Providing Safe Water: Evidence from Randomized Evaluations

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Annu. Rev. Resour. Econ. 2010. 2:237–56

The *Annual Review of Resource Economics* is online at resource.annualreviews.org

This article's doi: 10.1146/annurev.resource.012809.103919

1941-1340/10/1010-0237$20.00

Key Words

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

Abstract

This paper uses a public economics framework to review evidence from randomized trials on domestic water access and quality in developing countries and to assess the case for subsidies. Water treatment can cost-effectively reduce reported diarrhea. However, many consumers have low willingness to pay for cleaner water; few households purchase household water treatment under retail models. Free point-of-collection water treatment systems designed to make water treatment convenient and salient can generate take-up of approximately 60% at a projected cost as low as $20 per year of life saved, comparable to vaccine costs. In contrast, the limited existing evidence suggests that many consumers value better access to water, but it does not yet demonstrate that better access improves health. The randomized impact evaluations reviewed have also generated methodological insights on a range of topics, including (*a*) the role of survey effects in health data collection, (*b*) methods to test for sunk-cost effects, (*c*) divergence in revealed preference and stated preference valuation measures, and (*d*) parameter estimation for structural policy simulations.

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. 2009). 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" (**http://www.un.org/millenniumgoals/**). 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 because the intersection of these characteristics accounts for the bulk of the drinking water–related diarrheal disease burden.

Policy makers in many infrastructure sectors typically seek user-financed cost recovery for at least maintenance and recurrent costs of investments. In contrast, policy makers in health have long seen investments in the 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 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 the good's value in alternative uses. Public finance theory suggests that subsidies may be appropriate to promote the 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 the household's 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.

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 reflect residents' preferences and weigh competing local priorities better 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.

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

We argue below that 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 such funding increases are 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 support 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 locally promoting ongoing 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% to approximately 60%.

The limited evidence available from randomized studies suggests that consumers realize substantial nonhealth benefits from, and are willing to pay for, convenient access to water. At this point, however, the evidence 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 promote ongoing provision of water services. Nonexperimental 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 leads to better service quality and maintenance outcomes than do 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. 2009a).

Methodologically, randomized evaluations provide evidence that the process of collecting data through surveys can 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. However, this section 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 the 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 the article.

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. In contrast, 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 nonexperimental evidence on the health impact of water and sanitation makes it difficult to separate the impact of quantity and quality (Cutler & Miller 2005, Galiani et al. 2005, Watson 2006, Gamper-Rabindran et al. 2010) 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 1980s and 1990s, nonrandomized studies were frequently cited as evidence that water quantity was more important for health impacts than was water quality (Esrey et al. 1991, Esrey 1996). Some researchers argued that these results could be explained because increased availability and convenience of water facilitate more frequent washing of hands, dishes, bodies, and clothes, thus reducing disease transmission (Esrey et al. 1991, Esrey 1996, Curtis et al. 2000). There is indeed strong evidence that hand washing is important for health.[2] However, it is difficult to assess 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 finds 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, because 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, these authors randomly selected half the households eligible for a first connection to receive (*a*) information about and an offer of credit toward a new connection and (*b*) administrative assistance in applying for credit. Take-up was 69% (compared with 10% in the control group).

These researchers compare outcomes of those who received this treatment with outcomes 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 treatment on a subjective ranking of health of the family or on diarrhea in children under age six (although baseline rates were relatively low, with the average child in the control

[2]A meta-analysis by Curtis & Cairncross (2003) of seven hand-washing intervention studies indicates a 50% reduction in diarrheal diseases. Rabie & Curtis (2007) report a 24% reduction in respiratory infection in a review of eight hand-washing interventions. Several authors (Khan 1982, Han & Hlaing 1989, Luby et al. 2004) provide randomized evidence on this question.

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 that respondents in the treatment group washed themselves (through baths or showers) during the past seven days is 25% 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.

In the study by Deveto et al. (2009), having a piped water connection had substantial private benefits, despite the lack of impact on self-reported diarrhea, consistent with the evidence that most households that received information and an offer of credit toward a new connection were willing to pay for it. In particular, a piped water connection 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 did the encouragement design result 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 that took water from their neighbors). Other authors also note evidence of substantial willingness to pay for water quantity in observational studies (see, e.g., Whittington 2010). The benefits of water quantity may flow particularly to women (Chattopadhyay & 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 nonhealth benefits. Yet insofar as these benefits 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 be, however, a distributional case for national or supranational investments in improving water access as a way of redistributing resources 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. (2009c) estimate that protecting springs reduced fecal contamination, as measured by the presence of *Escherichia coli* bacteria, by two-thirds for water at the source but by only 25% 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 approximately 25% less child diarrhea in the treatment group. The importance of recontamination suggests either to treat water at the point of use, close to the time of use, or to treat water 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 h.

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% (achieved via frequent visits and reminders to subjects), household water treatment reduces child diarrhea by 20–40%. There are multiple comprehensive reviews of this literature (Fewtrell et al. 2005, Clasen et al. 2006, Arnold & Colford 2007, Waddington & Snilstveit 2009). Schmidt & 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 the comparison groups, such bias may make it harder to statistically detect reductions in diarrhea. If the reductions in diarrhea were 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% reduction in diarrhea makes water treatment extremely cost-effective. To get a sense for how cheap it is to treat water, a 1.42-gallon generic bottle of bleach with approximately 6% sodium hypochlorite concentration sold at Walmart 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 (disability-adjusted life year) of chlorine provision using the traditional social marketing approach is less than $40,[3] considerably less than 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 that 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.

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

[3]The Centers for Disease Control (CDC) estimated that in Zambia 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 $0.30, but this price 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.

Kremer et al. (2009c) 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 vulnerable young children. In a set of impact evaluations that tested both price and nonprice interventions to increase take-up of chlorine, households were randomly assigned either to 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, the name brand for point-of-use chlorine marketed by Population Services International (PSI), through normal retail channels at approximately $0.30 for a one-month supply (roughly a quarter of the agricultural daily wage).

Although 70–90% of households in the study region had heard of the local brand of point-of-use chlorine and roughly 70% volunteered that drinking "dirty" water is a cause of diarrhea, only 5–10% percent of households reported that their main supply of drinking water was chlorinated prior to the interventions. Almost 60% of people used chlorine when a field worker delivered it free to their houses. Demand for chlorine with coupons for a 50% discount was very similar to that when people had to pay the full price. The point estimate for take-up under the discount coupon treatment suggests a four-percentage-point increase relative to the comparison group, but this increase 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] An unpublished paper by P. Dupas, V. Hoffmann, M. Kremer & A. Zwane on the distribution of chlorine through clinics in Kenya also finds that willingness to pay for improved water quality is low. Results reported by Berry et al. (2008) on the distribution of water filters in Ghana also support this general conclusion.

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 may indicate a low valuation of child health or a 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.

Ashraf et al. (2009) use a two-stage price randomization that enables (*a*) measurement of willingness to pay for water treatment and, under specific assumptions, (*b*) testing of whether higher prices induce a sunk-cost effect that leads households who pay more for chlorine to use it more and of 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 1,000 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, the household was 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 may 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

[5]The positive-price group received coupons, whereas 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.

marketing campaign, the survey team visited households to test for the presence of chlorine in stored drinking water supplies.

Ashraf et al. (2009) find that many more households are willing to purchase chlorine at low prices. Consistent with other evaluations, these researchers do not find that charging higher prices leads to more effective targeting of those households with higher potential health gains, i.e., households with children under age five or pregnant women.

Ashraf et al. (2009) also do not find 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.

Additionally, Ashraf et al. (2009) find that when the price is lowered, the marginal households that were induced to buy chlorine are less likely to show chlorine residual in their water two weeks later than households that were willing to buy chlorine at higher prices. The hypothesis that Ashraf et al. favor is that these households start using the products for other off-label uses such as cleaning clothes or toilets. They draw evidence for this hypothesis from a convenience sample separate from the main study. However, this hypothesis is somewhat puzzling because, 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, because if questions are framed around water treatment, households may feel social pressure to underreport off-label use. In contrast, if questions are framed around home cleanliness, as in Ashraf et al. (2009), there may be social desirability bias to overreport 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 may 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, such diversion is likely to be acceptable from a social welfare perspective if it occurs as a result of a process that increases the 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.

Policy makers 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 than do 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, consumption 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.

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

4. NONPRICE DETERMINANTS OF CLEAN WATER ADOPTION

In this section, we review experimental evidence on several nonprice variables that may potentially affect household behavior regarding water quality. The emphasis in this section is on identifying potential mechanisms that may increase uptake of safe water rather than judging their cost-effectiveness or potential for scale as a program. Section 5 discusses potentially scalable models, drawing on the lessons of this and previous sections.

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 changes in the price of water treatment mechanisms 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 increased salience of water contamination.

Jalan & Somanathan (2008) randomly assign households in their urban Indian sample to receive information on whether their drinking water tested positive for fecal contamination. Approximately 42% of the study population purified their water at baseline (where purified water means filtered water, boiled water, purchased bottled water, or, more rarely, chemically treated water). 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. Those households also increased water purification expenditures by approximately $7 per year. Households that initially purified their water but that received information that their water was probably not contaminated (on the basis of tests of untreated water in their households) were not statistically more likely than the control group to change their purification behavior. 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 that 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% and 23% 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 and colleagues (A. Tarozzi, S. Balasubramanya, L.S. Bennear & A. Pfaff, unpublished working paper), 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 offering 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 than control households to switch sources within one

year. The former households increase their walking time 15-fold (approximately 4 min) 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 and colleagues (A. Tarozzi, S. Balasubramanya, L.S. Bennear & A. Pfaff, unpublished working paper) 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 subsample 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 may 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 may 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-Versus-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 with a variety of point-of-use water treatment technologies for free in Kenya and then randomly assigns 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 have a bigger effect on people's choices and behavior (Kahneman & Tversky 1979, Tversky & Kahneman 1981). 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). Luoto (2009) compares framing of safe water technologies as increasing health with framing of such technologies 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. Some households within the sample were assigned to make a commitment to treating their water to improve their family's health and were also given a pictorial reminder to treat their water. This increased water treatment by five to eight percentage points, but this increase was significant in only 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. (2009c) 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. However, differences are limited to the case in which 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 the household level, the 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, although statistically insignificant, and very small compared with the main effect (−0.02 compared with 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. If one considers 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.

Moreover, Kremer et al. (2009c) 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 to occur 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. Using self reported chlorine use as a measure of treatment for home drinking water, Kremer et al. find statistically and economically significant effects of peer exposure on chlorination. Through use of chlorine tests, an objective measure, point estimates are much smaller and generally not statistically significant.

Personal contact more generally is important to behavior change and adoption decisions (Manandhar et al. 2004, DellaVigna & Gentzkow 2010). Biweekly monitoring, discussed further below, suggests that contact with an enumerator can boost take-up of water products (Kremer et al. 2009d). 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 (Deveto et al. 2009).

5. POTENTIALLY SCALABLE APPROACHES TO IMPROVING WATER QUALITY

This section discusses potential low-cost, scalable models for water treatment on the basis of the findings summarized in Sections 2, 3 and 4. Section 2 indicates that households are willing to pay for convenient access to water, whereas Section 3 suggests limited willingness to pay for water treatment. It is thus unsurprising that most households that 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 nonrandomized studies by Cutler & Miller (2005) find large health benefits from water treatment in the United States, and Galiani et al. (2005) find major health benefits from the 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. Two groups of authors have developed and tested alternative approaches to providing clean water when networked supply is infeasible, both involving free distribution.

P. Dupas, V. Hoffmann, M. Kremer & A. Zwane, in an unpublished paper, report the provision of coupons for dilute chlorine solution to mothers who bring children to vaccination clinics. These coupons are 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 are urged to treat water for their children during this vulnerable stage of their life. At an unannounced follow-up visit three to four months later, among those who were offered a 50% discount on immediate purchase of a month's supply of chlorine, less than 15% had detectable chlorine in their water. This can be compared with the almost 40% of those who were given a year's supply of free chlorine 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 slightly more than 20% at follow-up.

Kremer et al. (2009c) 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 the product's 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, which 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 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 they have the opportunity to ask questions; they will also 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 approximately 40% in the short run (three weeks) but climbed to more than 60% 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. More than 40% of households that were given coupons redeemed them 8 months into the program, but this figure fell to 20% by 12 months. This finding suggests that the success of the dispenser is due not 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 may be as low as $20 at scale. A study by the Abdul Lateef Jameel Poverty Action Lab at the Massachusetts Institute of Technology suggests that this is the most cost-effective of a range of low-cost approaches to reducing diarrhea (Dhaliwal & 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. It also suggests the potential for and the need to investigate other point-of-collection approaches, such as in-line chlorination, to improve health at low cost. An important challenge 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. Whereas some water quality investments (for example, leaving out water in the sun or adding chlorine) require virtually no investment in infrastructure, others (for example, spring protection) require hardware. Along with infrastructure investments comes the challenge of maintenance, which has historically been a major problem in developing countries.

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 & Gugerty (2005) report that nearly 50% of borehole wells dug in a large project

[7]One issue to assess 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, because 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.

in western Kenya in 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 frequently mentioned as potential elements of a solution to this infrastructure challenge are (*a*) empowering women to manage water resources and (*b*) including communities in participatory management schemes. Chattopadhyay & 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 & 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 or negative) on project outcomes. This has a positive interpretation: Empowerment goals can be met without costs to project outcomes. However, there is also a more negative interpretation: Including women in management cannot alone solve the water infrastructure maintenance challenge, even if these investments are priorities for women.

In addition to models increasing women's participation and decision-making power, another standard model for maintaining donor-funded infrastructure projects is to establish user groups that 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 to 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 & 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 services). This makes it difficult to determine whether alternative project designs would have had different results.

The limited empirical evidence suggests that the impact of the community-based development approach on infrastructure maintenance is mixed at best. In the same study described above (Kremer et al. 2008), in addition to randomly assigning the gender empowerment encouragement intervention, the nongovernmental organization randomly assigned communities to contracted maintenance and community-based management schemes. Kremer et al. (2008) compare outcomes of (*a*) a group in which private contractors were paid for spring maintenance, (*b*) a group in which user committees received ongoing grants, and (*c*) a control group in which user committees received no grants. The traditional model (*c*), user committees without grants, performed worse than either alternative (*a* or *b*) across a range of maintenance outcomes. Providing grants to user committees improved a measure of overall water source maintenance quality by approximately 30% of one standard deviation on average, whereas paying contractors to maintain water sources and monitoring these contractors led to an average improvement in measured maintenance quality of approximately 50% of one standard deviation. This difference is significant at the 10% level.

This evidence from the 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. Nonexperimental evidence from Argentina (Galiani et al. 2005) also suggests that contracted private provision of service can expand coverage and improve health outcomes compared with 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. This result has broader implications.

Many studies measure child diarrhea through reports by mothers of young children in high-frequency household visits. Kremer et al. (2009d) 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 (as 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 affects reporting and behavior. These effects are sufficiently large to change the conclusions about the effectiveness of spring protection as a water quality intervention.

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 could also be tracked without direct interaction with subjects.

In the particular case of the literature on water, sanitation, and hygiene, survey effect concerns imply that more research that does not measure impacts via subjective reports of diarrhea is needed. 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 both larger sample sizes to detect small treatment effects (e.g., on stunting, cognition, and ultimately mortality) as well as 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 on the basis of actual choices and address omitted variable bias, thus dealing with the main concerns of both contingent valuation and nonexperimental 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. (2009a) conduct 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. Because water quality improvements are randomly assigned, these researchers 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. Kremer et al. 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 contingent valuation. These researchers find that the stated preference approaches generate higher valuation estimates than do 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). However, the qualitative guidance given by stated ranking and revealed preference estimates appears to be consistent.

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 & Wolpin 2006). Kremer et al. (2009a) combine experimental results with a structural model of water infrastructure investment to

explore the implications of alternative property rights institutions on social welfare and to assess the welfare impacts of alternative institutions governing water property rights. Using the valuation results discussed above as inputs into policy simulations, the authors compare the welfare impacts of alternative social norms regarding property rights. For example, a hypothetical case of pure privatization 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) because households' willingness to pay for cleaner water is low. However, under this hypothetical case, large static losses result because landowners can extract consumer surplus by charging for even unprotected spring water, although the marginal cost of provision is zero. Kremer et al. conclude that at lower income levels common property likely yields greater social welfare than does private property but that private property yields higher social welfare at higher income levels or under water scarcity. Kremer et al. 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. Additionally, a government-financed voucher system for spring users can 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 its Millennium Development Goals is to reduce by half the proportion of people without sustainable access to safe drinking water. Public finance theory suggests 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 of these factors, externalities, intra-household inequities, and behavioral biases, may be at play for water treatment to reduce microbiological contamination. 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 of the water sector, which typically relies on significant community and individual contributions toward programs, and the strategies of the health sector, for which 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. 2009c) is approximately 60% 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, including in-line chlorination and chlorine dispensers, might be considered.

Further work to evaluate the health and nonhealth impacts of improved access to water is warranted, in particular to identify circumstances under which improved water access

can promote hand washing, which generates 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.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

This paper builds on other work undertaken in collaboration with Esther Duflo, Rachel Glennerster, Robyn Meeks, Edward Miguel, and Clair Null. It also grows in part out of discussions at the Harvard Center for International Development's Sustainability Science Initiative 2009 Executive Session on Sustainability. We are grateful to participants for their insights, which deeply influenced this paper. We also thank Vivian Hoffman for assistance on cost-effectiveness calculations; Lori Bennear, Steve Luby, Sheila Olmstead, and Dale Whittington for comments; and Jessica Vernon for research assistance. All errors are our own. Views are those of the authors and are not those of the Bill & Melinda Gates Foundation.

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Annual Review of
Resource Economics

Volume 2, 2010

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