment.

Preliminary results from Dupas and colleagues (in progress) on distribution of chlorine through clinics in Kenya and from Berry et al. (in progress) on distribution of water filters in Ghana also support the general conclusion that willingness to pay for improved water quality is low.

Ashraf et al. (2009) use a two-stage price randomization that enables both measurement of willingness to pay for water treatment and also, under specific assumptions, for testing of whether higher prices induce a sunk-cost effect that leads households who pay more for chlorine to use it more and for whether higher prices screen out households less likely to use the product to treat water in the short run. In a door-to-door marketing campaign, roughly 1000 households in the study were first asked if they wanted to purchase a bottle of dilute chlorine at a randomized *offer price*. If a household agreed to purchase and was able to come up with the cash needed for the transaction, they were then offered an additional randomly assigned discount that determined the *transaction price*. Variation in transaction prices is used to test for a sunk-cost effect that might lead households who actually paid more for chlorine to be more likely to use it, controlling for willingness to pay. Variation in offer prices is used to test for whether higher prices screen out households less likely to use the product in the short run. Approximately two weeks after the marketing campaign, the survey team visited households to test for the presence of chlorine in stored drinking water supplies.

The authors found that many more households are willing to purchase chlorine at low prices. Consistent with other evaluations, Ashraf et al. do not find that charging higher price leads to more effective targeting to those households with higher potential health gains, i.e., households with children under age five or pregnant women.

Ashraf et al. (2009) also find no evidence of a sunk cost effect, finding that the actual transaction price does not affect propensity to use, controlling for offer price. Thus, there is no evidence that the act of paying for a product makes consumers more likely to use it.

Ashraf et al. (2009) find that when the price is lowered, the marginal households induced to buy chlorine are less likely to show chlorine residual in their water two weeks later than households who were willing to buy chlorine at higher prices. The hypothesis that they favor is that these households start using the products for other off-label uses such as cleaning clothes or toilets. They present evidence for this hypothesis drawn from a convenience sample separate from the main study. However, this is somewhat puzzling since, as they note, dilute chlorine sold for water treatment is considerably more expensive per unit of chlorine than commercially available bleach. It is difficult to assess whether and how often dilute chlorine solution sold for water treatment is used for cleaning, since if questions are framed around water treatment, households may feel social pressure to under-report "off-label" use, whereas if questions are framed around home cleanliness, as in Ashraf et al. (2009), there may be social desirability bias to over-report use. The authors present some evidence that households are using the product "off-label" rather than storing the product for later use during disease outbreaks, giving it away for water treatment usage by others, or using the "free sample" to see how they like the taste of treated water. These hypotheses have quite different policy implications, as only the first is "wastage" that might reduce the social value of a program that subsidized the product. Even if diversion to alternative uses is common, because chlorine is very cheap and can have a large impact on health, this is likely to be acceptable from a social welfare perspective if this occurs as a result of a process that increases use of water treatment overall. Assessing the magnitude of off-label use of dilute chlorine may be a useful topic for further research as existing hard data are limited.

Policymakers confronted with this evidence of low valuation of water quality and child health must determine whether subsidies for water quality interventions like chlorination are warranted. If governments or external donors place more value on child health relative to other consumption compared to local households, the lack of valuation for water quality and child health provides a potential rationale for subsidies. Externalities from consumption provide another potential rationale for subsidies in some cases. Although there is no direct evidence on health externalities from water treatment in any of the papers reviewed here, to the extent that consumption reduces disease incidence for the user, it is also likely to reduce disease transmission from the user to others.[6] In that case, subsidizing water quality improvements is likely to be welfare maximizing. In fact, given the externalities combined with the low cost of water disinfectant, negative prices may be optimal.

4 Non-price determinants of clean water adoption

In this section, we review experimental evidence on several non-price variables that could potentially affect household behavior regarding water quality. The emphasis in this section will be on identifying potential mechanisms that could increase uptake of safe water rather than judging their cost effectiveness or scalability. Section 5 discusses potentially scalable models drawing on the lessons of this and previous sections.

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[6] Although we are not aware of direct evidence on the health externalities of water treatment, the mechanism of the spread of water-borne diseases through the feces of infected individuals is well understood. Reduced disease transmission can result in potentially large externality benefits.

4.1 Information on water contamination levels

Several papers suggest that providing households with information about source water quality can change behavior, but that the effects of information are small relative to price and that people may not be responding as Bayesian decision makers rationally processing information. Rather, information may be important because of psychological factors, such as increasing the salience of water contamination.

Jalan and Somanathan (2008) randomly assign households in their urban Indian sample to receive information on whether or not their drinking water had tested positive for fecal contamination. About 42 percent of the study population purified (meaning either filtered, boiled, purchased bottled water or, more rarely, chemically treated) their water at baseline. Among households not purifying their water initially, this information led to an 11 percentage point increase in reported water purification as measured eight weeks after information provision. They also increased water purification expenditures by about $7. Households that initially purified their water but who received information that their water was probably not contaminated (based on tests of untreated water in their household) were not statistically more likely to change their purification behavior than the control group. This finding of an asymmetric response to testing suggests that the channel through which information campaigns work may be salience of some sort rather than Bayesian learning. Bayesian learners would respond to information that their water is safer or cleaner than they thought by reducing expenditure on purification. Of course, one could imagine some initial distribution of priors which would rationalize the results within a Bayesian framework.

Luoto (2009) finds through a randomized controlled trial in Kenya that sharing information on fecal contamination with Kenyan households in a context in which treatment products were provided for free increases water treatment by 8-13 percentage points (or between 12-23 percent of baseline usage rates). The study also suggests that once information on the quality of source water is provided, providing additional information on the quality of water stored in the home has no further impact on take-up.

Further evidence consistent with the idea that psychological factors may be important is provided by Madajewicz et al. (2007) and Tarozzi et al. (2009), who study how people respond to information about water quality in an area of Bangladesh, where wells are frequently contaminated with arsenic. Madajewicz et al. evaluate the effectiveness of providing coarse information about well safety by providing information to a random sample of households about whether their water source has arsenic concentrations above a threshold level. Households informed that their water exceeds this threshold are 37 percentage points more likely to switch sources than control households within one year. They increase their walking time fifteen-fold (about four minutes), on average, in response to the information.

Information does not always lead to improved optimization. In more recent research from Bangladesh following the introduction of a standardized labeling system for arsenic contamination in wells, in which safe sources are labeled green and unsafe sources red, Tarozzi et al. (2009) perform an evaluation in which all subjects receive the coarse information about water safety for all sources around them. Despite this binary labeling, the relationship between arsenic and health is likely to be continuous. In the experiment, a random sub-sample receives additional information about relative safety along a continuous scale. Thus, if households are Bayesian decision makers, continuous information should be more useful. Households far from any uncontaminated well might switch to a well that is just above the cutoff level for being colored red, for example. Similarly, households using a well that is just below the cutoff might switch to a well that is much further below the cutoff. In practice, contrary to this prediction, receiving continuous information does not substantially affect risk perceptions or the likelihood of switching sources. In fact, providing continuous information significantly decreases the impact of the arsenic level on the probability of switching to a new source of drinking water. Additional information leaves people less able to improve their drinking water quality than when they are armed with only coarse information.

4.2 Gain vs. loss framing and other behavioral marketing

Given the evidence above that a simple Bayesian learning story is unlikely to fully explain water treatment and handling behavior, we now turn to evidence on ideas from behavioral economics and psychology. Luoto (2009) provides households a variety of point-of-use water treatment technologies for free in Kenya and then randomly assigned households to receive various promotional strategies to increase use of these products. First, she examines whether emphasizing the gains from water treatment versus the losses from not treating water affected use. There are competing hypotheses in the literature for which framing should bring about the larger response. Prospect theory predicts that loss aversion will cause the loss-framed message to realize a bigger effect on people's choices and behavior (Tversky and Kahneman 1981, Kahneman and Tversky 1979). However, there is evidence that decisions regarding health behaviors respond more to gain-framed messages in some cases and more to loss framings in others (Rothman et al. 1999). The study compares a framing of safe water technologies as increasing health compared to one in which it is framed as both increasing health and avoiding disease. The latter approach increased usage by approximately four to six percentage points, a statistically significant difference.

Luoto (2009) also tests whether a combination of commitment and a visual reminder to treat water changes behavior. A subset of the sample was assigned to make a commitment to treating their water to improve their family's health, and also given a pictorial reminder to treat their water. This increased water treatment by five to eight percentage points, but was significant only in some specifications. A commitment to the interviewer had relatively large effects on households that showed evidence of high discount rates in responses to hypothetical questions about future payoffs.

4.3 Communal versus individual persuasion

Kremer et al. (2009a) provide some evidence that a communal approach in which households are aware of the messages other community members receive is more effective than an individual approach in encouraging treatment of household drinking water with dilute chlorine disinfectant, although differences are limited to the case when households had to pay for the product. Their study tested three variants of a persuasion campaign in which promotional messages targeted to mothers were delivered at either the household level or community level, or both. The treatment was cross-cut with providing subsidized (free) chlorine to households.

The results confirm the importance of price as a key determinant of take-up. When chlorine was subsidized, community messages had no measurable impact on household water treatment. The point estimate of the effect of messaging is actually negative, though statistically insignificant, and very small compared to the main effect (-0.02 as compared to 0.52).

Messages can influence take-up, however, when positive prices are charged. At normal retail prices, treatment of household drinking water with chlorine increased by between three and five percentage points (as measured by testing household drinking water for chlorine) for the community-based and combined scripts in the short run. There was no measurable impact of the household script alone, but community-based messaging, a much cheaper approach to marketing, had a small but positive effect.

None of the promotion scripts had any significant effect on take-up at the medium-run follow-up three to six months after exposure. Considering the short-run nature of the effects and the high cost of marketing during one-on-one conversations during household visits, or even through community-level meetings, such strategies do not appear to hold much promise as cost-effective means of promoting individually packaged retail chlorine take-up at scale.

It is also worth noting that Kremer et al. (2009a) find little evidence for peer effects in take up of chlorine packaged for household use. Using detailed data on conversation frequency and topics collected in the second and fourth survey rounds (of the first phase of the research), they find strong evidence that the distribution of free chlorine marketed as WaterGuard promoted conversations about the product as well as about drinking water more generally and, to a lesser degree, child health. In particular, conversations about WaterGuard were roughly three times more likely to occur if the respondent was a member of a treatment household and slightly more than twice as likely if the other household in a relationship pair was in the treatment group. Although the distribution of free WaterGuard prompted more conversations about the product, the evidence is consistent with the hypothesis of weak social network effects on actual use, with larger impacts on social desirability bias. They find statistically and economically significant effects of peer exposure on self-reported chlorination but point estimates that are much smaller and not generally statistically significant using positive chlorine tests in home drinking water.

Personal contact more generally has been previously identified as important to behavior change and adoptions decisions (DellaVigna and Gentzkow 2009, Manandhar et al. 2004). Biweekly monitoring (BWM, discussed further below, suggests that contact with an enumerator can boost take up of water products (Kremer et al. 2009c). Personal contact may also have played a role in achieving high levels of take-up in the evaluation of the water quantity intervention described in section 2.1 (Deveto et al. 2009).

5 Potentially scalable approaches to improving water quality

This section discusses potential low-cost, scalable models for water treatment based on the findings summarized in sections 2, 3 and 4.

Section two indicates that households are willing to pay for convenient access to water, while section three suggests limited willingness to pay for water treatment. It is thus unsurprising that most households which use treated water use piped municipally treated water, in which water quality is bundled with water quantity. We are unaware of randomized evaluations of municipal treatment, but well-identified non-randomized studies by Cutler and Miller (2005) find large health benefits from water treatment in the United States, and Galiani et al. (2005) find major health benefits from extension of municipal water in Argentina.

In rural areas of low-income countries with dispersed populations, piped water is likely to be too costly to adopt for some time. Dupas et al. (in process) and Kremer et al.

(2009a) developed and tested two alternative approaches to providing clean water when networked supply is infeasible, both involving free distribution.

Dupas et al. (in process) provide coupons for dilute chlorine solution to mothers who bring children to vaccination clinics sufficient to cover water supplies for the 12 months until children reach approximately age two. Mothers are told how and where to redeem coupons and urged to treat water for their children during a vulnerable stage of their life. At an unannounced follow-up visit three to four months later, among those who were offered a 50 percent discount on immediate purchase of a month's supply of chlorine, less than 15 percent had detectable chlorine in their water. This can be compared to almost 40 percent of those who were given a year's supply either directly or through coupons redeemable at local shops. Another group of mothers, given just one month's free supply, had a usage rate of just over 20 percent at follow-up.

Kremer et al. (2009a) examine free provision of dilute chlorine via a point-of-collection system, which includes a container to dispense the product placed at the water source, a local promoter to encourage its use, and free provision of a supply of chlorine solution packed in bulk. This bulk supply dramatically reduces delivery costs relative to the retail approach that requires packaging chlorine in small bottles and relative to door to door distribution, which in addition significantly raises marketing costs; hence, bulk distribution to water sources makes free provision more realistic. Additionally, this delivery method also makes chlorine use very convenient. Users can treat drinking water when they collect it. The required agitation and wait time for chlorine treated water are at least partially accomplished automatically during the walk home from the source.

The source-based dilute chlorine disinfection approach to water treatment makes this act salient and public, in addition to making it cheaper and more convenient. The dispenser provides a daily visual reminder to households to treat their water at the moment when it is most salient – as water is collected – and maximizes the potential for learning, norm formation, and social network effects by making the dispenser public. Potential users can see others who use the dispenser and have the opportunity to ask questions; they also will know that others will see whether they use the dispenser.

Take-up of chlorine provided through dispensers dramatically exceeded take-up of chlorine for treating water for in-home use. When communities were randomly assigned to treatment with a promoter and a community dispenser, take up was about 40 percent in the short run (three weeks) but had climbed to over 60 percent by the medium term (three to six months), representing 37 and 53 percentage point gains respectively over the control group. In contrast to the take-up levels achieved with the dispensers, the clinic-based coupon distribution approach proved initially promising, but resulted in much lower coupon redemption over time. Over 40 percent of households who were given coupons redeemed them eight months into the program in that sample, but this fell to 20 percent by 12 months. This suggests that the success of the dispenser is not due only to the zero price, but also to the reduction in the psychic cost of remembering to treat water that is achieved by source-based treatment as well as other attributes, like the visual reminders. Although take-up rates are slightly lower than those achieved in medical trials, the dispenser system relies far less on outside personal contact (e.g. from repeated household visits from enumerators) than do approaches used in medical trials; hence, costs are significantly lower.

The chlorine dispenser is extremely cost-effective, with a cost per DALY saved that could be as low as $20 at scale. A study by the Abdul Lateef Jameel Poverty Action Lab suggests that this is the most cost -effective of a range of low-cost approaches to reducing diarrhea (Dhaliwal and Tulloch 2009). The success of the chlorine dispensers at the proof of concept stage described here suggests that exploring how to scale up this approach to water treatment warrants further attention in its own right. It also suggests the potential for other point-of-collection approaches, such as inline chlorination, to improve health at low cost; such approaches also warrant further investigation. An important challenge for the future for point-of collection approaches will be to determine how best to handle the supply side under free provision and in particular how to scale supply chain management.[7]

6 Maintenance

Many water interventions require significant investments in infrastructure. This is particularly true of water quantity investments, whether bundled with water quality improvements or not; while some water quality investments require virtually no investment in infrastructure (for example, leaving water in the sun or the addition of chlorine) others require hardware (for example spring protection). Along with infrastructure investments comes the challenge of maintenance, which has historically been a major problem in developing countries.

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[7] One issue that will have to be assessed is whether there is substantial diversion of dilute chlorine to other uses. This is difficult to assess given the potential for social desirability bias but the evidence from the coupon program suggests that households are not inclined to exert that much effort to obtain chlorine if they are not going to use it. However, rates of coupon redemption and household chlorination appear similar. Moreover, since the dispenser releases only 3 ml of liquid with each turn, collecting sufficient quantities for use in cleaning would be difficult. There have not been reports of dispensers being emptied of chlorine solution, as would likely be the case if people were collecting solution to use for cleaning.

The rural water sector in particular has a poor track record of maintaining infrastructure investments. For instance, a quarter of India's water infrastructure is believed to be in need of repair (Ray 2004). *World Development Report 2004* (World Bank 2003) estimates that more than a third of rural water infrastructure in South Asia is not functional. Miguel and Gugerty (2005) report that nearly 50 percent of borehole wells dug in a large project in western Kenya the 1980s, and subsequently maintained using a community-based maintenance model, had fallen into disrepair by 2000. Difficulties with maintaining water infrastructure, particularly in rural areas, reduce the cost-effectiveness of these interventions relative to other measures that prevent diarrhea.

Two options are frequently mentioned as potential elements of a solution to this infrastructure challenge: empowering women to manage water resources and including communities in participatory management schemes.

Chattopadhyay and Duflo (2004) find that a randomized policy change in India that increased the role of women in policy decision making led to more investment in water infrastructure. A 1993 constitutional amendment called for one-third of village council leader positions to be reserved for women. Rules ensured random assignment of the leadership reservations. Chattopadhyay and Duflo show that village councils headed by women were significantly more likely to invest in public infrastructure for drinking water.

Kremer et al. (2008) provide evidence from a randomized field experiment in Kenya that enhanced women's involvement in infrastructure management did not lead to better maintenance of water supplies. This evaluation studies the impact of female affirmative action policies on actual management outcomes relevant for protected springs (e.g., time since storm drains or drainage trenches were cleaned). When protected springs were provided to 100 communities in rural Kenya, all communities formed water user committees. Additionally, one-half of the communities received messages encouraging women to take leadership roles in their water user committees. Communities that received the female participation intervention were significantly more likely to have women members and twice as likely to have a woman in the role of water committee chair. However, this did not lead to differences in the effectiveness of the user committees' spring management as measured by the maintenance outcome variables. Thus, the authors conclude that advocacy for female participation can increase women's involvement without any impact (either positive of negative) on project outcomes. This has a positive interpretation: empowerment goals can be met without costs to project outcomes, as well as a more negative one: including women in management cannot alone solve the water infrastructure maintenance challenge, even if these investments are priorities for women.

In addition to increasing women's participation and decision-making power, another standard model for maintaining donor-funded infrastructure projects is to establish user groups who are responsible for maintenance and management. This approach grew out of the widespread perception that centralized government maintenance was unsuccessful. Giving communities direct control or ownership over key project decisions was intended to improve the quality of public services and increase financial sustainability.

There is little convincing empirical evidence, however, that local user-committee management of local public goods such as improved drinking water sources results in better quality service than other models relying on ongoing centralized funding from public budgets. Collective action problems may be difficult to overcome, and voluntary committees tasked with collecting user fees may be difficult to sustain or empower. In a recent comprehensive review of community-based development projects, Mansuri and Rao (2004) note that existing research examining "successful" community-based projects does not compare these projects with centralized mechanisms for service delivery or infrastructure maintenance (for example, city or state financed). This makes it difficult to determine whether alternative project designs would have had different results.

The limited empirical evidence suggests the impact of the community-based development approach on infrastructure maintenance is mixed at best. In addition to randomly assigning the gender empowerment encouragement intervention, in the same study as described above, the NGO randomly assigned communities to contracted maintenance and community-based management schemes. Kremer et al. (2008) compare payments to private contractors for spring maintenance and ongoing grants to user committees, with the outcomes of a control group, in which user committees received no grants. The traditional model, user committees without grants, performed worse than either alternative across a range of maintenance outcomes. Providing grants to user committees improved a measure of overall water source maintenance quality by around 30 percent of one standard deviation on average, while paying contractors to maintain water sources and monitoring these contractors led to an average improvement in measured maintenance quality of around 50 percent of one standard deviation. This difference is significant at the ten percent level.

This evidence from maintenance of spring protection, a relatively simple technology that seems favorable to community-based management, suggests that contracting for private maintenance service may be a promising alternative to committee-based management schemes. Non-experimental evidence from Argentina (Galiani et al. 2005) also suggests that contracted private provision of service can expand coverage and improve health outcomes as compared to government service provision in at least certain settings in middle-income countries. Certainly, further research is needed that transparently compares direct and contracted subsidized public service provision and community-based management schemes.

7 Methods and theory: Contributions of randomized evaluations of domestic water interventions

The evaluations surveyed in this paper have provided policy guidance on several questions related to health, technology adoption, and pricing regimes. The work has also made a number of methodological contributions that are of broader interest in resource economics. We review these contributions in this section.

7.1 Survey effects

A recent randomized evaluation of a water quality intervention provides evidence that the act of surveying can affect behavior in ways that can interfere with estimates of treatment effects, a result with broader implications.

Many studies measure child diarrhea through reports by mothers of young children in high-frequency household visits. Kremer et al. (2009c) provide evidence that frequent collection of self-reported diarrhea data through repeated interviews leads to health protective behavior change in addition to respondent fatigue and social desirability bias. As part of a larger study of the impact of spring protection, rural Kenyan households were randomly assigned to be interviewed about diarrhea either every two weeks or every six months. The authors also find that frequent data collection leads to lower reports of child diarrhea by mothers relative to infrequent surveying and also to higher rates of chlorination verified by tests for chlorine in water. They also show that in many published studies of diarrhea prevalence falls over time, in the absence of interventions consistent with the hypothesis that surveying itself affects reporting and behavior. These effects are sufficiently large as to change the conclusions about the effectiveness of the water quality intervention being studied, spring protection.

The potential for survey effects implies that researchers relying on both self-reported or otherwise subjective data and objective data to measure outcomes should consider designing data collection strategies that minimize interaction with subjects. For example, outcome data could be collected via administrative records maintained at clinics or schools. Purchases or collection of products from central locations can also be tracked without direct interaction with subjects.

In the particular case of the literature on water, sanitation, and hygiene, survey effects concerns imply that more research is needed that does not measure impacts via subjective reports of diarrhea. Researchers in this field should expand their data collection strategies to emphasize other health outcomes that can be measured objectively and infrequently. This will likely require larger sample sizes to detect small treatment effects (e.g., on stunting, cognition, and ultimately mortality) and longer study times, which funding will need to accommodate.

7.2 Valuation: revealed preference versus contingent valuation

Contingent valuation relies on stated preference data from hypothetical situations to identify the price that households would be willing to pay. Randomized pricing experiments enable analysis based on actual choices and address omitted variable bias, thus dealing with the main concerns of both CV and non-experimental discrete choice data. This method also has the potential to enable examination of the allocative role of prices in targeting populations of interest and the isolation of specific channels of causality for effects of prices on demand.

Kremer et al. (2009b) use an experiment in which springs are randomly assigned to protection to estimate a revealed preference model of demand for clean water from source quality improvements. Since water quality improvements are randomly assigned, they can use a travel cost approach that measures the number of trips made to the improved source relative to an unimproved source at a different distance. Random assignment allows them to exploit exogenous changes in the trade-off that households face when choosing between multiple water sources, some of which are close but contaminated and others of which are far but clean. They then contrast this revealed preference estimate of willingness to pay for spring protection with two different stated preference methodologies: stated ranking of alternative water sources, and CV. They find that the stated preference approaches generate much higher valuation estimates than randomized pricing evaluations, by a factor of three. The survey approaches also exhibit much greater dispersion and considerable sensitivity to question framing, casting doubt on the reliability of stated preference methods (Whittington 2010).

7.3 Combining randomized evaluations with structural modeling

Several recent papers combine data from randomized experiments with structural econometric methods in development economics (e.g., Todd and Wolpin 2006). Kremer et al. (2009b) combine experimental results with a structural model of water infrastructure investment to explore the implications of alternative property rights institutions on social welfare and assess the welfare impacts of alternative institutions governing water property rights. Using the valuation results discussed earlier as inputs into policy simulations, the authors compare the welfare impacts of alternative social norms regarding property rights. A hypothetical case of pure privatization, for example, in which landowners could restrict access to the spring and charge for water, results in relatively little investment in environmental protection (i.e., spring protection) since households' willingness to pay for cleaner water is low, but leads to large static losses since landowners can extract consumer surplus by charging for even unprotected spring water even though the marginal cost of provision is zero. They conclude that at low income levels common property likely yields greater social welfare than private property, but that private property would yield higher social welfare at higher income levels or under water scarcity. They also argue that government investment or a voucher arrangement under which private landowners are compensated for their investment in environmental protection can improve social welfare and approximate the solution that would be chosen by public investment or a government-financed voucher system for spring users could approximate the solution for either a social planner who respects households' spring protection valuations or a paternalistic social planner who places extra value on child health.

8 Conclusion

As noted in the introduction, the sole quantifiable environmental goal selected by the United Nations as part of the United Nations Millennium Development Goals is to reduce by half the proportion of people without sustainable access to safe drinking water. Public finance theory suggests that a case for subsidies in the presence of disease externalities when goods benefit household members that are not well-represented in household decision-making processes, and perhaps when decision-making is subject to behavioral biases. Randomized evaluations suggest all three factors may be at play for water treatment to reduce microbiological contamination. Since investments in water treatment are extremely cost effective relative to other expenditures for prevention of communicable disease, even expenditures such as vaccination. There seems a strong case for zero prices or even negative prices for water treatment. These differences between the effects and demand for water quantity versus water quality interventions may also contribute to the difference in funding strategies followed by the water sector, which typically relies on significant community and individual contributions toward programs, versus by the health sector, where free distribution of products and services is more often the norm.

This paper also surveys evidence from randomized evaluations on strategies to drive take-up of water treatment products. Free, convenient, salient, and public provision of chlorinated water at the point of collection, together with local promotion efforts, can boost take up. Take-up of chlorination via communal chlorine dispensers (Kremer et al. 2009a) is between 60 to 70 percent and reduces costs relative to individually-packaged bottles. The feasibility of this approach depends on the ability to solve the challenge of refilling and servicing. A number of technological approaches can be considered, including inline chlorination and chlorine dispensers.

Further work to evaluate the health and non-health impacts of improved access to water is warranted, in particular to identify circumstances under which improved water access can promote handwashing, which has been shown to generate major health benefits. The design of institutional arrangements that facilitate infrastructure maintenance also remains an important area for further investigation.

The methodological lessons from the research on water investments and valuation reviewed here have broad relevance. They can inform study design on scale up of alternative approaches to water treatment as well as future experiments on a range of issues in resource economics.

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