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Setting Priorities, Targeting Subsidies among Water, Sanitation, and Preventive Health Interventions in Developing Countries

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Summary. — The paper challenges the conventional wisdom that water and sanitation improvements and other preventive health interventions are always a wise economic investment. Costs and benefits are presented for six water, sanitation, and health programs—handwashing, sanitation, point-of-use filtration and chlorination, insecticide-treated bed nets, and cholera vaccination. Model parameters are specified for a range of conditions that are plausible for locations in developing countries. We find that the parameter values needed for such cost–benefit calculations are not available for setting global priorities. We reflect on the implications of our findings for more "evidence-based" planning of public health and development interventions.

Key words — benefit–cost analysis, health, water and sanitation, technological adoption, Monte Carlo analysis

1. INTRODUCTION

Economists who do not work in water and sanitation and hygiene (WASH) and other preventive health interventions in developing countries will likely be surprised at the current policy debates in this sector. Professionals in these fields are wrestling with three related puzzles that outside observers might well expect to have been resolved long ago.

First, although the health benefits from use of preventive health goods and services are purported to be high, demand for them is usually very low among households in developing countries. Preventive health interventions which require single or occasional uptake, such as insecticide-impregnated mosquito nets (bed nets) and vaccines, have been shown to be effective in saving lives and reducing general morbidity, as well as cost effective, yet household demand for these interventions has been found to be consistently low and price elastic (Kremer, Leino, Miguel, & Zwane, 2009; Whittington, 2010). Some of these technologies (e.g., home-based water chlorination and bed nets) have been around for decades, yet market penetration has been very slow (in sharp contrast to cell phones), perhaps because these interventions also involve significant disamenities (taste and odor problems, discomfort or inconvenience in use, etc.). On the other hand, household demand for piped water services in developing countries is very inelastic (Nauges & Whittington, 2009), even though the health benefits from these services in developing countries are ambiguous and controversial (Bennett, 2010; Cairncross *et al.*, 2010; Fewtrell *et al.*, 2005; Waddington & Snilstveit, 2009). This may be because households value the time savings and privacy the services provide. [1]

A second puzzle relates to experts' differing positions on the importance of user fees for preventive services and products. Public health professionals and development economists generally support free or heavily subsidized improved water and sanitation services and other preventive health interventions, such as vaccinations, bed nets, and point-of-use water treatments, on the basis of economic, financial, and moral arguments. On economic grounds they make the Pigovian case that positive externalities from such health interventions justify public subsidies (Pigou, 1932). On financial grounds they argue that because demand is so price elastic, the revenues generated by user fees do not justify the costs of administration and collection. On moral grounds they argue that both water and health are basic human rights: user fees would prevent the poorest households from accessing services. The fact that penetration and/or sustained usage of many of these preventive health interventions often remains low despite free or highly subsidized provision has not led proponents of free services to reconsider these arguments (Cairncross, Shordt,

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Zacharia, & Govindan, 2005; Pattanayak *et al.*, 2009; Waddington & Snilstveit, 2009).

On the other hand, professionals in the water and sanitation sector tend to insist on the need for user charges for both network and nonnetwork water and sanitation technologies. They argue that user charges achieve the financial goal of cost recovery, the economic-efficiency goal of delivering appropriate amounts of water and preventing water wastage, and the political goal of creating a sense of ownership in the capital facilities and management decisions (Rogers, De Silva, & Bhatia, 2002). The consensus that user charges are important in this sector may also be due to what Howells (1996) has termed "tacit knowledge," that is, long experience of trying without great success to provide services with no user charges.

A third puzzle is that in contrast to public health professionals, governments in developing countries often may support large subsidies for piped water and sanitation infrastructure at the expense of other, supposedly more beneficial health improvements. Ramsey pricing would suggest that if revenues need to be raised to finance piped water services and nonnetwork water and sanitation interventions, as well as other public health interventions, prices should be increased on piped water services (the price inelastic good) in order to cross-subsidize the nonnetwork services such as point-of-use treatment (the price elastic good) (Ramsey, 1927). But what actually occurs is the precise opposite. Governments of developing countries are typically extremely reluctant to price piped water services at anything close to the true costs of service, much less to extract from them extra revenues to finance nonnetwork services, even those with demonstrated positive public health outcomes (Cairncross, 2003). Governments provide massive subsidies for piped water and sewer services (which tend to be disproportionately captured by upper- and middle-income households), while nonnetwork public health interventions receive little funding (Evans, 1999). In fact donors attempting to subsidize vaccination, bed nets, and point-of-use water treatment are often concerned that national and regional governments may try to divert funds earmarked for these preventive health services toward other uses, or that donor financial support will simply become a substitute for government budget allocations for preventive health activities.

Discussion below addresses what we believe is one underlying reason for all three of these puzzles: the high uncertainty (for given sites) and inherent variability (across sites) in the economic costs and benefits of water and sanitation and hygiene and preventive health interventions in developing countries. We report on an analysis of the variation in costs and benefits of six different interventions (promotion of handwashing and improved hygiene; "total sanitation" campaigns, designed to curb open-air defecation; biosand water filters; point-of-use chlorination of drinking water; insecticide-treated bed nets; and cholera vaccination), and show that . . .

(1) At the median parameter values in the benefit–cost model, all six interventions deliver positive net benefits, but the magnitude of the net benefits to a household from all of the six interventions is relatively modest.

(2) There are many combinations of parameter values that yield a benefit–cost ratio (BCR) that is less than 1 for all six interventions. (For the median assumptions about uptake and usage, anywhere from 20% to 55% of simulation outcomes have costs that outweigh benefits depending on the intervention.)

(3) Given the heterogeneity in benefit–cost outcomes from the model simulations, developing a priority ranking of water and sanitation and hygiene and preventive health interventions—and setting cross-sectoral investment priorities—is much more complicated than commonly appreciated.

Our findings challenge the conventional wisdom in the water and sanitation and public health sectors that the economic case for such interventions is overwhelming and noncontroversial. We also find reasons to agree with researchers who have expressed skepticism about the confidence that health sector professionals sometimes place in new innovations in service delivery and technology and in rigorous program evaluation methods such as randomized controlled trials, for finding "evidence-based" solutions to these policy puzzles (Deaton, 2010). To illustrate this point we show the limited utility of zeroing in on a better estimate of any single parameter in the benefit–cost calculation, given the multitude of factors that are relevant. We also demonstrate that global estimates of the costs and benefits of such interventions are of very limited worth given the heterogeneity one can expect to find across target locations in developing countries. Our results also have implications for recent debates about the role that pricing can play in allocating public health goods and services in developing countries (Ashraf, Berry, & Shapiro, 2010; Cohen & Dupas, 2010).

In Section 2 of the paper we show why benefit–cost and cost-effectiveness calculations in the water and sanitation and hygiene and preventive health fields are fraught with uncertainty. Section 3 presents our benefit–cost model and discusses the assumptions made. In Section 4 we briefly describe the six interventions and the specific assumptions made to estimate the costs and benefits of each. Section 5 presents the results of our benefit–cost calculations and sensitivity analyses. Section 6 discusses some of the implications of these findings.

2. BACKGROUND

The desire to establish investment priorities in water and sanitation and hygiene and preventive health initiatives is understandable, virtually universal, and not new. Budgets to support such interventions are limited, and government agencies and donors want to allocate available financial resources so as to do the most good. But a strong desire to set global funding priorities does not make the task easy. Priority-setting analyses have adopted two main analytical approaches: cost-effectiveness analysis (CEA) and benefit–cost analysis (BCA). Centralized planning institutions have always struggled to improve the quality and availability of the information needed for such calculations. The kinds of information required to implement CEA and BCA differ somewhat, but both require up-to-date, site-specific data that have proven extremely difficult to obtain.

The problem that global planners in these sectors confront is conceptually not very different from that faced by economic planners in the former Soviet Union: how can a central planning office procure accurate, reliable information from the field to set production and investment targets? To address this question, water and sanitation and hygiene and preventive health professionals working for donor organizations confront two further major hurdles. First, even if the needed data are obtained, they are nonstationary; that is, one cannot assume that parameter estimates will remain constant over time. For example, when climate change, demographics, migration patterns, and economic growth are changing baseline conditions, studies of the burden of disease incidence or case fatality rates may quickly become out of date.

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Second, mistakes compound. Because CEA and BCA calculations require that uncertain parameters be multiplied by each other, the range of uncertainty in their products quickly expands. A simple example illustrates this point. Suppose one wants to calculate the mortality reduction benefits of vaccinating a target population (Pop) against cholera. The first parameter needed is the burden of disease (Inc_{before}), that is, the baseline incidence of disease in the target population before the vaccination intervention. The second parameter is the effectiveness (Eff) of the vaccine at reducing the incidence of cholera in the population if a specified number of individuals are vaccinated ($Inc_{after} = Eff * Inc_{before}$). The change in the number of cases due to the intervention is:

$$\Delta Cases = Pop * Eff * Inc_{before} \tag{1}$$

The next step is to calculate the change in the number of deaths due to cholera. This is done by multiplying the number of cases avoided by the case fatality rate (CFR):

$$\Delta Deaths = CFR * Pop * Eff * Inc_{before} \tag{2}$$

To calculate the economic benefits of avoiding these deaths in the target population, the benefit–cost analyst multiplies the number of lives saved by the value of the mortality risk reduction, as judged by the members of the target population themselves. This economic measure can be summarized as the value of statistical life (VSL) (Viscusi & Aldy, 2003). The final calculation is thus:

$$\text{Mortality benefits} = VSL * (CFR * Pop * Eff * Inc_{before}) \tag{3}$$

Typically none of the values of these four parameters—Inc_{before}, CFR, Eff, or VSL—is known with much certainty for a specific location. Public health planners typically focus a great deal of attention on the estimation of Eff, but often more is already known about this parameter than about the other three. The multiplication of the four parameters in Eqn. (3) implies that their product—the economic value of the deaths avoided—will be highly uncertain. [2]

But resource allocation decisions must still be made in the face of uncertainty. How then should an analyst who wants to set priorities proceed? There is a continuum of planning protocols from extremely centralized to decentralized decision making. Health economists and public health policy makers favoring centralized planning protocols commonly rely on CEA approaches to set investment priorities. Advocates of CEA make two arguments to justify their selection of CEA over BCA for centralized priority-setting exercises. The first is that it is not desirable to put monetary values on health outcomes, nor is it necessary to do so. Competing interventions for addressing particular diseases can be ranked in terms of cost-effectiveness ratios (CERs)—lives saved or disability-adjusted life years (DALYs) avoided per dollar spent—and funds can be allocated to the activities that have the highest ratios. The second argument is that the health benefits of the interventions are the salient outcome of interest, nonhealth benefits are of secondary importance. Rights-based arguments for provision of safe water, for example, typically focus on the importance of access to good health.

Benefit–cost analysts do not accept either argument. They prefer to convert health outcomes to a monetary measure and are typically indifferent to the relative sizes of the health- and nonhealth-related benefits of a policy intervention. They focus more on the preferences of the beneficiaries of the interventions and believe that there are good reasons (e.g., risk aversion, heterogeneity in risks and preferences, aversion to pain and suffering) why some individuals would prefer an intervention and others might prefer alternatives.

Despite their differences in analytical approach and philosophy, CE and BC analysts working within a centralized planning paradigm have generally relied on the same two strategies for dealing with the uncertainty in the data they need for their calculations. The first approach is what environmental economists refer to as "benefit transfer," that is, obtaining values for parameters from one or more field locations ("study sites"), and applying ("transferring") those values to analyses aimed at a location of interest (the "policy site"), often using sophisticated econometric methods (Smith, Van Houtven, & Pattanayak, 2002; Boyle, Kuminoff, Parmeter, & Pope, 2010). In practice the "policy site" is often not specified but may be a region or a country. Literature from the health sector offers numerous studies that have employed simple benefit-transfer methods to calculate global or regional CERs or BCRs (Hutton & Haller, 2004; Hutton, Haller, & Bartram, 2007). The authors of such analyses gathered the values of specific parameters from empirical studies in the literature to supply data for their CE or BC calculations. Those parameter values could be taken from studies conducted in widely disparate sites and in different time periods. The second strategy adopts regional or global averages for parameter values and applies those averages to target regions or representative locations. Some analyses also combine specific transferred values for a few parameters with average values for others.

One reason why benefit-transfer methods are popular is that individual empirical studies that establish a parameter value in a particular time and place may be extremely impressive. Examples here would be two studies (Ali *et al.*, 2005; Longini *et al.*, 2007) that documented herd immunity resulting from a cholera vaccination program in the Matlab region of Bangladesh in the 1980s, and, more recently, a study (Miguel & Kremer, 2004) that convincingly used randomized controlled trials to establish the effectiveness of deworming treatments in rural Kenya. In the absence of other well-executed studies, it might seem uncontroversial to transfer such carefully measured parameter estimates to other locations and other time periods to determine CERs or BCRs for a prospective cholera vaccination or deworming intervention. But analysts who carry out such transfers may overstate the external validity of the original researchers' results or in various ways misrepresent the case for transferring such results to other locations. It is all too easy for analysts engaged in transferring benefits to new locations to neglect or to pass over local conditions, such as environmental or behavioral assumptions, that may have led to the results observed in the original research design.

The authors of such CE and BC studies almost always conclude that preventive health interventions are extremely cost effective (or, for BC studies, that benefits greatly exceed the costs) and that the economic case for such interventions is therefore clear and compelling. Sensitivity analysis is usually limited to varying just one of the uncertain parameter values at a time. The overwhelming impression received from reading the majority of the CEA and BCA literature on water and sanitation and hygiene and preventive health interventions in developing countries is that the economic case for these interventions is well established and noncontroversial. Somewhat ironically, analysts who argue that the results of their CE and BC studies prove the economic case for their particular interventions are often reluctant to rely on the results of these same studies to rank public health interventions and to compare them with investments in other sectors.

CE and the BC studies are alike in tending to ignore several obvious questions: If these preventive health investments are so economically attractive, why has their uptake been relatively limited? It is not for want of trying; donor-funded programs in the water supply sector have been littered with white elephants (Therkildsen, 1998). Why is household demand for preventive health interventions typically low? Why are governments often reluctant to invest scarce resources in these sectors?

A few cross-sectoral BC comparisons of development priorities exist that have included water and sanitation and hygiene and preventive health interventions (Lomborg, 2004). But like within-sector analyses, these studies too have used benefit-transfer methods or global or regional averages for key parameter values. This genre of priority-setting analyses typically ignores behavioral evidence that suggests that adoption and usage of water and sanitation and hygiene and preventive health interventions vary considerably over time and place and are often quite low, despite relatively intensive promotion or social marketing (Arnold & Colford, 2007; Cairncross *et al.*, 2010; Hoque, Juncker, Sack, Ali, & Aziz, 1996; Waddington & Snilstveit, 2009).[3] It also ignores evidence that demand among potential beneficiaries varies and is not static, and therefore may be misinterpreted by central planners; see for example Jenkins and Curtis (2005), Mukherjee (2000), and Casabonne and Kenny (2012) for examples of demand heterogeneity.

A recent paper comparing the costs and benefits of various water sector investments (Whittington, Hanemann, Sadoff, & Jeuland, 2009) used a different approach to compare interventions. In their benefit–cost model, the analysts specified ranges and distributions for each of about 25 parameters that varied across locations in developing countries, and then conducted Monte Carlo simulations to determine outcomes for 10,000 random combinations of those parameters. Although the actual variation in these model parameters across locations and time periods is poorly understood, the uncertainty surrounding these distributions has important consequences for setting priorities in water and sanitation and hygiene and preventive health interventions. The authors argued that the "distributions of benefit–cost ratios . . . are more useful than point estimates because they allow one to focus on the policy-relevant question of where water and sanitation investments are likely to be most economically attractive." This approach also helped identify which types of projects were more likely to improve household welfare across a wide range of plausible situations in developing countries. For example, the results showed that investments in conventional piped water and sanitation services were unlikely to yield net economic benefits in many locations because of their high capital costs. A similar analytical approach (Jeuland & Whittington, 2009) compared the probability distributions of BCRs for cholera vaccination programs versus two improved water supply interventions (deep boreholes with handpumps and biosand filters; a point-of-use water treatment technology). These two studies suggest that probabilistic approaches to decision-making provide more useful information for setting priorities among different types of interventions than the point estimates of average benefit–cost outcomes.

3. ANALYTICAL FRAMEWORK

To more fully explore aspects of the high level of uncertainty inherent in centralized priority-setting calculations, we here extend the BC approach developed in the studies described above (Jeuland & Whittington, 2009; Whittington *et al.*, 2009) in two ways. First, we focus more carefully on the effect that behavioral assumptions about initial uptake and the sustained usage of new technologies have on the net benefits of preventive health interventions. We define "uptake" as a household's initial acquisition of a technology or participation in a program. Usage is conceptualized as the rate (or frequency) of regular use among those "uptaking" households. For example, households may be perfectly happy to obtain a water filter from a new point-of-use program intervention, particularly if it is given to them free of charge, but then may never actually use it. With many types of technologies, such as point-of-use chlorination of drinking water, the possibility arises that usage rates will decline over time (Hunter, 2009) or that the products may be used for nonhealth purposes, such as cleaning dirty laundry, or converting latrines to storage sheds (Ashraf *et al.*, 2010).

Second, we expand the scope of the analysis to include six interventions: four water and sanitation and hygiene interventions (handwashing, total sanitation campaigns, point-of-use chlorine treatment, and point-of-use biosand water filters) and two preventive health interventions (long-lived insecticide-treated bed nets and cholera vaccination programs). The water and sanitation and hygiene interventions reduce multiple diseases by reducing fecal-oral transmission. In contrast, the preventive health interventions target specific diseases (malaria and cholera). It may seem odd to compare four general health interventions with two that target specific diseases, but many aid organizations do just that when setting investment priorities.

The unit of analysis for our BC calculations is the individual household; the monthly costs of providing each intervention to a representative household in a given community are compared with the economic benefits that the household would receive. We present BCRs to compare the overall economic attractiveness of these six interventions. The typology of costs and benefits used in the model is described below and presented in Table 1.

The implementation of each of the six interventions involves expenditures for products (technology and supplies) and program "software." The capital costs of our chosen interventions include household infrastructure and supplies such as filters, bed nets, and vaccines. "Software" expenses include administrative and delivery costs of programs, such as salaries and the opportunity cost of health workers' time, the development and logistical costs of promotion or educational campaigns, and/or any incentives provided to communities in order to encourage participation. In our BC model, one-time capital and program expenses are annualized using a capital recovery factor that depends on two parameters: the discount rate and the lifetime of each intervention. Annualized costs are then divided by 12 to obtain monthly costs.

Operation and maintenance costs are the ongoing monthly expenses required for upkeep of technologies or purchase of additional materials or supplies needed to sustain project benefits. Another component of the economic costs of the interventions is the time spent by beneficiaries to access (or use) the services. Individuals may attend educational sessions to learn how to use a particular technology or become informed about hygiene behaviors that can improve their health. Communities may need to develop institutions to maintain projects. To express "time costs," time spent in these training and educational activities is converted to monetary amounts by multiplication with an (uncertain) opportunity cost of time. Because training and educational activities usually occur at the beginning of an intervention, these costs are annualized and divided into monthly amounts similar to the capital costs. Regular, periodic time costs for maintenance or other activities related to the project are also expressed in monthly terms and monetized in the same way.

A characteristic of all six interventions is that in addition to time costs, their use involves disamenities that may make people less interested in using them. Some may feel that sleeping under a bed net is uncomfortably hot. Some may worry about the side effects of vaccines or find the injection itself unpleasant. Some may find that the residual chlorine from point-of-use chlorination leaves an unpleasant taste in drinking water. Biosand filters may take up valued space within a small house. We do not include such costs in the model directly. However, we do expect that these disamenities will affect both initial uptake and sustained usage of the interventions, and this expectation provides some of the motivation for our sensitivity analysis on assumptions about uptake and usage.

The model includes the economic benefits from both health and nonhealth outcomes. The economic benefits from improved health result from reductions of diarrheal disease and from cholera and malaria morbidity and mortality (Table 1). The reduction in the economic cost of morbidity is estimated by multiplying cost of illness (COI) per case by the decrease in expected annual cases per household. COI includes private and public expenses for diagnosis, treatment, and hospitalization; other costs borne by patients, such as transport to hospitals; and productivity losses for sick patients and caretakers, during the period of illness and recovery. [4] Reduction in the annual economic cost of mortality is estimated by multiplying the value of a statistical life (VSL) by the decrease in the expected annual risk of death per household due to the disease. [5] We assume that benefits are directly proportional to adoption and usage rates, except for the case of cholera vaccination, for which the effect of coverage on overall protection has been carefully measured. The relationships between the benefits of water and sanitation interventions and coverage, and malaria-prevention interventions and coverage, also may be nonlinear due to positive externalities, but are surprisingly not well documented.

Nonhealth economic benefits include time savings, and/or improved productivity (in activities such as child care or otherwise), and esthetic benefits. [6] Total sanitation programs are the only one of the six interventions that provides time savings, due to reductions in the time a household spends accessing latrines or other toilets (note that time savings and productivity benefits due to not getting sick are already included through the COI measure). These time savings are estimated in monthly terms and are converted to monetary benefits by multiplying the same value for the opportunity cost of time that is used in estimating program software costs. For fear of double-counting, and because of the measurement challenges, we do not include additional benefits related to improved productivity. The interventions considered for our model may also provide esthetic benefits, such as improved cleanliness, improvements in social standing stemming from ownership of particular types of technologies, etc. Except for the case of handwashing these esthetic benefits are not directly included in the model, although they also influence uptake and usage rates. For handwashing, the net economic value of increased water use can be approximated from assumptions about the demand curve for water (for details see Whittington *et al.* (2009)) net of the cost of acquisition of that water.

Most CE and BC analyses in the literature include only a subset of these costs and benefits (Clasen, Schmidt, Rabie, Roberts, & Cairncross, 2007; Clasen, Haller, Walker, Bartram, & Cairncross, 2007; Larsen, 2002; Mueller *et al.*, 2008; Varley, Tarvid, & Chao, 1998). Most high-quality studies include capital, program, and operation and maintenance costs. Very few studies account for the time required of individual and community participants. On the benefits side, most economic studies attempt to quantify health benefits but fail to include time savings. In particular, CE studies almost always ignore nonhealth benefits unless these are expressed in the form of cost offsets. CE and BC studies almost always ignore esthetic benefits and disamenities. Like other analysts conducting CE and BC studies, we were forced to make a large number of assumptions to estimate the economic outcomes of water and sanitation and hygiene and preventive health

Table 1. *General typology of costs and benefits of the interventions*

Costs	Examples	Benefits	Examples
Capital products	Infrastructure needed for interventions (e.g. cost of latrine, tippy tap, water containers, filters, bed nets, etc.)	Morbidity and mortality reductions	POU water treatment, sanitation and hygiene interventions reduce fecal-oral transmission and incidence; bed nets decrease malaria incidence; lower incidence means fewer deaths
Program "software"	Implementation/delivery cost (NGO and government staff time, promotion materials, rewards and incentives for open-defecation free villages, etc.)	Time savings	In-house latrines reduce travel time to defecation sites
Operation and maintenance	Replacement/cleaning of equipment (e.g. sanitization of latrines, purchase of chlorine product, soap, insecticide, etc.)	Esthetic gains	Hand-washing and increased water-use improves cleanliness
Household time expenses	Training and education programs; use and maintenance of improved technologies requires time; water needed for handwashing takes time to collect	Improved social standing	Household status is associated with having in-house sanitation, handwashing facilities, or durable good (filters, bed nets)
Community time expenses	Community maintenance or ongoing promotion of programs by community members	Socialization benefits	Participants enjoy the social interactions of the awareness-raising or education activities; care-taking benefits to parents from improving their children's health and well-being
Discomfort/ inconvenience	Heat from bed nets; latrines are unpleasant; filters are bulky and consume valuable living space; chlorinated water tastes bad, intrusive visits from NGO or government workers		

Table 2. *Summary of field evidence on usage and uptake rates from the literature for the six interventions*

Intervention	Location	No. of HHs	Summary description	User fees charged (Y/N)	Subsidy (%)	Uptake rate (%)	Usage rate (%)	Disuse over time (%)
Handwashing								
Cairncross *et al.* (2005)	Kerala, India	345	Hygiene promotion + sanitation investment evaluation conducted over 9 years (Ranges are for different genders and ages)	Latrines only	100%	40%	10–84%	No evidence
Wilson and Chandler (1993)	Lombok, Indonesia	57 mothers	4-yr handwashing promotion with mothers	N	100%	N/A	79%	No evidence
Borghi, Guinness, Ouedraogo, and Curtis (2002)	Burkina Faso	37,319 mothers[‡]	Cost-effectiveness study based on hygiene campaign with target population of mothers	For soap only	Nearly 100%	N/A	19%	?
Waterkeyn and Cairncross (2005)	Zimbabwe	13,555[‡]	Integrated sanitation and hygiene campaign in two districts, conducted through intensive awareness-raising through Health Clubs (Range is for each district)	N	100%	25–40%	60–88%	?
Total sanitation								
Pattanayak *et al.* (2009)	Orissa, India	1,050	Cluster-randomized experiment to evaluate a campaign combining “shaming” and subsidies to only poor hhs in Orissa (Usage imputed from overall reported usage as a fraction of uptake)	Y	Poor: 85% Nonpoor:0%	29–46%	55–83%	N/A
WSP (2005)	Rajarghat, Bangladesh	NA	Bangladesh government-run. Small program since 2001, serving 180 villages	Y	40%	83%	30–70	Some evidence
	Bangladesh	NA	NGO Forum—Bangladesh. Started in 2001	Y	67%	?	30–70	Some evidence
	Bangladesh	NA	Plan Bangladesh. Started in 2002	Y	83%	?	30–70	No evidence
	Ahmednagar, India	NA	Government of India pilot TSC. Started in 2003	Y	80%	22%	>70%	No evidence
	Andhra Pradesh India	NA	Government of India TSC. Started in 2003	N	100%	15%	<30%	Some evidence
	Gramalaya, India	NA	NGO/gov hybrid TSC. Started in 2003	Y	96%	?	>70%	No evidence
	West Bengal, India	NA	Government of India TSC. Started in 1999	Y	84%	29%	>70%	No evidence
Cairncross *et al.* (2005)	Kerala, India	345	Hygiene promotion + sanitation investment evaluation conducted over 9 years. (Ranges are for different genders and ages)	Y	75%	26–62%	48–100%	No evidence
Hoque *et al.* (1996)	Bangladesh	1,068	5-yr follow-up evaluation of WASH promotion project	N	100%	Nearly 100%	77%	6%
Trémolet, Kolsky, and Perez (2010)	6 countries	NA	6-country analysis of attributable increase in coverage with sanitation facilities (Excluding Bangladesh, uptake is 15–38%)	Y	Varying (12–82%)	15–70%	70–82%	No evidence

Waterkeyn and Cairncross (2005)	Zimbabwe	13,555[‡]	Integrated sanitation and hygiene campaign in two districts, conducted through intensive awareness-raising through Health Clubs (Range is for each district)	Y	?	17–41%	50–95%	?
Chlorination								
Quick *et al.* (1996)	Bolivia	42	9-week study with 3 groups: A) storage vessels & chlorine, B) storage vessels only, C) control. HHs interviewed and water sampled every 3 weeks	N	100%	100%	73%	?
Macy and Quick (1998)	Nicaragua	100	Storage vessels, chlorine, and educational program provided; Baseline surveys recorded water sources, storage & disinfection practices prior to intervention. Follow-up surveys were conducted 3 months after intervention	N	100%	100%	55%	?
Semenza, Roberts, Henderson, Bogan, and Rubin (1998)	Uzbekistan	240	62 study HHs were provided with storage vessels and trained to chlorinate the water. Other groups were a) connected to the municipal systems, and b) control. Also found low willingness to pay for a bottle of chlorine (mean US$0.30)	N	100%	100%	?	?
Mong *et al.* (2001)	Madagascar	123	HHs that were affected by a cyclone. Thousands of storage vessels and chlorine were distributed to affected villages after the cyclone; survey was conducted to monitor the effectiveness of the distributed aid products	N	100%	85%	65%	?
Reller *et al.* (2003)	Guatemala	492	Study with five groups: (1) flocculent-disinfectant, (2) flocculent-disinfectant & vessel, (3) bleach, (4) bleach & vessel, and (5) control. Attrition over 50 weeks period was high (about 15%). Diarrhea rate was monitored weekly	N	100%	100%	35–43%	?
Sobsey, Handzel, and Venczel (2003)	Bolivia & Bangladesh	140 (Bolivia); 275(Bangladesh)	Intervention with storage vessels + chlorine. Study period in Bangladesh was 8 months and 6 months for Bolivia. Study accounted for low-level chlorination of drinking water at system level using control group	N	100%	100%	74%	?
Olembo *et al.* (2004)	Zambia	1,319	Cross-sectional surveys of areas with social marketing of chlorination products. Door-to-door promotion, and TV and radio ads did not increase usage	Y	Varying	64%	13%	6%
Arnold and Colford (2007)	N/A	N/A	Meta analysis of 22 studies from 20 different studies in 13 countries. Found that most intervention studies were over a short period of time (average of 30 weeks) and there was an attenuation of diarrhea protection in children under 5 for longer studies	N/A	N/A	?	36–100%	Some evidence
Ashraf *et al.* (2010)	Zambia	1,260	Study of the effect of user fees and random discounts on uptake and usage of Chlorin liquid bleach, over 6 week period	Y	Varying	45–80%	40–60%	?

(*continued on next page*)

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Table 2. (*continued*)

Intervention	Location	No. of HHs	Summary description	User fees charged (Y/N)	Subsidy (%)	Uptake rate (%)	Usage rate (%)	Disuse over time (%)
Biosand filters								
Vanderzwaag (2008)	Nicaragua	214	Evaluation of the use and performance of biosand filters in Nicaragua. (Note: very high reported breakage rates)	N	100%	?	?	15%
Duke, Nordin, Baker, and Mazumder (2006)	Artibonite Valley, Haiti	107	Evaluation of performance and use of biosand filters installed over a 5-year period	Y	50–67%	?	92%	2%
Sobsey, Stauber, Casanova, Brown, and Elliott (2008)	Cambodia; Dom. Republic	N/A	Results of two field trials with the biosand filter	?	?	?	85%	3%
Long-lived Insecticide-treated bed nets								
Hanson *et al.* (2003)	Tanzania	440,000[‡]	Assessment of the costs and consequences of a social marketing approach to malaria control in children using ITNs in two rural districts	Y	70%	54%	14–23%	?
Wiseman, Scott, McElroy, Conteh, and Stevens (2007)	The Gambia	1,700	Study of the determinants of bed net ownership and purchase	Y	Varied	32%	75–80%	?
Müller *et al.* (2008)	Burkina Faso	572 of 1052	RCT of ITN distribution systems: Social marketing arm	Y	65%	5%	34%	?
		480 of 1052	Free distribution arm	N	100%	22%	39%	?
Mueller *et al.* (2008)	Togo	NA	Cost-effectiveness analysis of free ITN distribution in Togo Integrated Child Health Campaign	N	100%	?	54%	?
WHO (World Health Organization) (2009)	Various countries	NA	Malaria report 2009 summarizing data from multiple countries (uptake is defined as the % of hhs with at least one ITN, which is not an uptake rate per se)	N/A	N/A	30–50%	14–68%	4–18%
Dupas (2010)	Kenya	1,120	Results of a field experiment with different subsidies for Olyset LLINs conducted with 1120 households (Uptake rates are % of hhs obtaining one net and are decreasing in price)	Y	40–100%	10–90%	60–90%	No evidence
Tarozzi *et al.* (2010)	Orissa, India	612 of 1844	Experiment on distribution versus sale of ITNs: Free distribution arm (usage is increase in ITN use divided by uptake)	N	100%	24%	54%	?
		592 of 1844	Microfinancing arm (usage is increase in ITN use divided by uptake)	Y	0%	52%	88%	?
Cholera vaccination								
Ali *et al.* (2005)	Matlab, Bangladesh	73,999[‡]	Oral cholera vaccine trial in Matlab with spatially heterogeneous coverage levels conducted during the 1980s. (Average is reported)	N	100%	27%	N/A	N/A

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Jeuland, Lucas, Clemens, & Whittington 2010)	Beira, Mozambique	11,175‡	Cholera vaccine evaluation among targeted population in one urban district (Target zone coverage only is reported)	N	100%	51%	N/A	N/A
Thiem *et al.* (2003)	Hue City, Vietnam	118,555‡	Analysis of mass immunization program against cholera	N	100%	79%	N/A	N/A

Notes: (1) For chlorination, usage measured by chlorination residual.
(2) Most intervention evaluation studies are cross-sectional and conducted shortly after the program is administered.
(3) Few studies measure long-term usage rates, so disuse over time may be unreliable.
(4) The scale of programs described here is highly variable, ranging from very small to large.
(5) Number of households is for the evaluation sample unless marked by the symbol ‡, in which case it is the population covered by the intervention.

interventions, because parameter values for local conditions are both unknown and nonstationary. These assumptions about the parameter values and the model structure create a risk that the results of both CE and BC calculations will be misinterpreted. This risk is especially dangerous with regard to assumptions about uptake and usage of the interventions, because it is difficult to generalize about individuals' preference tradeoffs across time and space. To better characterize the uncertainty in our economic results, we conducted Monte Carlo simulations of the net benefits for the six interventions in nine hypothetical situations characterized by combinations of low, moderate, and high uptake and usage. These nine cases were constructed on the basis of an extensive literature search for information about behavioral responses to each of the six interventions (see Table 2 for a summary of the studies containing such information, and Table 3 for the ranges of values used in this study). The moderate case is for the median of each of the ranges in Table 3; low and high cases use the lower and upper bounds, respectively. For simplicity, the low usage case combines low usage and high rate of disuse; the opposite is true for the high usage case.

These ranges should be interpreted carefully. We believe that it is quite plausible that usage rates found in the literature are overestimates, because many impact assessments are carried out shortly after interventions occur. Also, somewhat surprisingly, many program evaluation studies do not track uptake and usage. Those that do often rely on proxy measures (for example, recording whether there is soap in a household, rather than direct observation of how often it is used). Uptake and usage rates will be influenced by the balance of disamenities and esthetic benefits of the interventions as perceived by households, as well as the delivery mechanism, especially whether users are charged the full cost of the intervention, are offered some reduced subsidy price, or receive the product free of charge (Ashraf *et al.*, 2010).

With respect to the delivery mechanism and pricing policy, some of the low, moderate, and high cases for each intervention in our Monte Carlo simulations may be unrealistic if uptake and usage are interdependent. For example, some argue for user fees for piped network services interventions in order to reduce the risk of providing costly services to households that may not value them highly. One would expect that user fees would reduce initial uptake, but these might also yield higher initial and long-term usage rates among those who have invested in the interventions. On the other hand, free distribution of, for example, soap for handwashing to all households in a community might result in high levels of uptake but low levels of usage if some households see little value in the intervention. However, the evidence for higher usage rates among purchasers is mixed (Table 2); see in particular Tarozzi *et al.* (2010) and Dupas (2010), emphasizing our point about the high degree of uncertainty in such calculations.

The Monte Carlo simulations treat all other BC model parameters—there are 15–21 of them in this model, depending on the intervention—as uncertain. Three types of assumptions were made for each uncertain parameter. First, a range of plausible values for "typical" programs was specified on the basis of our reading of the literature and our professional judgment. [7] Second, the uncertain parameter values were assumed to be uniformly distributed over those ranges. Third, likely correlations between parameters in the model were specified. A similar approach could be applied to the uptake and usage parameters, but as described above we treated uptake and usage differently because we were particularly interested in isolating the effect these behavioral parameters have on the benefit–cost results.

Table 3. *Low and high coverage parameters affected by program design and the behavioral response of beneficiaries*

Parameter	Handwashing		Total sanitation campaign		Chlorination		Biosand filters		Long-lived Insecticide-treated bed nets		Cholera vaccination	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Initial uptake (%)	20	60	20	60	–	–	–	–	20	70	10	80
Regular usage (%)	20	80	50	90	10	80	60	100	15	80	–	–
Rate of disuse over time (% of users/yr)	–	–	6	0	12	4	15	1	20	5	–	–
Sources	Wilson and Chandler (1993); Borghi *et al.* (2002); Cairncross *et al.* (2005); and Waterkeyn and Cairncross (2005)		Hoque *et al.* (1996); Cairncross *et al.* (2005); WSP (2005); Pattanayak *et al.* (2009); and Trémolet *et al.* (2010)		Quick *et al.* (1996); Macy and Quick (1998); Semenza *et al.* (1998); Mong *et al.* (2001); Quick *et al.* (2002); Reller *et al.* (2003); Sobsey *et al.* (2003); Olembo *et al.* (2004); Waterkeyn and Cairncross (2005); and Arnold and Colford (2007)		Expert judgment and Duke *et al.* (2006); Sobsey *et al.* (2008); and Vanderzwaag (2008)		Hanson *et al.* (2003); Wiseman *et al.* (2007); Müller *et al.* (2008); Mueller *et al.* (2008); WHO (2009); Dupas (2010); and Tarozzi *et al.* (2010)		Ali *et al.* (2005); Thiem *et al.* (2003); Jeuland *et al.* (2010)	

A probabilistic sensitivity analysis was then conducted, in which a BCR was calculated for each of the interventions for all of the 10,000 different realizations of values for the parameters in the benefit–cost models. This yielded a distribution of BCRs for each of the interventions, which was associated with the ranges of parameter values that we thought were likely to exist in developing countries. Since these ranges were informed by published information and judgment, we would expect to find site-specific circumstances in developing countries with a similar range of BCRs. However, we emphasize that the frequency with which any specific combination of parameter values—and hence benefit–cost outcomes—would arise is unknown.

Table 4. *General parameters, consistent across interventions*

Parameter	Value	[Min–max range]	Sources (if applicable)
Household size	5	[4–6]	N/A
Number of adults per hh	2	[1–3]	N/A
Market wage (US$/day)	1.25	[0.5–2]	N/A
Value of time/market wage (%)	30	[10–50]	Jeuland *et al.* (2010)
Diarrheal disease incidence (cases/person-yr)	0.9	[0.4–1.4]	Whittington *et al.* (2009)
Diarrheal disease case fatality rate (%)	0.08	[0.04–0.12]	Whittington *et al.* (2009)
Diarrheal disease cost of illness (US$/case)	6	[2–10]	Whittington *et al.* (2009)
Malaria incidence (cases/person-yr)	0.3	[0.02–0.6]	Snow, Craig *et al.*, 1999; Snow, McCabe *et al.* (1999); Mueller *et al.* (2008)
Malaria case fatality rate (%)	0.2	[0.05–0.35]	Snow Craig *et al.* (1999); Mueller *et al.* (2008)
Malaria cost of illness (US$/case)	26	[12–40]	Russell (2004)
Cholera incidence (cases/1000 persons-yr)	2	[0.1–3.9]	Jeuland, Cook *et al.*, 2009; Jeuland, Lucas *et al.*, 2009
Cholera case fatality rate (%)	1.75	[0.5–3.0]	Jeuland and Whittington (2009)
Cholera cost of illness (US$/case)	50	[15–85]	Jeuland and Whittington (2009)
Value of a statistical life (US$)	30,000	[10,000–50,000]	Whittington *et al.* (2009)
Discount rate (%)	4.5	[3–6]	N/A

Table 5. *Summary of intervention-specific parameters (where applicable, sources in parentheses or in footnotes)*

Parameter	Handwashing	Total sanitation campaign	Chlorination	Biosand filters	Long-lived Insecticide-treated bed nets	Cholera vaccination
Benefit parameters						
Reduction in diarrhea cases (%)	45 [25–65] (Curtis & Cairncross, 2003; Ejemot, Ehiri, Meremikwu, & Critchley, 2009)	30 [10–50] (Fewtrell *et al.*, 2005)	37.5 [25–50] (Arnold and Colford, 2007; Clasen *et al.*, 2006; Hunter, 2009)	40 [20–60] (Fewtrell *et al.*, 2005)	–	Cholera reduction is a function of uptake (see technical Appendix available online)
Reduction in malaria cases (%)	–	–	–	–	30 [15–45] (Lengeler, 2004)	–
% of esthetic benefits that are health-related	25 [0–50]	–	–	–	–	–
Round trip travel time to defecation site (min)	–	15 [10–20]	–	–	–	–
Number of trips to defecation site per day	–	1 [0.75–1.25]	–	–	–	–
Cost parameters						
Capital cost ($)	3.5 [2–5] (online sources)	20 [10–30] (WSP, 2005)	8.5 [5–12] (expert judgment & Lantagne *et al.* (2007))	75 [60–90][a]	7 [4–10] (Hanson *et al.* (2003), Mulligan *et al.* (2008), De Allegri *et al.*, 2010)	[1.4–6.6] (Jeuland, Cook *et al.*, 2009; Jeuland, Lucas *et al.*, 2009)
Transportation/ distribution cost ($)	–	–	–	25 [15–35][a]	6 [3–9] (Hanson *et al.*, 2003)	Included above
Program software cost (% of upfront expenses)	Same as CLTS amounts	30 [20–40]	Same as total sanitation amounts	–	Included above	–
Initial time expense: uptakers (hours)	40 [20–60]	10 [5–15]	1 [0.5–1.5]	8 [4–12][a]	1 [0.5–1.5]	1.5 [0.5–2.5]
Initial time expense: nonuptakers (hours)	10 [5–15]	3 [2–4]	N/A	–	1 [0.5–1.5]	–
Operation and maintenance cost ($/yr)	Per person-yr: 3 [2–4] (Borghi *et al.*, 2002)	5 [2–8] (Trémolet *et al.*, 2010)	4.4 [3.2–5.6] (Clasen, Haller *et al.*, 2007; Clasen, Schmidt *et al.*, 2007; Lantagne *et al.*, 2007)	–	–	–
Water collection time (hr/20 L jerrican)	1 [0.1–2]	–	–	–	–	–
Water needed for washing (L/person-day)	0.8 [0.25–1.4]	–	–	–	–	–
Number of filter washes/ yr	–	–	–	6 [2–10][a]	–	–
Ongoing community time expenses (hr/hh–yr)	–	–	–	2 [1–3][a]	–	–

Ongoing household time expenses (hr/hh)	—	Per year: 10 [5–15]	—	Per wash: 0.25 [0.2–0.3][a]	—	—
Time out of operation after maintenance (days)	—	—	—	5 [3–7][a]	—	—
Project lifespan (yr)	1.5 [1–2]	3 [2–4]	2 [1–3]	8 [6–10]	4 [3–5]	3 [2–4]

[a] Whittington *et al.* (2009).

4. DESCRIPTION OF THE INTERVENTIONS

This section briefly describes the interventions that were analyzed and presents the ranges for the uncertain parameters that appear in the benefit–cost equations (additional details and discussion of parameter assumptions and the equations in the full model are presented in online Appendix). To ensure comparability, some of the parameters have values and ranges that are the same across all six interventions (Table 4), while others are intervention-specific (Table 5).

(a) *Promotion of handwashing and improved hygiene*

Handwashing (HWS) interventions attempt to reduce fecal-oral transmission of contaminants via hand contact, by encouraging communities of households to engage in more frequent cleansing of hands with soap and water (Curtis, Cairncross, & Yonli, 2000). Studies show that handwashing with soap prior to organized HWS interventions can be very infrequent (Curtis & Cairncross, 2003; Curtis *et al.*, 1993; Hutly *et al.*, 1994). HWS interventions are usually organized by local NGOs or governments and vary widely in scale and design. Capital costs of appropriate technologies, such as the "tippy tap," are low.[8] Program costs are larger because the personnel needed to raise awareness must be deployed to deliver health-promotional messages, often in remote areas, and they must be retained until behavior change is achieved. One key problem with evaluating the effectiveness of HWS campaigns is that few studies track handwashing over time; those that do, suggest that sustained handwashing ranges from very modest to high (Table 2).

The main objective of HWS campaigns is to deliver health benefits. We consider only reductions in diarrheal disease, though there is evidence that HWS may also reduce pneumonia (Luby *et al.*, 2005). HWS interventions may also generate esthetic improvements and improved social standing. Many people feel that clean hands and a hygienic household are pleasant and esthetically pleasing as well as effective in improving health. Socialization benefits may result if community meetings lead to improved interactions among neighbors (Waterkeyn & Cairncross, 2005), but these apparent benefits may be spurious if participants who naturally enjoy such interactions simply self-select into participation; nonparticipants and others may see lengthy community meetings and house visits as time-consuming and disruptive to their daily lives. Households' monetary and time contributions are usually limited to the purchase of soap and to increased water collection time for extra amounts to use on handwashing. We expect that these private expenses, time costs, and perceptions of esthetic benefits influence the extent to which households ultimately change their behaviors. The model used here includes estimates of these various costs and benefits, except those associated with increased social capital, for which we judge there to be insufficient evidence.

(b) *Total sanitation campaigns*

A different approach for reducing fecal-oral transmission of contaminants is to encourage improved sanitation. Numerous innovative, low-cost technologies exist for hygienic disposal of excreta. However, as with the HWS interventions, the economic and health benefits from improved sanitation require both improved technologies and important behavioral changes on the part of participating households (Feacham, Bradley, Garelick, & Mara, 1983; Jamison *et al.*, 2006; Sannan &

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Moulik, 2007; WSP (Water & Sanitation Program), 2005).[9] A low-cost Community-Led Total Sanitation (CLTS) approach has recently been popularized in South Asia, and is now a central element in government water and sanitation programmes in India and Bangladesh (WSP, 2005). It focuses on mobilizing communities to achieve total sanitation, or open-defecation-free environments, through intensive promotion campaigns aiming at behavior-change galvanized by the application of social pressure and walks of shame. Efforts to take this approach from the pilot stage to scale have met with varied success: reported uptake and long-term usage varies considerably across intervention sites (Table 2).

As with the program implementation model for large-scale hygiene and handwashing campaigns, sanitation programs are typically designed by NGOs in collaboration with communities and local governments and require considerable program infrastructure to be successful. Capital costs vary depending on which toilet technologies are chosen by households. The most basic improved latrine technologies are relatively inexpensive, and program rules initially emphasized the need to avoid the use of subsidies; but protocols have evolved, and households no longer always pay the full capital costs. The awards or incentives provided to communities that achieve open-defecation-free status must also be included in the costs. Private costs include time spent in community meetings and also maintenance costs (time, water, cleaning agents, purchase of proper footwear). Project benefits include improvements in health, convenience, and time savings, and the privacy and dignity that come with proper toilet usage. The BC model used here does not account for either the privacy and dignity benefits associated with latrine use, or the disamenities associated with having space-consuming or malodorous latrines within the dwelling or yard. The model also does not include benefits from innovative designs that allow the productive reuse of urine or fecal material, such as humanure or ecofert toilets being tested in Zimbabwe.[10]

(c) *Biosand filters*

A third approach for breaking the fecal-oral transmission pathway is to improve the quality of drinking water at the point of use (POU). Water may become contaminated during transport from the drinking water source or from a water intake treatment plant to the home, or while stored in the house. Biosand filters are one simple technology that households can use to remove pathogens from their drinking and cooking water. They have important advantages over other POU technologies, such as boiling, chlorination (see next intervention), solar disinfection, other types of filters, or single-use chemical packets. For example, biosand filters are built from materials that are commonly available locally (PVC pipe, sand, gravel and a concrete or plastic chamber). They are also convenient, durable, and simple to use; household members simply pour water into the top of the filter and allow water to pass through the sand. Water can then be safely consumed almost immediately, and the health improvements are large (Clasen & Bastable, 2003; Clasen, Roberts, Rabie, Schmidt, & Cairncross, 2006; Fewtrell *et al.*, 2005). Vanderzwaag (2008) reports high breakage rates for filters in Nicaragua, but this does not appear to be a common problem.

The full costs of biosand filters are fairly high, especially when they must be transported (they are bulky and heavy). Program software costs for dissemination are limited to short training activities explaining the need to maintain the filters and the process for doing so). In programs implemented to date, households have paid very little to receive the filters. Thus uptake rates appear to be very high in intervention communities, though these are rarely reported (Table 2). The filters do require cleaning every few months and are less effective at pathogen removal for three to five days after cleaning. The BC model used here includes all of the filter costs and benefits, except the disamenities that arise from the space required by the biosand filter within the home, which can be significant, especially in densely populated slums.

(d) *Point-of use chlorination of drinking water*

Chlorination at the point of use may also help reduce the burden of waterborne diseases. Chlorination is highly effective for killing most bacteria and viruses and provides residual protection during storage if the dosage is correct. It is widely available and very cheap (Lantagne, Quick, & Mintz, 2007). There are also significant disadvantages associated with chlorination. For example, it is ineffective against some waterborne protozoa and viruses (including for example cryptosporidium); it is ineffective for treating turbid water; it requires careful monitoring of dosage and storage times; and many people complain that it causes taste and odor problems. Perhaps because of these factors, household chlorination rates have been found to decrease significantly over time following promotion campaigns (Lantagne *et al.*, 2007; Olembo, Kaona, Tuba, & Burnham, 2004). One approach for addressing this problem when people collect water from sources away from home might be to provide easy-to-use chlorine dispensers at the water source rather than expecting people to chlorinate their drinking water at home (Kremer *et al.*, 2008). But chlorination at the source would require the establishment of new institutional roles and responsibilities, and the delivery of such services in remote rural areas is likely to be complicated.

Our analysis is based on parameter values from the Safe Water System (SWS) programs conducted over the last 20 years by the Pan American Health Organization and the US Center for Disease Control (Lantagne *et al.*, 2007). The only capital costs in the SWS are for purchase of a safe container such as a 20-liter jerry can with a screw cap. Most programs depend on local NGOs for promotion, training, and marketing of products and therefore involve significant program costs, including training (on dosage) and general hygiene education. Operation and maintenance costs are for purchase and delivery of chlorine supplies. Many POU chlorination programs provide supplies to households free of charge, and social marketing of products is common. Initial uptake of subsidized products is typically high, but sustained usage varies widely (measured by the presence of a chlorine residual) (Table 2). The BC model does not include the esthetic disamenities resulting from taste and odor problems, but these may account for the wide variation reported in usage.

(e) *Insecticide-treated bed nets*

Numerous CE studies find that insecticide-treated nets (ITNs) are cost effective for the prevention of malaria (Hanson *et al.*, 2003; Lengeler, 2004; Mueller *et al.*, 2008). Different types of nets exist, one of which is the long-lasting insecticide-treated net (LLIN). LLINs have two main advantages: they are durable; and unlike normal ITNs, they do not require reimpregnation with insecticide every six months, a maintenance need that has proven problematic in other ITN interventions (Snow, Craig, Deichmann, & Marsh, 1999; Snow, McCabe *et al.*, 1999). There are various mechanisms for encouraging uptake and use of bed nets, ranging from free distribution to social marketing strategies, and these appear to have a substantial influence on rates of uptake (De Allegri *et al.*, 2010; Dupas, 2010; Mulligan, Yukich, & Hanson, 2008). There is much less information, however, on how different distribution methods influence long-term usage (Table 2). The dissemination of LLINs requires up-front expenditures for impregnated bed nets and for delivery and program administration. Users must accept the potential discomfort associated with sleeping under nets, which restrict movement and may restrict air flow; our BC model does not account for such disamenities. There are no operation and maintenance costs, and negligible training costs, associated with LLINs.

(f) *Cholera vaccination*

One strategy for preventing cholera cases is immunization with new-generation vaccines. These oral vaccines are cheap, are now being produced in Vietnam and India, and have been shown to be effective in field trials (Thiem *et al.*, 2006; Trach *et al.*, 1997). Cholera vaccination also provides herd protection to nonvaccinated individuals. As vaccine coverage rises among the target population, herd protection increases but at a decreasing rate (Ali *et al.*, 2005). Herd protection and lower local production costs greatly improve the cost-effectiveness of cholera vaccination programs (Jeuland, Cook, Poulos, Clemens, & Whittington, 2009; Jeuland, Lucas, Clemens, & Whittington, 2009). However, delivery costs and nonpecuniary private time costs of vaccine acquisition are important, especially because vaccine protection is thought to last only two to three years. User fees are rare for vaccinations, but uptake rates still vary a great deal depending on the design of the vaccination program (Table 2). One major advantage of vaccination, similar to the LLINs, is that no ongoing operation and maintenance costs are involved. In addition, household members do not experience any disamenities following immunization, though they may not like the vaccination experience itself.

5. RESULTS

This section presents the results of the benefit–cost analyses of the six interventions and the associated sensitivity analyses. We begin with a discussion of the magnitude of the different components of costs and benefits for each of the interventions, assuming that all parameters, including uptake and usage, take the midpoint values of the assumed ranges presented in Tables 3–5. We then present the range of outcomes from the Monte Carlo analysis for the different cases of usage and uptake. We close with additional sensitivity analyses concerning those behavioral assumptions.

(a) *The components of the net benefits of the six interventions*

At the median parameter values most of the economic benefits of these six interventions are due to improved health outcomes (Figure 1). Furthermore, the majority of these health benefits are due to reductions in mortality, not in morbidity. Because disease incidence factors into calculation of both mortality and morbidity, the morbidity burden reductions become relatively more important only if the VSL and disease case fatality rates are low, or if the COI is high. Total sanitation is the only intervention of the six that appears to deliver significant time savings, but the economic value of these is relatively small in comparison with that intervention's total health benefits. At the median parameter values, all interventions deliver positive net benefits. This result is consistent with the usual finding from the CEA and BCA literature that WASH interventions are economically attractive.

However, at the median parameter values the magnitude of the net benefits to a household from all of the six interventions is relatively modest. In absolute terms, the biosand filter and POU chlorination interventions offer the largest benefits to a household's well-being. These interventions would increase a household with a real income of US$1 per capita by about 2%, if the interventions were given to them free of charge. The handwashing and total sanitation interventions would increase such a household's real income by perhaps 1%, and cholera vaccination and impregnated bed nets by perhaps 0.5%, again assuming no user fees.

(b) *Heterogeneity of benefit–cost ratios*

The results of the Monte Carlo simulations tell a more nuanced story. If the behavioral parameters for uptake and usage are at their median values, there are many combinations of other parameter values that yield a BCR that is less than 1 for all six interventions (Figure 2). Depending on the intervention, anywhere from 20% to 55% of simulation outcomes have costs that outweigh benefits. When uptake and usage are both low, the proportion of outcomes with BCRs less than 1 increases from 40% to 90%. On the other hand, with high uptake and usage, fewer than 10% of simulations yield BCRs that are less than 1, except for the case of cholera vaccination (this result is explained below). The 90% confidence intervals from the simulations for all nine combinations of low and high uptake are presented in Table 6. These results show that there are nearly always plausible situations in developing countries for which each of the six interventions would fail a BC test, and that the magnitude of poor economic outcomes is highest when uptake is high and usage is low.

The results of these Monte Carlo simulations also show that developing a priority ranking of the interventions is much more complicated than commonly appreciated. Consider a single comparison of simulation outcomes, between the POU chlorination and total sanitation interventions. When usage and uptake are low (for both interventions), the majority of combinations of parameters lead to better BCRs for the total sanitation campaigns (that is, most outcomes lie above the dotted diagonal line in Figure 3). [11] When usage is high, the majority of combinations of parameters lead to better BCRs for POU chlorination. Yet in both cases there are a large number of simulation outcomes for which this ranking is reversed, in part because the factors that influence uptake of improved latrines and participation in total sanitation campaigns will generally be very different from those that lead to high uptake and sustained usage of POU chlorination. Our point is not to say that sanitation is more or less effective at delivering benefits than is chlorination, but simply to emphasize that the factors that lead to high sustained usage are not well known, and that these are likely to be highly contextual. Even for a case that would appear to favor one intervention (for example, the high-uptake case that appears to favor LLINs over cholera vaccines; see Figure 2), there are still parameter combinations for which cholera vaccination outperforms the LLINs.

We conclude that even if one could accurately predict uptake and usage (which is itself doubtful and highly dependent on unobserved factors that explain the demand for improved health services), it is impossible to develop a clear ranking of these interventions, without knowing the values of the other parameters in the BC model. These other parameters are largely site-specific and generally unknown.

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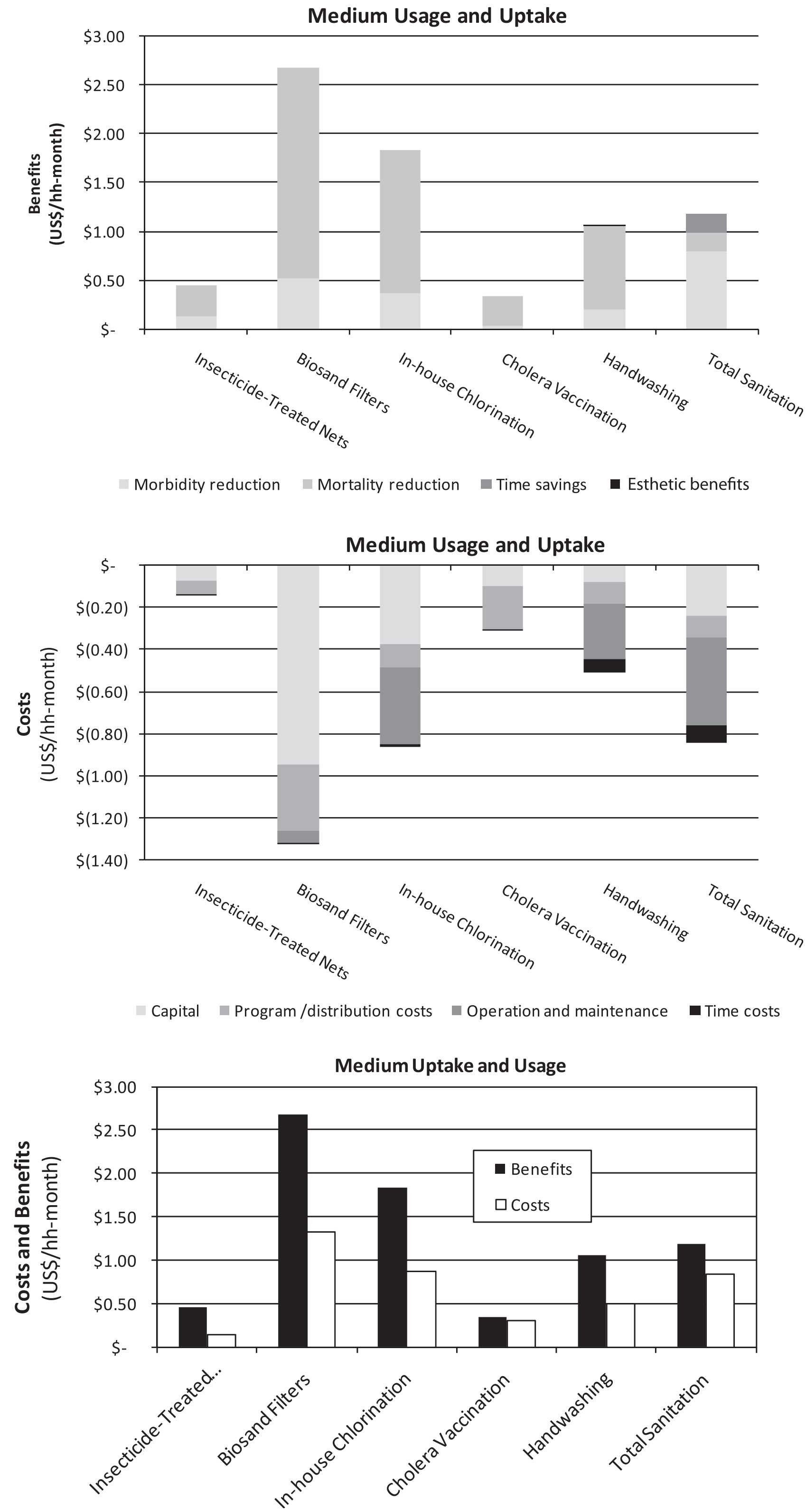

Figure 1. *Costs and benefits of the six interventions at median parameter values.*

(c) *The effects of assumptions about usage and uptake on benefit–cost ratios*

Although the increasing use of randomized controlled trials has offered new insights into household uptake and usage, predicting behavioral responses to each of these six interventions remains extremely difficult. Benefit–cost outcomes for these six interventions are quite sensitive to these behavioral assumptions. When usage and uptake are moderate and all other parameters are set at their median values, all interventions

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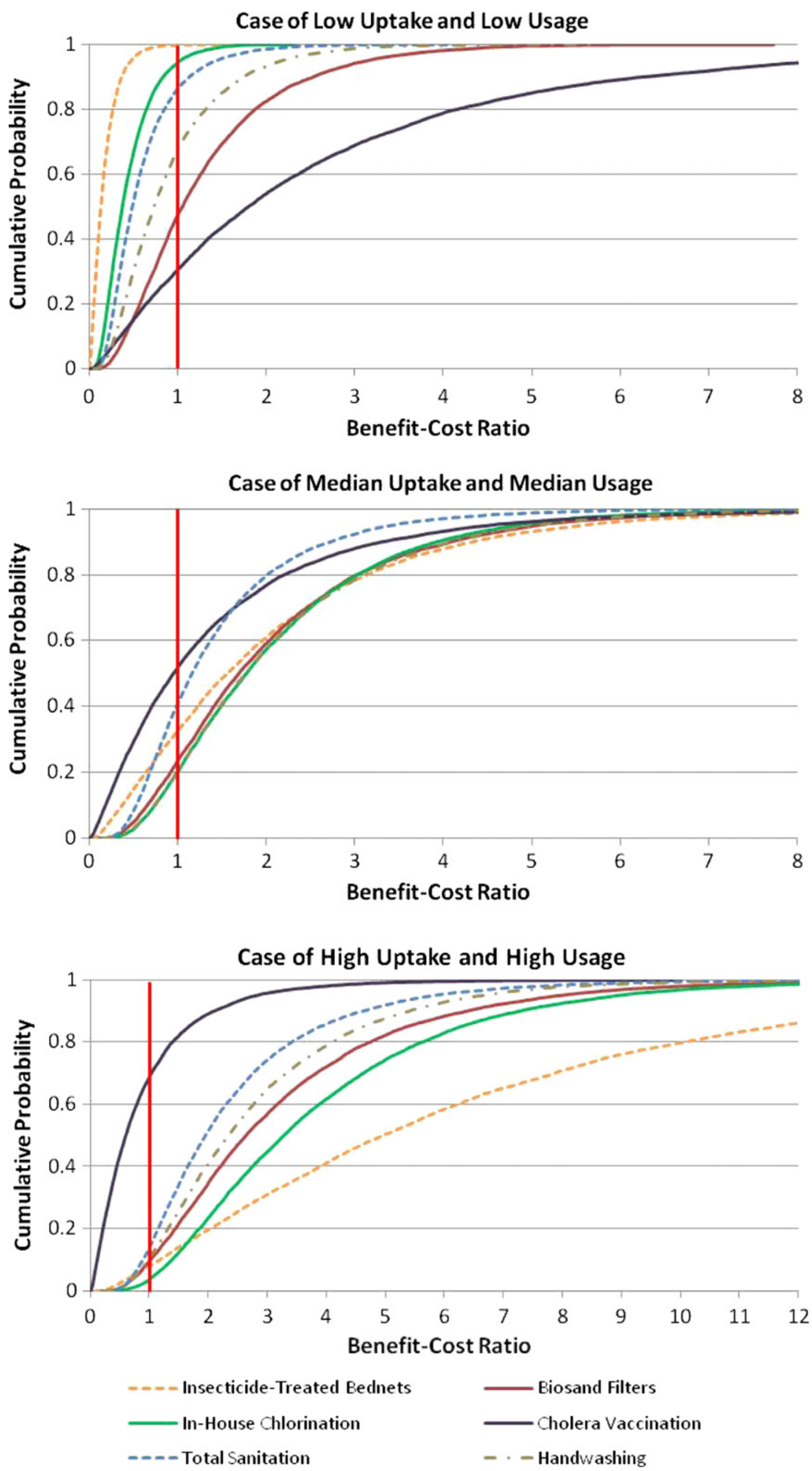

Figure 2. *Benefit–cost ratios from simulations for low, moderate and high cases of uptake and usage.*

deliver positive net benefits, though only barely for cholera vaccination. If usage and uptake are low, however, only the biosand filters and cholera vaccination deliver positive net benefits. If usage and uptake are high and if all other parameters are at their median values, cholera vaccination fails a BC test (the other five interventions all pass). When other parameters deviate from the median values, these outcomes will be better or worse, depending on the direction of those deviations.

For cholera vaccination, higher levels of uptake yield more outcomes with benefits less than costs than for lower levels of uptake. This result runs counter to the conventional wisdom among public health decision-makers that higher coverage levels are more desirable. Because herd protection increases with

Table 6. *90% Confidence intervals for benefit–cost ratios for the six interventions with different behavioral responses*

Usage	Uptake			
	Low	Median	High	No variation in uptake
	5–95%	5–95%	5–95%	5–95%
Low				
Handwashing	−0.2 to 0.9	−0.2 to 2.0	−0.3 to 3.0	
Total sanitation	−0.7 to 1.3	−0.6 to 3.0	−0.6 to 4.8	
Chlorination				−0.9 to 0.8
Biosand filters				−0.8 to 7.1
Long-lived insecticide nets	−0.1 to 0.0	−0.2 to 0.1	−0.3 to 0.1	
Median				
Handwashing	−0.1 to 2.5	−0.1 to 5.2	−0.1 to 7.8	
Total sanitation	−0.6 to 2.1	−0.4 to 4.7	−0.4 to 7.3	
Chlorination				−0.2 to 7.2
Biosand filters				−0.5 to 11.8
Long-lived insecticide nets	0.0 to 0.8	−0.1 to 1.8	−0.1 to 2.9	
High				
Handwashing	−0.1 to 4.1	−0.1 to 8.4	0.0 to 12.6	
Total sanitation	−0.5 to 3.0	−0.3 to 6.5	−0.1 to 10.0	
Chlorination				0.3 to 14.0
Biosand filters				0.0 to 18.7
Long-lived insecticide nets	0.0 to 2.7	0.0 to 6.0	0.0 to 9.3	
No usage				
Vaccination	0.0 to 0.9	−0.3 to 2.0	−0.6 to 2.1	

vaccine coverage levels at a decreasing rate, each additional vaccination delivers marginal protection that is decreasing in coverage. Unless significant economies of scale (decreasing unit costs) are also gained by delivering large numbers of vaccinations, which is unlikely, the marginal net benefits of vaccination will thus decrease as coverage increases (Cook *et al.*, 2009). This is indeed what happens in our model results, as herd effects have been included and marginal costs of vaccinations are assumed to be constant.

Although empirical evidence of herd protection for the other interventions is largely absent, this result may well apply to the other preventive health interventions modeled in this analysis. The possibility of a nonlinear relationship between herd protection and extent of coverage warrants careful consideration in the design of subsidy schemes and user fees, because the net economic benefits of achieving higher uptake may be overstated by our analysis. The advantages of subsidized provision would thus be reduced, and the optimal subsidy (from an economic efficiency perspective) would be lower than expected.

One-way sensitivity analyses confirm that these economic outcomes are quite sensitive to behavioral assumptions. For example, Figure 4 shows that the LLIN intervention outcomes are highly sensitive to assumed usage rates; this is both because reported usage rates vary widely for this intervention (15–80%) and because almost all of the costs of the intervention are the up-front costs of providing the LLINs. The net benefits of in-house chlorination are also sensitive to usage rates (again due to the wide variation in measured usage, 10–80%). The biosand filter and LLIN outcomes are especially sensitive to declines in usage over time. Cholera vaccination is most sensitive to uptake rates. Total sanitation is also most sensitive to uptake rates because usage appears to be relatively high among households that invest in this technology.

Isolating the effects of uptake and usage reveals several other important points (Figure 5). First, the contribution of uncertainty about usage to variation in economic outcomes is greatest when uptake is high. This is because a greater number of people could potentially receive health benefits when ownership of the improved technologies is high and costs have been incurred. Usage then makes a large difference in the extent to which those benefits are realized.

Second, when usage is low, increasing uptake may actually reduce net benefits on average (as shown for LLINs in Figure 5). This occurs because capital costs increase faster than benefits, which are suppressed by low usage rates. This potential problem will be most important for capital-intensive interventions or in locations where the other parameters (incidence, case fatality rates, etc.) result in lower benefits. This effect of capital intensiveness is one important reason why the water/sanitation and hygiene sector has widely adopted a demand-driven planning model and user fees, that is, to avoid including in a program people or communities that are unlikely to utilize and/or maintain a technology. In contrast, the nonWASH preventive health sector has favored free distribution of impregnated bed nets and vaccines in order to increase uptake.

Third, for interventions that suffer from declining usage over time, user attrition can significantly reduce net benefits. Again, this effect is greatest when uptake is high, because the fixed costs of program software have already been incurred.

Fourth, as shown by the example of cholera vaccination, the possibility of herd protection effects adds significantly to the uncertainty in the economic analysis. If herd protection were to be demonstrated for the five interventions in addition to cholera vaccination, the most efficient levels of uptake would be hard to predict and would depend on the nature of the relationship between herd protection and type of coverage. This would be true even if one ignored behavioral feedback from herd protection (owing to reduced risk of disease) and the resulting reduced uptake or usage of the intervention.

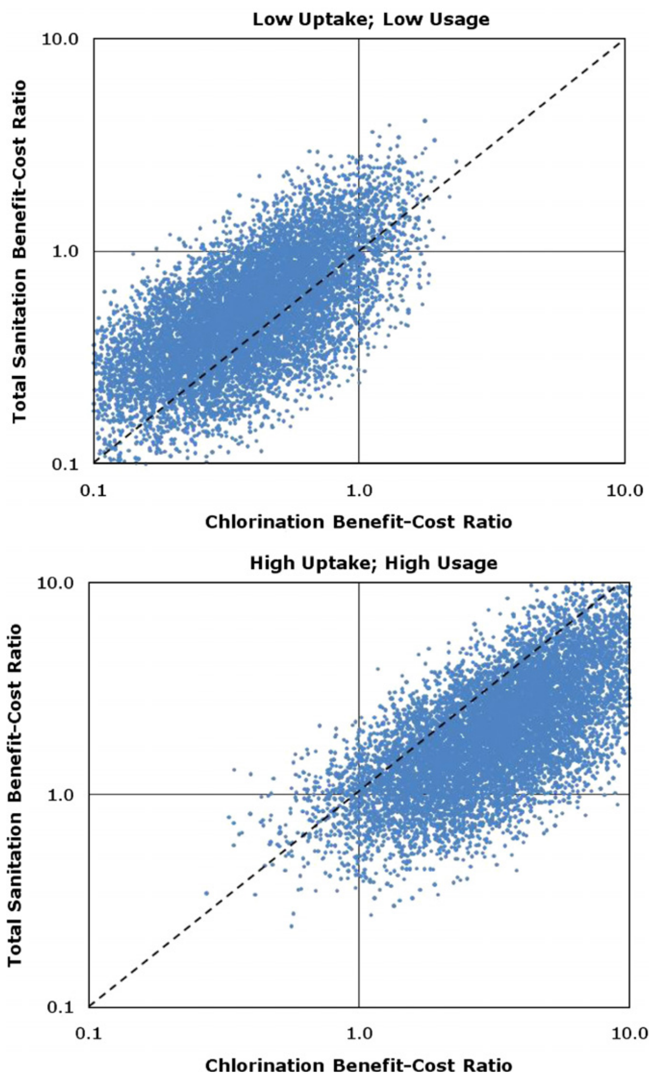

Figure 3. *Scatter plot of BCR outcomes from simulations of chlorination and total sanitation interventions, for low and high cases of uptake and usage (dotted diagonal represents the line for which the two BCRs are equal).*

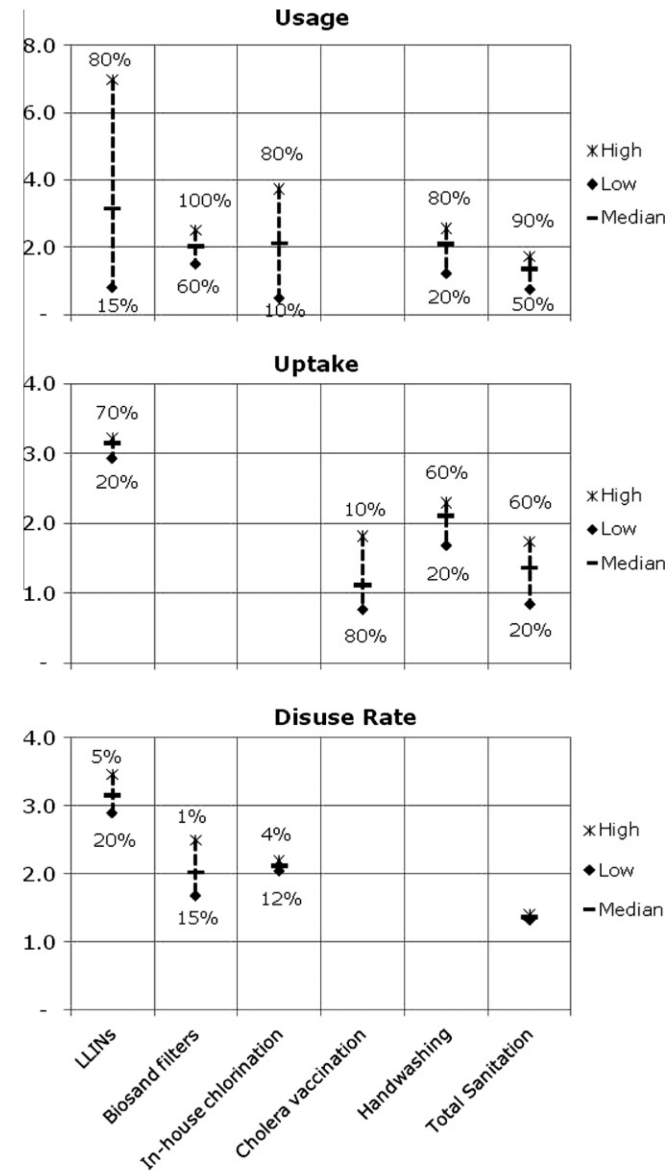

Figure 4. *One-way sensitivity analyses on the behavioral parameters—assumed values are shown—for the different interventions (all other parameters set at median values).*

6. DISCUSSION

Researchers have spent decades debating the effectiveness of water and sanitation and hygiene and preventive health interventions and trying to bring them successfully to scale. Many questions remain, and the market penetration of such interventions, particularly in places that appear to need them the most, often remains limited. It seems that households in many developing countries remain unconvinced that the interventions provide them with the benefits that many donors and public health experts anticipate. We have illustrated here one reason why debates over the economic attractiveness and implementation of these interventions continue. Information on parameters such as burden of a disease and case fatality rates, which are critical in households' economic calculations but are generally unknown to policymakers, is very expensive to obtain. Moreover, local conditions are nonstationary, which implies that point estimates carefully measured by comprehensive research enterprises may quickly become outdated. Research results can take decades to be translated into practice; in the meantime, new technologies are developed, new policies are implemented, and households' behavioral incentives and priorities change.

Our calculations indicate that typical water and sanitation and hygiene and preventive health interventions (such as those analyzed in this paper) may be extremely attractive economic investments in many locations, but not in others. This finding has a number of important implications, and contradicts the prevailing wisdom that the economic case for them is always clear cut (see for example the arguments presented by the Water and Sanitation Program of the World Bank, available at: http://www.wsp.org/wsp/content/economic-impacts-sanitation). It follows that setting priorities among competing interventions at the global level, and between these health interventions and investments in other sectors, is generally inappropriate. Using benefit–cost rather than cost-effectiveness analysis, it is easier to see why there is such pervasive uncertainty associated with the economic outcomes experienced by households in developing countries.

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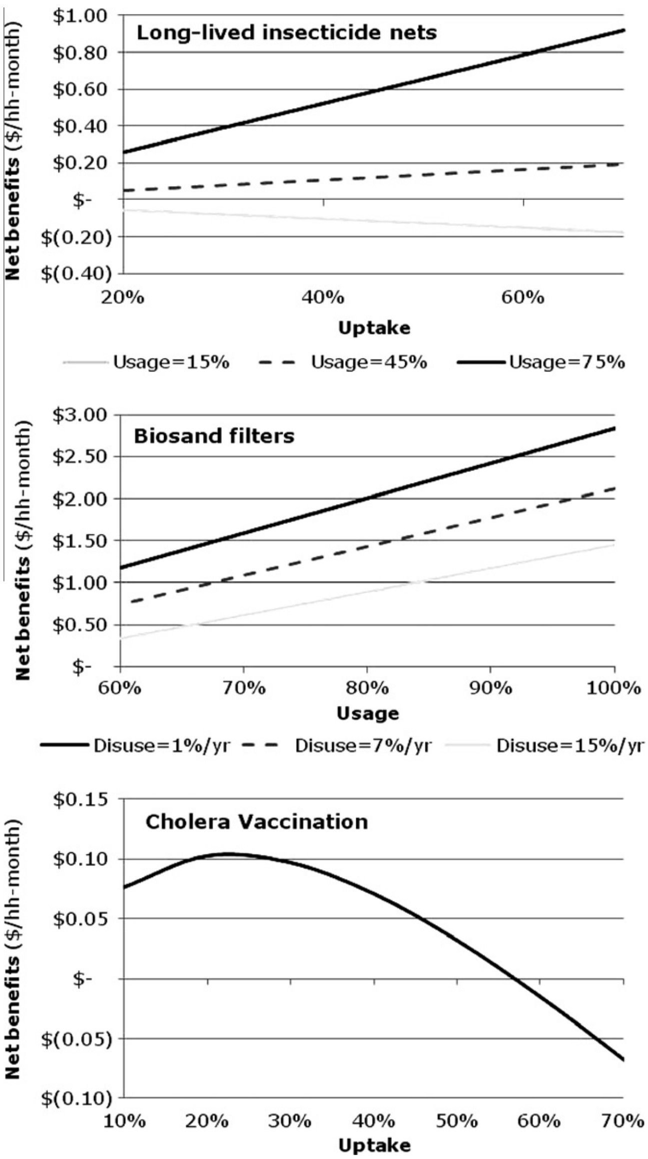

Figure 5. *Selected model relationships between net benefits and usage and uptake parameters (all parameters not shown are set at median value).*

Benefit–cost analysis requires identification not only of health outcomes but of the nonhealth outcomes, which are especially important in understanding how households' behavior can shape predictions of usage and uptake of desired interventions.

The wide variation in plausible benefit–cost outcomes and the extreme uncertainty of the calculations in the analysis presented here raise a fundamental question: Is centralized priority-setting the best planning approach? One critical assumption in the current donor push for "evidence-based policy" is that central planners will be able to chart the most effective course of action once they know the results from a few more rigorously-designed randomized control trials. In contrast, our findings suggest that intensified research will not easily remove the high level of uncertainty that plagues global priority-setting exercises. Too many of the important parameters that factor into benefit–cost (or cost-effectiveness) calculations for the interventions being compared may vary over space and time and may remain unknown to policy makers. Moreover, most existing program evaluations probably overestimate usage and underestimate disuse over time, due to Hawthorne effects and the short duration of the evaluations.

Global health planners face severe information constraints in their efforts to set program priorities and target subsidies. Thus the establishment of "evidence-based" priorities remains an elusive goal, fostered by what some have called "scientistic prejudice" (Hayek, 1974), and the external validity of research findings is weak (Zoellick, 2010). As a result, there is a strong case for decentralizing program design and investment decisions to the regional and local levels where people are more likely to have firsthand, experiential data that they can use in decision making about efficient allocation of resources. Part of this task involves building decision-making capacity among government officials in developing countries and among sector professionals engaged in fieldwork, and enabling cross-sectoral investment planning at the regional and local levels. Local knowledge and information seems an important tool in avoiding white-elephant projects and outcomes (Altaf, 2011). So long as potential beneficiaries are properly consulted when planning interventions, local authorities closest to beneficiary households are most likely to predict accurately whether the context for particular interventions is right and whether uptake and usage of interventions at a specific time and place is likely to be satisfactory. As we have shown, these interactions between context and behavior greatly affect economic outcomes. However, transparent and sufficient user consultation at the local level should not be assumed, and local authorities may allocate resources based on favoritism rather than on actual benefits, suggesting the need for enhancing accountability in decentralized programs.

One reaction to the findings presented here might be to question whether a "mistake" could be made, in the sense of investing in one of the analyzed interventions where costs turned out to exceed benefits. One could argue that all such initiatives have some wastage; are not some "mistakes" inevitable? And on equity grounds, is it not justifiable to deliver benefits to poor beneficiaries via highly subsidized services, even if economic efficiency suffers? Our own view is that behavioral, financial, and institutional issues need to be carefully considered to ensure long-term success for programs of this nature. Donor funding alone will never be sufficient to finance completely the health care and basic infrastructure needs of poor populations. The active involvement of local and national governments in setting investment priorities, managing programs, and paying for services is also necessary. Without local ownership, it will be difficult to avoid the moral hazard that could diminish the financial resources allocated to maintain free or highly subsidized goods and services.

Overgeneralization and misunderstanding of individuals' preference tradeoffs are one reason why many international aid projects prove unsustainable in the long term. Unfortunately, from the perspective of global planners, there are no easy answers to this problem. All of the interventions selected for our analysis rely on personal and community behavior change to be successful. A key challenge is to adapt and implement context-appropriate mechanisms and incentives to accomplish desired changes, so as to avoid costly mistakes. Sometimes this may involve limiting uptake using price as a "demand filter"; other times uptake might need to be stimulated. Which strategy to pursue will depend on local circumstances. Seen in this light, innovations in design (technological features, community participation, facilitation of

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operation and maintenance) and delivery mechanism (free or subsidized distribution, social marketing, market provision, etc.) can only do so much. These innovations are unlikely to provide a silver bullet for resolving the problem of scaling-up interventions. The difficult task remains of establishing and developing effective institutions that deliver financially sustainable services. This is especially true for capital-intensive interventions in the water and sanitation sector, where services must be rendered and monitored on a continuous, long-term basis (unlike one-time or occasional interventions such as vaccines or bed nets).

With modest "demand filters," the chances of a "mistake" in investing in piped water and sanitation services in a dynamic, growing economy are relatively modest. There is compelling global evidence that people everywhere want piped water and will use it, even when they cannot afford the full costs (Devoto, Duflo, Dupas, Pariente, & Pons, 2011; Whittington, 2010). The screening effect of "demand filters" may in some instances better reveal which households really want and benefit from particular interventions than do observable household characteristics (Ashraf *et al.*, 2010). For piped water and sanitation, subsidies are widespread because governments have correctly read household preferences (Whittington, 2010). We are not convinced this is always the case for the six interventions analyzed here. Cholera vaccination programs will do little good if the burden of disease is low. Bed nets that are simply packed away or water disinfectant that is used only for washing clothes will not do much to increase human well-being.

Our findings resonate with the following observation by Douglas North, the 1993 Nobel Laureate in Economics:

> We should be very tentative about how we understand the world. That doesn't mean you don't do things. You've got to do things, but you've got to recognize that you may be wrong. We don't know enough. And so it is terribly important to recognize that you can be wrong, and to be, therefore, very susceptible to modifying the theories you hold in light of new evidence (quoted in King and Schulz (2009)).

More recently, other scholars have also emphasized the need for caution in setting policy on the basis of "evidence" and what analysts claim to know (Green, Ottoson, Garcıa, & Hiatt, 2009; Manski, 2010). Even so, as North notes, decisions must be taken in the face of uncertainty, and we believe our results point toward three concrete policy directions.

First, the information required for the economic analysis of water and sanitation and hygiene and preventive health interventions at the global level, with the precision needed to set programmatic priorities, is generally unavailable. This problem is not going to be solved. This finding provides strong support for a policy of decentralization, moving decisions about priority setting and targeting subsidies out of the central offices of large donors and international organizations. Incorporating local knowledge of health and environmental conditions and of household preferences and behavior into decisions on the targeting of subsidies among competing interventions requires greater involvement by governments and local decision makers in developing countries. We are not arguing that local decision makers have all the information they need for setting priorities, or that decentralization is a panacea. But decision makers in developing countries are best positioned to use their knowledge, experience, and intuition about what will actually work at a particular time and place.

Second, government officials in developing countries often seek assistance from the global community in thinking systematically about issues of targeting and priority setting. Our findings point to the need for capacity-building efforts in economic analysis at both the national and regional levels to ensure timely and successful health interventions. Professionals in this sector need training in the use of policy and decision analysis, including economic tools such as cost-effectiveness and benefit–cost analysis, in order to evaluate investment options systematically and grasp the implications of findings and experience from other parts of the world. Many donors and organizations (e.g., the Global Development Network) are now actively engaged in such capacity-building efforts, and this work should be more strongly supported.

Third, improved basic knowledge of the determinants of usage and uptake in water/sanitation and hygiene and preventive health interventions under a variety of local conditions is an important global public good. Of particular importance is developing a better understanding of when user fees are needed to screen potential recipients efficiently, and when they are not, so as to maximize the net benefits of particular interventions. Also critical are efforts of the research and donor community to understand the heterogeneity of impacts among users, particularly when groups marginalized by the power structure—for example women or children—are involved. In addition, governments and other institutions working in developing countries routinely seek assistance in understanding program effectiveness and measuring program outcomes. These institutions will likely continue to ask for such help in the future. International organizations and academic researchers have a comparative advantage in supporting the production of this kind of knowledge, but they will need to continue to collaborate and engage with experienced local, regional, and national sources from a wide variety of developing countries to most effectively produce and disseminate such knowledge.

NOTES

1. Household demand for water from nonnetwork suppliers (e.g., water vendors) is also price inelastic. Households are often willing to pay for increases in water quantity, but demand for water-quality improvements is low in many places.

2. Consider a simple example calculation. Suppose that the following ranges are possible for each of these parameters in a given location: (a) $Inc_{before} = 0.1$–0.5 cases/person-yr; (b) $CFR = 1$–3%; (c) $Eff = 50$–80%; (d) $VSL = \$100{,}000$–$\$300{,}000$. The mortality gains could range from a lower bound of \$50/person-yr to an upper bound of \$3,600/person-yr. In general, even in a specific location, there will be much more uncertainty in each of these parameters than this simple case suggests. Generalizing to a large number of locations will be even harder.

3. One explanation that is frequently offered for the low uptake and usage of these and other similar types of interventions is that individuals do not understand their own self-interest. There is evidence to support this interpretation, but we believe that observed outcomes are not solely due to "irrational" behavior.

4. It is important to recognize the limitations of the COI measure for measuring the economic benefits of reduced morbidity. The avoided COI benefits will be inaccurate when individuals are able to adopt behaviors that reduce their risks of illness ex ante, such that the sample of sick individuals for whom COI is known may not be representative of all affected persons. Another problem is that COI does not include the disutility associated with the nonpecuniary pain and suffering associated with nonfatal illness.

5. VSL is typically obtained from studies that look at large numbers of individuals' risk-wage tradeoffs or expenses on private goods that reduce mortality risks, such as safety products or sickness-prevention technologies (e.g. vaccines, prophylaxis, etc.).

6. It is not as common in the literature as one might expect for estimates of the economic benefits of water and sanitation improvements to include nonhealth benefits such as time savings. Full cost accounting is also unusual. An exception is the WASH cost project financed by the Bill and Melinda Gates Foundation, which has costed interventions across the full life cycle, including, for example, the cost of soap in hygiene (http://www.washcost.info).

7. Note that judgment is required to characterize typical programs and implementation modalities, as well as the results such programs are capable of generating.

8. A tippy tap is made by suspending a plastic jug of water from some sort of crossbar; a hole is made in the jug so as to release a small stream of water when the jug is tipped, usually by a simple foot pedal connected to it with string; the jug rights itself when the pedal is released. This permits users to wet their hands briefly without directly touching the jug. A bar of soap may be tethered to the crossbar as well. This "tap" has several advantages: it is cheap and made of locally available materials; it releases only small amounts of water in successive tips and causes few local drainage problems; and if properly used (with a foot pedal), it addresses concerns about cross-contamination.

9. Most importantly, households must accept usage of latrines or toilet facilities within their private homes. Surprisingly, a significant number of new, subsidized latrines are never actually used.

10. See for example studies on urine diversion toilets in Nepal and Zimbabwe (Guzha, 2006; WaterAid, 2008). http://www.wateraid.se/pdf/sanitet/WaterAid_beyond_construction.pdf

11. This is because we assumed that the lower bound for usage in the case of sanitation is higher than it is for point-of-use chlorination. The literature suggests that this is the case. However, usage rates are rarely measured in practice, so one should not place much confidence in this result.

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.worlddev.2012.03.004.

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