

# Benefit-Cost Analysis of Community-Led Total Sanitation: Incorporating Results from Recent Evaluations

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# Benefit-Cost Analysis of Community-Led Total Sanitation: Incorporating Results from Recent Evaluations

Mark Radin,<sup>1</sup> Marc Jeuland,<sup>2</sup> Hua Wang,<sup>3</sup> and Dale Whittington<sup>4</sup>

## Abstract

We analyze the costs and benefits of “Community-Led Total Sanitation” (CLTS), a sanitation intervention that relies on community-level behavioral change, in a hypothetical rural region in Sub-Saharan Africa with 200 villages and 100,000 people. The analysis incorporates data on the effectiveness of CLTS from recent randomized control trials (RCTs) and other evaluations. We value reduced mortality benefits by adjusting estimates for the value of statistical life (VSL) from high income countries to reflect incomes in Sub-Saharan Africa. Reduced morbidity benefits are calculated using a cost of illness (COI) approach based on recent studies quantifying the cost of diarrheal disease in Sub-Saharan Africa. Time savings from owning a latrine are valued using estimates for the shadow value of time based on a proportion of the average local wage. Costs include the cost of intervention implementation and management, households’ time costs for participating in the community behavioral change activities, and the cost of constructing latrines. We estimate the net benefits of this intervention both with and without the inclusion of a positive health externality, which is the additional reduction in diarrhea for an individual when a sufficient proportion of other individuals in the community construct and use latrines and thereby decrease the overall load of waterborne pathogens and fecal bacteria in the environment. We examine the sensitivity of the results to changes in the effectiveness of the CLTS intervention. A probabilistic sensitivity analysis using Monte Carlo simulation is used to examine the sensitivity of the results to changes in all of the parameters in the benefit-cost model. We find that CLTS interventions would pass a benefit-cost test in many situations, but that benefit-cost metrics are not as favorable as many previous studies suggest. The model results are sensitive to baseline conditions, including the income level used to calculate the VSL, the discount rate, and the time spent traveling to defecation sites. We conclude that many communities will have economic investment opportunities that are more attractive than CLTS, and recommend careful economic analysis of CLTS in specific locations.

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## I. Introduction

One of the most important remaining global challenges facing professionals in the water, sanitation, and hygiene (WASH) sector is how to end the practice of open defecation in South Asia and Sub-Saharan Africa. While there is universal agreement that open defecation is a serious problem, governments have limited policy options for addressing it. The most common approach has been to subsidize construction of improved pit latrines, but having a latrine does not ensure that a household will use it. The economist's standard prescription of a tax or fine on the negative externality<sup>1</sup> resulting from poor disposal of feces is common throughout high-income countries, but is commonly judged to be politically infeasible in low-income countries (Braütigam et al., 2008). Health education interventions have met with limited success (Garn et al., 2017).

The WASH community was thus understandably excited at the beginning of the 21<sup>st</sup> century when a new and promising approach – “Community-Led Total Sanitation” (CLTS) – was added to its arsenal of tools to end open defecation. This community-level behavioral change technique was developed by Dr. Kamal Kar and rolled out in Bangladesh beginning two decades ago (Kar and Chambers, 2008). CLTS has since been promoted by most major donors working in the WASH sector, including the World Bank, UNICEF, and the Water Supply and Sanitation Collaborative Council's Global Sanitation Fund. CLTS interventions have now been implemented in approximately sixty countries, and today the approach is mentioned in the official rural sanitation policies of about thirty countries (USAID, 2018).

The approach taken in a CLTS program is very different from that of most other health education interventions. Instead of teaching people about the health benefits households can obtain from improved sanitation, CLTS facilitators conduct community participatory exercises that aim to “trigger” behavioral change by engendering a sense of shame and disgust among village residents who engage in open defecation, leading to a community rather than an individual or household response. The approach has offered WASH practitioners hope that there is a practical, low-cost way to end open defecation practices in situations where other policy instruments have failed.

Importantly, the rise in CLTS has been accompanied by a large body of research focusing on its impacts. Over the past decade, numerous randomized controlled trials and field studies have been conducted to estimate the effects of CLTS on a range of outcomes, such as reduction

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<sup>1</sup> We define a sanitation externality as the benefit accruing to an individual due to the sanitation choices of other people in the community. For illustration purposes, imagine that the members of household A decide to construct and use a latrine. Members of household A will then experience a health benefit due to this behavior change (this is not an externality). Additionally, members of household B experience a health benefit when the members of household A no longer defecate in the open (this is an externality). The members of household A's decision to construct and use a latrine therefore reduces the total load of waterborne pathogens and fecal bacteria in the environment, which benefits individuals in household B, as well as any other individuals in the community, regardless of their own specific sanitation behaviors. Thus, everyone benefits from a cleaner environment and experiences a decrease in diarrhea rates. As discussed later in the paper, we assume that this sanitation externality only exists when a sufficient percentage of households use a latrine, however. Once the percentage of households using a latrine passes this threshold, we assume that everyone benefits from the cleaner environment, at a rate that is increasing in that level of use.

in open defecation, increase in latrine ownership, and reduction in diarrhea prevalence (Pattanayak et al., 2009; Elbers et al., 2012; Cameron et al., 2013; Patil et al., 2014; Pickering et al., 2015; Guiteras et al., 2015; BDS-Center for Development Research, 2016; Hammer and Spears, 2016; Makotsi et al., 2016; Crocker et al., 2016a; Crocker et al., 2016b; Crocker et al., 2017a; Briceño et al., 2017; Orgill-Meyer et al., 2018). However, no benefit-cost analyses (BCAs) of CLTS interventions have incorporated the body of new evidence emerging from these studies. The purpose of this paper is to fill this gap in the literature.

The next, second section of the paper describes both the methodological approach and the findings of the limited number of benefit-cost studies that have been conducted on sanitation interventions (including CLTS) in low and middle-income countries. The third section then presents an overview of the benefit-cost model that we use to compare the benefits and costs of a representative CLTS campaign rolled out in a hypothetical region in Sub-Saharan Africa covering 200 villages. The fourth section summarizes the assumptions made for the parameters in this model, including new evidence from recent studies regarding the effectiveness of CLTS and the potential positive externality from improved sanitation. The fifth section presents the results of the benefit-cost calculations, including sensitivity analyses, and the sixth section concludes.

## II. Review of Previous Benefit-Cost Analyses (BCAs) of Sanitation Interventions (including CLTS) in Low- and Middle-Income Countries

We identified and reviewed fourteen studies that have previously compared the costs and benefits of sanitation interventions in low and middle-income countries (Table 1). Only three of these studies were published in peer-reviewed journals (Hutton et al., 2007; Whittington et al., 2009; and Whittington et al., 2012). Most of the studies were commissioned by the Copenhagen Consensus Center as part of their global and regional priority setting activities (Whittington et al., 2009; Rijsberman and Zwane, 2012; Hutton, 2015; Larsen, 2016; Whittington et al., 2017; Sklar, 2017; Larsen, 2018a; and Larsen, 2018b). The World Health Organization sponsored two early studies (Hutton and Haller, 2004; and Hutton et al., 2007). Two studies were conducted as part of the World Bank's "Economics of Sanitation Initiative" (Heng et al. 2012, and Winara et al., 2011). Hutton et al. (2018) is the most recent study included in the review and was sponsored by UNICEF to assess the benefits and costs of a national sanitation program in India.

These BCAs of sanitation interventions have a number of common features. First, all include the economic benefits of reduced mortality and morbidity from sanitation-related diseases, and most include the time savings from no longer walking to a place to defecate away from home. The authors of these studies also identify numerous other possible benefits, such as improved privacy, aesthetics, safety, dignity, and convenience. However, only the studies from the Economics of Sanitation Initiative (ESI) and Hutton et al. (2018) included any information on preferences for non-health and non-time benefits. These studies presented findings from surveys that included questions that asked households, businesses, and tourists how satisfied they were with sanitation conditions and environmental quality in potential intervention communities. However, these data on satisfaction were not monetized and were therefore not ultimately included in BCA calculations. Both Whittington et al. (2012) and Larsen (2018a and 2018b)

mention the possibility of a disamenity associated with ending open defecation, but only Larsen (2018a and 2018b) attempted to assign a monetary value to this disamenity.<sup>2</sup>

Second, most studies use the household as the unit of analysis. In contrast, the CLTS approach considers open defecation to be a community problem. Third, all fourteen existing BCAs use the benefit transfer approach, taking findings from other studies to both measure and value the health impacts of the sanitation intervention. The BCAs rely on systematic literature reviews, meta-analyses, or other studies to estimate reductions in disease, most often reductions in diarrheal morbidity and mortality. All the BCAs use benefit transfer techniques to assign monetary values to sanitation-related health outcomes, instead of estimating such values using primary data collection and nonmarket valuation techniques applied within the study sites.

Fourth, only one of the fourteen studies attempted to include a positive externality from improved sanitation; all others only estimated diarrhea reductions among households adopting a latrine. Hutton et al. (2018) instead estimated diarrhea reductions at the community level, which includes households that use a latrine and households that do not. Hutton et al. (2018) transferred a functional relationship between community diarrhea risk reduction and community latrine coverage as estimated by Andres et al. (2017) using survey data from India. Andres et al. found that latrines have only a small effect on diarrhea risk when fewer than 20% of the households in a community have a latrine. After community latrine coverage reaches 20%, diarrhea risk reduction appears to increase linearly with community latrine coverage. Beyond a coverage level of 75%, risk reduction increases faster and nonlinearly in community latrine coverage.

In their BCA, Hutton et al. (2018) also relied on the analysis of a household survey that found that only 85% people in households with latrines constructed due to the intervention in rural India reported using a latrine. The authors assumed this 85% was representative for all households and applied the model from Andres et al. (2017) to estimate a 34% diarrhea reduction for each household adopting a latrine due to the intervention. Since the BCA only analyzed the impact on households newly adopting a latrine, they did not value the benefits accruing to households that already had a latrine before the intervention but experience a further reduction in diarrhea due to externalities.<sup>3</sup>

Despite these similarities, the existing BCAs of sanitation interventions also have several important differences. First, some of the early studies of the economic costs and benefits of improved sanitation did not attempt to evaluate real-world sanitation interventions and their

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<sup>2</sup> One of the interventions Larson (2018) evaluated was a program that targeted individuals in households with latrines but who did not use the latrines. When calculating the cost of these intervention, Larson (2018) included the disamenity of using a latrine. While the value of this disamenity is unknown, Larson (2018) noted from a survey presented in Hutton et al. (2018) that the two most common reasons for individuals not using a latrine even when they had access to one were: 1) that they preferred open defecation or 2) that latrines were unclear or lacked sufficient water. Therefore, the disamenity was valued by calculating the value of time spent on open defecation and the cost of cleaning a latrine (as a lower bound estimate for the disamenity among those not using latrines). This total value was included in the cost of the sanitation promotion intervention. In a final BCA this would have the effect of negating any benefits from time savings.

<sup>3</sup> If 100% of households had used a latrine, Hutton et al. (2018) estimated that there would be a 47% decrease in diarrhea based on results from Andres et al. (2017).

associated outcomes. Instead, authors asked a hypothetical question: “What would the costs and benefits be if there were an ‘ideal intervention’ that could eliminate open defecation and the use of substandard sanitation infrastructure?” The costs of this intervention were assumed to be the infrastructure costs of installing improved sanitation facilities for everyone currently without coverage, and the benefits were assumed to be a complete (100%) reduction of all current (status quo) losses from poor sanitation.

Alternatively, the intervention could be assumed to achieve a specified improved sanitation coverage target. For example, Hutton and Haller (2004) and others (Hutton et al. 2007; Hutton, 2015; and Larsen, 2016) attempted to estimate the costs and benefits of an intervention that would achieve the Millennium Development Goal (MDG) of universal coverage. These studies implicitly assumed that all households would use the sanitation facilities once they were built. The authors of these studies uniformly argued that sanitation investments easily passed a benefit-cost test, and that investments in sanitation infrastructure should therefore be increased. However, neither of these two approaches – based on “ideal” interventions or on the achievement of a specified target – accounted for all of the non-infrastructure-related costs of achieving complete behavior change, especially the costs of reaching households that do not readily adopt new sanitation technologies.

In contrast, the majority of previous economic analyses tried to evaluate actual sanitation interventions, using field evidence about their uptake and effectiveness (Heng et al. 2012; Hutton et al. 2018; Larsen 2018a; Larsen 2018b; Rijsberman and Zwane 2012; Sklar 2017; Whittington et al. 2009; Whittington et al. 2012; Whittington et al. 2017; and Winara et al. 2011). These studies accounted for household responses to sanitation interventions in terms of uptake of improved sanitation technology, and then estimated the economic benefits that would result from those adoption rates. Although most of these studies suggested that the benefits of intervention would exceed their costs, the benefit-cost ratios (BCRs)<sup>4</sup> were unsurprisingly much lower than those that postulated an ideal intervention (see Table 1).

A second major difference among these fourteen analyses is how the authors included the costs of the software<sup>5</sup> components of the sanitation interventions. Most studies included the hardware costs, which include the cost of the improved infrastructure, and some software costs, such as the costs of education or behavior change activities. However, it is unclear in many of the studies whether these program costs included administrative effort, facilitator time, training costs, and community members’ time spent on CLTS activities. Given the very low program costs commonly assumed in the BCAs, it seems likely that these costs have been systematically underestimated in most of this prior literature.

For example, Hutton and Haller (2004), Hutton et al. (2007), Hutton (2015), Larsen (2016), Rijsberman and Zwane (2012), Larsen (2018a), Larsen (2018b), and Hutton (2018) all

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<sup>4</sup> It is well known that relying solely on BCRs is problematic if costs are treated as negative benefits, whereas net benefits and the economic rate of return are not sensitive to such definitions. In this case, all costs are treated as costs (not as negative benefits) and all benefits are positive; therefore, the BCR is a sufficient and reliable metric for comparing the BCA outcomes.

<sup>5</sup> Software refers to those project components that focus on program promotion and behavior change (including the promoters’ labor costs), while hardware refers to the physical inputs required to construct a latrine, such as wood, fuel, or cement.

assumed that per household software costs were only 5% of the capital costs of a latrine. On the other hand, Heng et al. (2012) collected primary data and found that the software costs were actually higher than the costs of latrine construction on a per household basis (US\$54 vs. US\$20 per household). Whittington et al. (2009), Whittington et al. (2012), Whittington et al. (2017) included software/program costs that were between two and six times larger than the capital costs of the latrines. Additionally, most studies calculated total costs by aggregating the per-household cost—including both software and hardware costs-- of households that were assumed to construct a latrine. On the other hand, in order to account for the community-level nature of the CLTS intervention, Whittington et al. (2009, 2012, 2017) included software costs for all households in a target community (i.e. all households “treated” by the behavior change element of the CLTS campaign), and not just for those that built a latrine.

Third, authors of these prior studies made very different assumptions about how to value time savings from reducing the time required to travel to and from open defecation sites. As a result, time savings as a percentage of total benefits have varied from 15% to 80%. Moreover, none of the studies used estimates of the value of time savings that were based on primary data collected in the locations being considered for CLTS intervention. Instead, most valued time savings benefits based on estimates of the value of time spent collecting water (Whittington and Cook, 2019). Of course, individuals may consider the value of time spent queuing for and carrying water differently from time spent walking to and from an open defecation site.

The objective of this paper is to improve on these available estimates of the costs and benefits of CLTS and related sanitation interventions in low and middle-income countries. The first improvement we make is to incorporate the best available evidence from the recent collection of rigorous field studies (including several RCTs) of real-world CLTS and related sanitation interventions, especially evidence about increases in latrine ownership, decreases in diarrhea, and software costs. Second, we analyze the impact of a CLTS intervention at a regional rather than household level. This approach will better serve policymakers because CLTS is typically implemented at a regional level, so it makes little sense to evaluate it at a household level. Also, a community analysis provides a more transparent framework for incorporating the positive health externality related to reduced open defecation.

Third, we present results at the regional level, and then disaggregate them to the village to illustrate how the benefits and costs vary depending on how households in different communities respond to CLTS interventions. We present benefit-cost results with and without inclusion of a positive sanitation externality to show the importance of this assumption. Unfortunately, as we will discuss further below, only limited data exist on the magnitude of this positive externality, and on how it changes as open defecation is reduced (Andres et al., 2017; Jung et al., 2017). This is in part because most sanitation evaluations are similar to the existing BCAs in that they focus and report on household rather than community outcomes. We explore this uncertainty in our sensitivity analyses, and discuss its policy implications.

### III. Benefit-Cost Model

#### *a. Overview*

We develop a model for estimating the benefits and costs of implementing a CLTS program in a hypothetical rural district or administrative region of a country in Sub-Saharan Africa. For simplicity, this region is assumed to include 200 villages, and each village has 100 households with five members (two adults, two children between five and fourteen, and one child under five), for a total population of 100,000 people. We assume that the CLTS campaign affects villages in the region differently. Specifically, we assume that the CLTS campaign can affect villages in three ways: 1) a large proportion of households in a village will build and use latrines (high-uptake); 2) a medium proportion of households in a village will build and use latrines (medium-uptake); or 3) a small proportion of households in a village will build and use latrines (low-uptake).<sup>6</sup> We make assumptions about the distribution of these three village types in the region based on the latest research. Benefits and costs are calculated at the household level for each of these three village types, and then aggregated to the village and regional levels. This approach provides a straightforward way to incorporate a village-level public health externality (described below).

Incorporating village-level heterogeneity has implications for other benefit-cost calculations as well. For example, program implementation costs are assumed to be independent of whether or not a household constructs a latrine after the CLTS intervention, since these are costs incurred by external agencies attempting to mobilize communities to change their sanitation behaviors. However, we assume that household time costs for participation in CLTS activities vary according to the level of latrine uptake in a village. Specifically, we assume that not every household in a village attends the initial or follow-up CLTS meetings. Households that attend these meetings and build latrines have higher time costs on average than households that do not attend the meetings or do not build latrines. Villages where fewer latrines are built thus incur lower time costs.

The total costs of building latrines in a village also vary depending on the level of uptake, as in villages where more people decide to construct latrines costs will be higher. Operation and maintenance costs depend on the extent to which members of households with latrines actually use them, which evidence suggests declines over time. For example, several studies find that a relatively high fraction of households owning latrines have members that do not use them (Barnard et al., 2013; Cameron et al., 2013, Orgill-Meyer et al., 2018). Other studies report an increase over time in open defecation rates (Crocker et al., 2017a) and latrine abandonment (Orgill-Meyer et al., 2018). Based on these findings, our analysis assumes that all households that build a latrine use and maintain it for five years, and that a fixed percentage of households abandon their latrine in each of the subsequent five years.

In the benefit-cost model the time stream of benefits to households in a village depends on whether households construct and continue to use latrines. The estimated diarrhea reduction

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<sup>6</sup> Hammer and Spears (2013) provide an interesting qualitative discussion of how such heterogeneity may arise. Orgill-Meyer et al. (2018) report evidence of heterogeneity in the long-term sustainability of a CLTS-like intervention in Orissa, India.



for households in a village targeted by a CLTS intervention is calculated in two different ways. In the first such calculation, we assume that households with improved sanitation facilities do not create a positive externality that benefits other households, and that health benefits to a household accrue only after a latrine is constructed. For the second calculation we include a positive health externality, but assume that this positive externality only “kicks in” once village coverage with improved latrines reaches a sufficient threshold. In this second calculation the magnitude of the diarrhea risk reduction is assumed to be different for households that i) adopt latrines due to the CLTS intervention, ii) do not adopt latrines, and iii) already had latrines before the intervention. We discuss the implementation of this threshold approach in the benefit-cost model further below.

The time streams of both benefits and costs extend for 10 years and are discounted using a real (net of inflation) discount rate. All parameters and model results that are expressed in monetary units are reported in 2016 international dollars (Int'l \$). Model results are presented in terms of three benefit-cost metrics: 1) Present value of net benefits (NPV); 2) BCR; and 3) Economic internal rate of return (ERR). The detailed equations used for the calculation of benefits and costs are included in Appendix A. We present a Monte Carlo analysis that varies all parameters to demonstrate the range of potential benefits and costs, and identify which parameters have the largest effect on the results (Johansson and Kriström 2018, and Whittington et al., 2009).

Our benefit-cost model does not include estimates of the benefits from reduced risks of assault (especially for women), enhanced dignity, and increased privacy that may result from households switching from open defecation practices to the use of latrines at their homes. Nor does our model include estimates of the disamenities from use of improved latrines, such as the unpleasantness of defecating in foul-smelling latrines or increased exposure to flies and mosquitoes (Coffey et al. 2014).

#### *b. Key Assumptions and Parameter Estimates*

The benefit-cost model described in the Appendix A has 52 parameters. For our benefit-cost calculations, we select values for these parameters and their ranges that we consider to be typical for many rural regions in Sub-Saharan Africa. In Appendix B we present a base-case value for each of these parameters, as well as minimum and maximum values. The values of several of the parameters are not independent of one another. For example, if the baseline sanitation coverage is lower, the baseline diarrheal incidence should be higher. We therefore include associations between related parameters in our Monte Carlo analysis. We next discuss our assumptions regarding some of the most important model parameters.

##### *i. Effects of the CLTS intervention*

The literature on the impacts of CLTS interventions typically reports changes in three common outcome variables: 1) latrine construction or ownership (in percentage points), 2) latrine use or open defecation practice (also in percentage points), and 3) diarrhea prevalence for children under five, commonly reported as a percent change. Although this literature often

presents results as a difference in means between treatment and untreated comparison villages, we assume that villages do not all respond to a CLTS intervention in the same way.

For example, the RCT literature on the effectiveness of CLTS interventions reports a wide range of increases in latrine construction or ownership. The increases reported in the literature for treated villages relative to control villages range from zero to fifty percentage points.<sup>7</sup> Garn et al. (2017) conducted a systematic review which included more than 35 studies covering different household sanitation interventions such as CLTS, community mobilization interventions, sanitation marketing, sewerage interventions, latrine subsidies, and a number of other interventions. Garn et al. (2017) found that CLTS-only interventions increased latrine coverage by an estimated twelve percentage points. In contrast, the Government of India's Total Sanitation Campaign, which included a version of CLTS along with other program elements, increased latrine coverage by an average of twenty-seven percentage points.<sup>8</sup>

Our benefit-cost model assumes that all villages experience a one-time jump in latrine ownership starting from a baseline of 45%. We assume that high-uptake villages have a thirty-five percentage points increase in coverage (45%  $\rightarrow$  80%). The increases in medium- and low-uptake villages, meanwhile, are assumed to be fifteen percentage points (45%  $\rightarrow$  60%), and five percentage points (45%  $\rightarrow$  50%), respectively. We assume in the base case that 20% of villages are high-uptake, 40% are medium-uptake, and 40% are low-uptake. This distribution of village types and effects is consistent with the latrine increase of 15 percentage points that is obtained from averaging across the uptake rates in the ten recent RCTs on the effectiveness of CLTS interventions that we reviewed.

The second relevant parameter related to CLTS intervention effectiveness is the increase in latrine use, or the decrease in open defecation. Nine of the ten CLTS evaluations found statistically significant declines in open defecation. The decreases in the nine studies ranged from four to twenty-five percentage points. However, as noted above, more limited evidence from this literature also indicates that these changes may decline over time. Our model assumes that 45% of household members in households with latrines use their latrine at baseline. We estimate that latrine usage for household members in households with latrines increases in all villages after the CLTS intervention, by thirty-five percentage points in high impact villages (reaching a total of 85% use), and by fifteen and ten percentage points in medium and low impact villages. We apply the increased usage rates both to households that adopt latrines due to the CLTS intervention and to households already owning latrines prior to it (given that these households are also triggered by the intervention and usage may not be universal in these households).<sup>9</sup> We

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<sup>7</sup> We want to emphasize here that when we use the percentage point descriptor for say, a ten-percentage point increase, we are describing a change from 50% to 60% coverage with latrines. Where we use the term percent change (e.g., for reductions in diarrhea), we use it in the traditional sense to mean that a 10% change is the change from 50% to 55%.

<sup>8</sup> The systematic review included, among other studies, nine of the CLTS we reviewed for this paper: Cameron et al., 2013; Clasen et al., 2014; Briceño et al., 2015; Elbers et al., 2012; Guiteras et al., 2015; Hammer and Spears, 2013; Patil et al., 2014; Pattanayak et al., 2009; and Pickering et al., 2015.

<sup>9</sup> Effectively, at baseline only some of the household members living in households with latrines use the latrine (45%). Therefore, there is some open defecation happening even in households with latrines. After the CLTS intervention, usage increases among those households in each village type so that household members in households with latrines at baseline and those in households with newly constructed latrines have equal usage rates. For

then assume that all households adopting latrines use them for five years. We further assume that the abandonment rate of latrines after five years, as discussed above, is 10% per year.<sup>10</sup>

The third outcome variable that researchers often report is the impact of CLTS on diarrheal prevalence. For reasons related to statistical power, this outcome is typically only measured for children under five years of age, who have higher prevalence. Seven CLTS RCTs report an outcome for diarrheal risk reduction. While all of these studies found decreases in diarrheal prevalence for children under five, only two found these reductions to be statistically significant.<sup>11</sup> In addition, two recent RCTs that evaluated the same non-CLTS sanitation intervention in two different countries obtained conflicting results. One study found a statistically significant 40% reduction in diarrhea prevalence for children under five (Luby et al., 2018), whereas the other found an insignificant 2% decrease (Null et al., 2018). Overall, when averaging all of the reductions from the RCTs mentioned above, whether statistically significant or not, we obtain an average decrease in diarrhea of about 20%.<sup>12</sup>

There are a number of reasons why an RCT might not find evidence for a reduction in diarrheal prevalence from a CLTS intervention. One potential problem could be insufficient sample sizes for detecting small changes in diarrheal prevalence, particularly in locations with low baseline diarrhea rates. This is especially important for RCTs that report changes in latrine coverage and open defecation as primary outcomes, since these RCTs typically focus on locations with low initial levels of sanitation where increases in coverage are unlikely to result in a positive sanitation externality. RCTs are also generally not designed to test for a sanitation externality, which would require a design that systematically induces exogenous variation in the final levels of sanitation coverage across communities. Another issue is measurement error, which can be common for variables such as self-reported diarrheal disease prevalence that require recall over the past two days, seven days, or two weeks. Other reasons can include confounding factors such as seasonal trends or different baseline conditions across communities.

Given the inconclusive findings of the RCTs, we also considered the findings from a recent meta-analysis of the impact of a variety of sanitation interventions on childhood diarrhea (Wolf et al. 2018). This systematic review did not solely include CLTS interventions, but was based on twenty-two observations from nineteen different academic studies, including five of the nine CLTS studies reviewed for this paper. Wolf et al. (2018) found that non-sewer sanitation

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example, in high impact villages latrine use increases to 85%, and also reaches 85% for new adopters (from 0, since they have no latrines at baseline).

<sup>10</sup> We define latrine abandonment to be when all members within a household stop using the latrine. Latrine abandonment could arise from choosing not to repair a broken latrine, flooding or other incidents that destroy latrines, or household members' deciding to revert to open defecation due to habit or preferences, as well as a host of other reasons.

<sup>11</sup> Given the lack of statistically significant results in the literature, we might conclude that the evidence that CLTS reduces diarrheal disease is inconclusive, even though the direction of the estimates across studies is consistent. Given this, we present the results of an analysis that assumes a zero impact on diarrhea and having only time savings benefits in Appendix C. The net benefits in this case are negative. We also used the model to solve for the breakeven point for the present value of the net benefits given base case values of all other model assumptions and found that this coincided with a diarrhea reduction of about 12% (which is lower than our base case estimate of effectiveness).

<sup>12</sup> When one study includes more than one measure of diarrhea, we use the measure with the shortest recall period. For example, Cameron et al. (2013) report data on diarrhea recall for the past 2 days and past 7 days. We therefore use their data for the past 2-day period in calculating our overall average percent reduction in diarrhea.

interventions decrease diarrhea rates by an average of 16% across all age cohorts, which is similar to the 20% reduction obtained from averaging the point estimates reported in the nine sanitation RCTs. Considering these findings and our assessment of the RCT results, in our “no externality scenario,” we assume in the base case that households who build a latrine experience a reduction in diarrhea of 20% relative to their baseline prevalence rate, in all village types.<sup>13</sup> This 20% reduction is broadly consistent with 1) the average treatment effect reported in Wolf et al.’s meta-analysis, and 2) the average reduction across the nine CLTS and sanitation-related RCTs that report impacts on diarrhea prevalence (Briceño et al., 2017; Cameron et al., 2013; Clasen et al., 2014; Hammer and Spears, 2016; Luby et al., 2018; Null et al., 2018; Patil et al., 2014; Dickinson et al., 2015, and Pickering et al., 2015).

## *ii. Positive Sanitation Externality*

If one ignores the benefits to households who fail to adopt latrines, the health benefits of the CLTS intervention will almost be certainly underestimated due to the positive sanitation externality. Wolf et al. (2018) test a model proposed in Andres et al. (2017) to see whether interventions, including both piped sewer systems and non-sewer interventions, that achieved community-level coverage of 75% or more had significantly larger reductions in diarrhea than those that achieved coverage below 75%. Their analysis found that interventions in rural and urban areas that achieved coverage above this threshold (including sewer interventions) had diarrhea rates that were reduced by 45%, while those achieving lower levels of latrine coverage only saw reductions of 25%. Therefore, for our benefits calculation that includes a positive sanitation externality, we assume that once the threshold level of coverage is exceeded, the risk reduction for households that construct latrines (“new latrine adopters”) increases linearly from the 20% “no externality” effect among adopters up to a maximum of 35% at a village coverage level of 100% (Figure 1 Panel A). This maximum reduction is perhaps conservative relative to the higher rate estimated by Andres et al., but nonetheless represents an average from the nine CLTS and sanitation RCTs, plus the interventions included in the Wolf et al. meta-analysis with coverage exceeding 75%. Households in high-uptake villages that do not adopt a latrine due to the intervention are assumed to experience a diarrhea reduction that increases linearly from 0% to 35% as coverage increases by 25 percentage points, from the 75% coverage threshold to 100% (Figure 1B). Households owning a latrine prior to the intervention are assumed to have already captured the initial 20% reduction, and receive less additional protection following the CLTS intervention. Thus, for households already owning a latrine, the diarrhea reduction is assumed to increase linearly from 0% to 20% after coverage exceeds the 75% threshold (Figure 1C), such that all households in a community with 100% coverage would experience a 35% reduction from a no-latrine counterfactual.

## *iii. Baseline Diarrhea Incidence*

The baseline diarrhea incidence rates are calculated using data from a report by the Global Burden of Disease Collaborative Network (2017) for all countries in sub-Saharan Africa. This report provides data disaggregated by age, which were used to estimate the baseline diarrheal incidence rate for children under five and children between five and fifteen years of

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<sup>13</sup> As mentioned previously we also assume that households owning a latrine at baseline have already experienced this 20% reduction in diarrhea rates.

age. For those fifteen and older, the baseline incidence estimate was calculated by weighting the country-specific estimates from the Global Burden of Disease Collaborative Network report with demographic data from the most recently available Demographic Health Surveys and Malaria Indicator Surveys from Angola, Burundi, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Rwanda, Senegal, Tanzania, Uganda, and Zimbabwe. All sub-Saharan African countries exhibited a similar pattern. The highest rate of diarrhea was for children under five. Children five to less than fifteen had the lowest rate of the three groups, and the rate for people fifteen and older fell between these two younger age cohorts. Based on these sources, we estimate that at baseline children under five average 2.4 diarrhea episodes per year, children five to fourteen average 0.5 diarrhea episodes per year, and individuals fifteen and older average 1 diarrhea episode per year.

We then use this average to calculate distinct estimates of the annual diarrhea incidence for members of households with and without latrines, prior to the CLTS intervention. We assume that the 45% of households with latrines before the intervention have already experienced a 20% decrease in diarrhea rates. We then estimate adjusted diarrhea incidence rates in the two groups such that the weighted average for those with and without latrines equals the average estimate from the Global Burden of Disease Collaborative Network report. For households without latrines, we estimate the baseline diarrhea rates to be 2.6 diarrhea episodes per year for children under 5, 0.55 diarrhea episodes per year for children five to fourteen, and 1.1 diarrhea episodes per year for individuals fifteen and older. For households with latrines, we estimate the baseline diarrhea rates to be 2.1 diarrhea episodes per year for children under 5, 0.44 diarrhea episodes per year for children 5 to 14, and 0.88 diarrhea episode per year for individuals 15 and older.

#### *iv. Value of Statistical Life (VSL)*

To obtain an economic value for mortality risk reductions, we follow the guidelines proposed by Robinson et al. (2018). We use a benefit transfer approach and assume a VSL of Int'l \$9.4 million in the United States.<sup>14</sup> According to the World Bank 2015 World Development Indicators, the United States has a Gross National Income (GNI) per capita of US\$57,878 and our subset of Sub-Saharan African countries have a 2016 median GNI per capita of Int'l \$2,000.<sup>15</sup> <sup>16</sup> We assume a VSL income elasticity of 1.5 as suggested by Robinson et al. (2018). Therefore, we estimate a base case VSL of around Int'l \$60,000. For our sensitivity analysis we use the same approach for calculating our VSL but vary the estimates for the for the GNI per capita in our intervention area. We assume the GNI per capita ranges from Int'l \$1,500 to Int'l

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<sup>14</sup> We estimate the VSL used in our benefit-cost model ( $VSL_{\text{Intervention}}$ ) with the following equation:  

$$VSL_{\text{Intervention area}} = VSL_{\text{U.S.}} * (\text{GNI per Capita}_{\text{Intervention area}} / \text{GNI per Capita}_{\text{U.S.}})^{\text{Income elasticity}}$$

<sup>15</sup> We use the following countries to calculate the GNI per capita: Angola, Benin, Burkina Faso, Cabo Verde, Burundi, Cameroon, Central African Republic, Chad, Comoros, Democratic Republic of Congo, Republic of Congo, Cote D'Ivoire, Eritrea, Ethiopia, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sao Tome and Principe, South Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe. We exclude the wealthier countries such as Botswana, Eswatini, Gabon, Mauritius, Namibia, and South Africa from this estimate.

<sup>16</sup> The Robinson et al. (2018) working paper provides a second and third approach for estimating VSL, which is to use 100\*GNI per capita and 160\*GNI per capita in the target country as default estimates for the VSL, which are based on using income elasticities of 1 and a U.S. estimate of VSL and an OECD estimate of VSL respectively. The VSLs according to this guidance are about Int'l \$200,000 and \$320,000 in 2016. We present the results of using these VSLs approaches with all other assumptions in the base case in Appendix F and Appendix G.

\$2,500, which results in VSL estimates with a lower bound of around Int'l \$30,000 and an upper bound of Int'l around \$85,000.

*v. Cost of Illness (COI)<sup>17</sup>*

The economic value of reductions in morbidity risk are estimated by multiplying the number of nonfatal episodes of diarrhea avoided by an estimate of the social costs of a nonfatal episode of diarrhea<sup>18</sup> (Robinson and Hammitt, 2018). The estimate of the social costs of an episode of diarrhea (“costs of illness,” or COI) includes both the direct and indirect cost of treatment (Robinson and Hammitt, 2018). Direct medical costs include expenses related to medical treatment -- such as medical consultations, diagnostic tests, staff time, and medicine—paid by both the households of sick individuals and the health system providing care. Direct non-medical costs include transportation, lodging, meals, and other treatment-related expenditures. Indirect costs include estimates of the lost productivity due to the illness.

*vi. Value of time*

Time savings benefits are estimated by multiplying an estimate of the time spent by household members walking to and from an open defecation site who switch to an improved latrine at their home, by an assumed value of travel time (Whittington and Cook, 2019). Time spent in CLTS activities is also multiplied by the same estimate of the value of time and included in the costs of the intervention. To the best of our knowledge, there are no studies that have attempted to estimate the economic value of time savings from reductions in time to reach open defecation sites. Acknowledging the difficulties associated with this type of benefits transfer, we value time savings by transferring estimates from studies of the value of time saved not having to carry water from outside the home. Carrying water from a source outside the home is hard work, whereas walking to an open defecation site is typically less arduous. On the other hand, an individual walking to defecate may be forced to interrupt planned activities, or may experience safety risks in going to isolated locations (this is a particular concern for young girls and

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<sup>17</sup> Robinson and Hammitt (2018) offer COI as one of the possible alternatives for valuing non-fatal health impacts when WTP measures do not exist. There is no appropriate WTP measure for decreases in diarrhea. Another possible alternative is to monetize the Years Lost due to Disability (YLDs) averted due to the intervention and to also include third party costs. We present the results of the analysis using the monetized YLDs approach in Appendix E. We value a YLD using the value of a statistical life year (VSLY), which is calculated by dividing the VSL by the life expectancy of the target population at mid-point age. According to the World Bank Development Indicators databank more than 40% of the population in Sub-Saharan Africa is under 14. Therefore, we assume the mid-point age to be slightly higher than 14, and within the 20 to 24 range. To estimate the life expectancy for this group, we refer to the WHO Life Tables and assume the average individual in the target population would expect to live for 47 more years. The VSL we use in our base case, Int'l \$60,380, is then divided by this future life expectancy, which results in a VSLY of around Int'l \$1,285. When using this approach, the results are only slightly lower than with the COI approach.

<sup>18</sup> The total economic cost of one non-fatal episode of diarrhea for a child  $\leq 5$ , who seeks care and receives inpatient care is Int'l \$205, for outpatient care the cost is Int'l \$16, and for someone not seeking care the cost is Int'l \$6. The total economic cost of one non-fatal episode of diarrhea for a person  $>5$ , who seeks care and receives inpatient treatment is Int'l \$207, for outpatient care the cost is Int'l \$17, and for someone not seeking care the cost is Int'l \$7.

women), in contrast to an individual carrying water who may have more flexibility concerning the timing of the activity.<sup>19</sup>

We assume that the value of time for the working age population, household members fifteen and older, is 50% of the local unskilled wage. We conduct sensitivity analysis using a range of 25% to 75% of this wage. For school-age children, we value time savings as 25% of the local wage rate and use a range of 0% to 50% in sensitivity analysis. We do not value time savings for children under five.

### *vii. Discount and Growth Rate*

We assume a real discount rate for the base case of 3% for all health and non-health costs and benefits as used in the iDSI reference case (Wilkinson et al. 2016). We use this discount rate in the base case. We refer to the Ramsey rule to construct a range of discount rates to be used for the sensitivity analysis. To calculate a discount rate requires estimates for the pure rate of time preference, plus the effect of wealth on the marginal utility of consumption (Claxton et al., 2019).<sup>20</sup> We use 0% as the lower bound, assuming no growth in per capita income and an elasticity of marginal utility with respect to consumption of one. We use an upper bound of 8%, assuming a per capita growth rate of 4% and an elasticity of marginal utility with respect to consumption of two.

We also include a parameter in the benefit-cost model to account for real wage growth. We assume an estimated real wage growth of 2% over the 10-year planning horizon (consistent with the above cited data on GNI per capita growth), with a range from 0% to 4% per year. This wage growth is incorporated into the analysis by 1) allowing the GNI per capita for the individuals in the intervention area component of the VSL<sup>21</sup> calculation to grow each year; and 2) increasing the value of time savings, and 3) increasing the benefits from fewer lost days of work.

### *c. Sensitivity Analyses*

We conduct two types of sensitivity analyses. First, we vary the effectiveness of the CLTS intervention. We analyze the benefit-cost results at the regional level for both a poor effectiveness and an enhanced effectiveness intervention by varying the proportions of low, medium, and high-uptake villages. In the base case we assume that 40% of the total 200 villages (80 villages) are low-uptake villages, 40% are medium-uptake villages, and 20% are high-uptake villages. For a poor effectiveness intervention, we assume that 60% are low-uptake villages, 30% are medium-uptake villages, and 10% are high-uptake villages. For an enhanced effectiveness

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<sup>19</sup> We note here that our estimate for time spent walking to defecation site (8 minutes round-trip) is lower than in several other analyses, most of which are for South Asia. Our estimate is based on data from BDS-Center for Development Research (2016), which estimates 6 minutes per round trip and from unpublished data from Crocker et al. (2017a)

<sup>20</sup> The Ramsey Rule estimates a discount rate with the following equation:  $r_c = \delta + \eta g_c$ , where  $r_c$  is the discount rate,  $\delta$  is the time preference for utility,  $\eta$  is the elasticity of marginal utility with respect to consumption, and  $g_c$  is the growth in future consumption (Claxton et al., 2019).

<sup>21</sup> We also allow the wage component of the VSLY in the sensitivity analysis to grow each year as shown in Appendix E.

intervention, we assume that 33% of the villages are low-uptake villages, 33% are medium-uptake villages, and 34% are high-uptake villages.

Second, we perform a Monte Carlo sensitivity analyses allowing for simultaneous variation in several model parameters.<sup>22</sup> Due to limited knowledge of the distribution of these parameters, we assume that all are uniformly distributed, i.e., all values within a parameter's range have an equal probability of being selected in any given simulation trial. We also allow for correlations between some specific variables. For example, areas with higher diarrhea rates are assumed to have lower baseline latrine coverage and latrines usage. Within each age cohort, higher diarrhea incidence rates are also associated with higher diarrhea case fatality rates, more seeking of care, and longer time ill per episode. Also, several valuation parameters are positively associated with local wage rates. For example, higher wage rates are correlated with a higher value of a statistical life, age-specific value of time, household and health system medical costs, CLTS training, facilitation and local participant costs. We present assumptions about each of the model parameters and assumed associations between them in Appendix C.

#### IV. Results of Benefit-Cost Calculation

##### *a. Summary*

In Table 2 we present the number of non-fatal statistical cases of diarrhea avoided, premature deaths averted, and hours saved by age group for each village type, and at the regional level.<sup>23</sup> Without including a positive sanitation externality, we find that around 50, 155, and 360 non-fatal statistical cases of diarrhea are avoided in each low, medium, and high- uptake village over the 10-year period, respectively. With the sanitation externality, additional reductions in diarrhea occur in all high-uptake villages, because coverage in these villages exceeds the threshold level beyond which the externality occurs, such that about 480 non-fatal statistical cases of diarrhea are avoided over the 10-year period in each such village. Overall, across the region with 100,000 people, we estimate that the intervention leads to a decrease of 28,650 non-fatal statistical diarrhea cases over the 10-year planning horizon when the externality is ignored, and 35,715 when the externality is included.

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<sup>22</sup> We vary the following parameters in the Monte Carlo analysis: the percent of village with low-, medium-, and high-uptake, the baseline diarrhea incidence rates per age group, the case fatality rates per age group, the size of the latrine increase in each type of village, the size of the increase in latrine usage in each village type, the baseline latrine coverage, baseline latrine use, the size of the diarrhea reduction for households using a latrine (with and without the externality), the size of the diarrhea reduction for households not using a latrine when externalities are included, the annual GNI per capita in the intervention area, income growth, the rate of abandonment, the percent of people seeking care under 5 and over 5, the percent under 5 and over 5 receiving inpatient or outpatient care, the household costs of diarrhea, the health system costs of diarrhea for inpatient and outpatient care, time spent sick under 5 and above 5 for inpatient, outpatient, and those not seeking treatment, the value of time by age group, the unskilled wage rate, the discount rate, round-trip time traveling to a defecation site, the average number of defecation trips per day, management costs, facilitation costs, training costs, local actor costs, time spent in triggering and follow-up activities, life of the latrine, capital costs of the latrine, time spent constructing a latrine, operational costs of a latrine, and the externality threshold.

<sup>23</sup> These are the values in expectation over the entire population. We calculate one premature death avoided as the sum of the reduced risk across the population. For example, if 100 people have a 1% decrease in the risk of dying from diarrhea we count this as one premature death avoided ( $100 \times 1\% = 1$ ).



Without the sanitation externality, the number of premature deaths averted are 0.024 per low-uptake village, 0.07 per medium-uptake village, and 0.16 per high-uptake village over the 10-year period. With the sanitation externality, the number of premature deaths averted in a high-uptake village is 0.22. Across the region, about 14 premature deaths are averted over the 10-year period from the intervention when the externality is not included and about 16 premature deaths are averted when the externality is included.

The distribution of health benefits across each age cohort is also presented in Table 2. Children under 5 receive most of the health benefits because almost half of the non-fatal cases avoided and two-thirds of the premature deaths averted are in this age cohort. Individuals fifteen and older experience a similar reduction in the number of non-fatal diarrhea cases avoided, while slightly less than one-third of the total premature deaths averted are for individuals fifteen and older. Since we assume that each household has two members between five and less than fifteen and two that are fifteen or older, the number of hours saved are the same for these two groups.<sup>24</sup>

Finally, more than 12,000, 25,000, and 70,000 hours of time are saved over the 10-year period in each low, medium, and high-uptake village, respectively. In the region more than 6,000,000 hours are saved over the 10-year due to adoption of latrines.

Table 3 presents the benefits, costs, NPV, BCR, and ERR of a CLTS campaign for villages with low, medium, and high-uptake of improved latrines from a CLTS program, and for all villages, with and without a positive sanitation externality. These results assume that all parameter values set to their base case assumptions. In the hypothetical region with a population of 100,000 people, the present value of the cost of the CLTS rollout is Int'l \$1,325,790. If there is no positive sanitation externality, the present value of the benefits is Int'l \$1,935,580. If there is a positive sanitation externality, the present value of the benefits is Int'l \$2,156,275. The BCRs are 1.5 and 1.6, respectively.

Looking at the benefits and costs at the village-level, in villages with high-uptake, the CLTS intervention has a BCR of 2.7 if there is no positive sanitation externality and 3.4 if a positive sanitation externality is assumed to exist. In medium-uptake villages the BCR is 1.4 while in low-uptake villages the BCR is less than one.<sup>25</sup> Obviously it would be desirable to focus the CLTS intervention only on high-uptake villages if these villages could be identified *ex ante*, but we know of no evidence that would facilitate such targeting. If such communities have local knowledge about the likelihood of the success of a CLTS intervention, then a lack of enthusiasm on the part of people living in low-uptake villages for a CLTS intervention may in fact reflect a realistic assessment of the economic costs and benefits of the intervention.

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<sup>24</sup> Due to limited information we are only able to discuss the distribution of benefits by age. We also acknowledge that a number of benefits that we do not value in this analysis are possibly more valuable to women, such as increased safety when using the bathroom and increased privacy when using the bathroom. Additionally, we are unable to identify any relationship between benefits and household income-levels or any other attributes.

<sup>25</sup> Because the positive sanitation externality is only assumed to exist in the villages with high CLTS effectiveness, there is no difference between the BCR in the low and medium CLTS effectiveness villages with and without the externality.

In this base case the program costs constitute the majority of total costs (~75%). In the villages with high and medium-uptake, the next largest cost component is the capital costs of latrine construction (~12%). In the villages with low-uptake, the second largest cost component is the time cost for households participating in CLTS activities (~6%). One of the possible reasons for the extremely high BCRs for sanitation interventions in many previous studies is an underestimate of program costs.

The mortality benefits from avoided premature deaths, the morbidity benefits from avoided non-fatal cases of diarrhea, and the time savings benefits from no longer walking to an open defecation site are shown in Figure 2. In the base case the largest component of the benefits is the mortality benefit. Mortality benefits constitute 44% of the benefits without the externality and 46% when including externalities. The morbidity benefits constitute 28% of the benefits without the externality and 29% with the externality. The time savings represent 28% of the total benefits when not including the sanitation externality, and about 25% for the case with externality (note that the magnitude of the time savings does not change depending on the existence of this externality).

#### *b. Results of Sensitivity Analyses*

The results of the one-way sensitivity analyses of CLTS effectiveness (as described in Section 3) are presented in Table 4. The present value of the costs of an intervention with low effectiveness is Int'l \$1,259,160 while in the high effectiveness intervention the cost increases to Int'l \$1,386,660. The majority of the difference in costs is due to the capital and operation and maintenance costs of the higher number of new latrines constructed in the enhanced effectiveness intervention. The benefits, on the hand, vary more substantially across low and high effectiveness interventions. In a poor effectiveness intervention, few villages achieve high enough coverage levels to experience the positive sanitation externality. The total present value of the benefits in a low effectiveness intervention without an externality is Int'l \$1,428,025 and reaches Int'l \$1,538,365 when the externality is included. In a high effectiveness intervention, the present value of the benefits is Int'l \$2,397,005 without an externality and increases to Int'l \$2,772,190 once the externality is included.

The effectiveness of the intervention has a large effect on the overall benefit-cost metrics. The NPV of the intervention on a regional level ranges from a low of Int'l \$168,865 to Int'l \$989,520 without an externality and from Int'l \$279,205 to Int'l \$1,385,530 with an externality. The BCRs range from around 1.1 in the low effectiveness intervention to 1.7 in the high effectiveness scenario without an externality and from 1.2 to 2 with an externality. The ERR ranges from a low of 6% in the low effectiveness intervention to 17% in the high effectiveness intervention without an externality and from 8% to 23% once the externality is included.

The results of the Monte Carlo analysis with 10,000 trials show a large potential range for all the CBA metrics. Figures 3 and 4 present the cumulative density functions (CDF) of the NPVs, BCRs, and the ERRs, without and with a positive sanitation externality, respectively. The 5<sup>th</sup> percentile of the NPV without externalities is negative Int'l \$(561,675) while the 95<sup>th</sup> percentile reaches Int'l \$1,572,730. When incorporating the externality the 5<sup>th</sup> percentile of the NPV is negative Int'l \$(481,680) while the 95<sup>th</sup> percentile reaches Int'l \$2,107,050. The 5<sup>th</sup>

percentile of the BCR without an externality is 0.55 and the 95<sup>th</sup> percentile is 2.2. When including the externality the 5<sup>th</sup> percentile of the BCR is 0.6 and the 95<sup>th</sup> percentile reaches 2.5. The 5<sup>th</sup> percentile of the ERR without an externality is -12% and the 95<sup>th</sup> percentile is 29%. When including the externality the 5<sup>th</sup> percentile of the ERR is -10% and the 95<sup>th</sup> percentile is 38%. The NPV was greater than zero, the minimum standard for passing a BCA test, in about 65% of the trials without an externality and in about 75% of the trials when including an externality. However, the majority of the outcomes have benefit-cost metrics that, while positive, could easily fall below the metrics for attractive interventions in other sectors. It is thus by no means clear that CLTS interventions would be near the top of an economic ranking of development projects in a specific region; this would very much depend on local, site-specific conditions.

Figure 5 shows the 10 parameters that explain the largest portion of the variance of NPV across the simulations when excluding and including a positive sanitation externality.<sup>26</sup> In both cases the top two most influential variables are the same. The size of the diarrhea reduction for households adopting latrines is the parameter that explains the largest change in BCA outcomes in the analyses with and without the externality. The percent of villages with low uptake is the second most influential variable in both cases. In the case without the externality, the next four most influential parameters are (in order of importance): the life of the project, the discount rate, the annual GNI per capita among those in the study areas, and number of open defecation trips per day. For the case including the externality, the next four most influential parameters are: the size of the increase in latrine coverage in high-uptake villages, the externality threshold, the annual GNI per capita among those in the study areas, and the life of the project.

## V. Discussion

The results from a series of recent field studies, including several RCTs, suggest that CLTS and similar sanitation interventions may be less effective in ending open defecation than CLTS proponents had hoped. In this paper we have incorporated these findings along with the findings from other sanitation-related studies into an economic model designed to compare the benefits and costs of CLTS interventions at the regional level in a Sub-Saharan Africa context. There are five key messages from our benefit-cost calculations.

First, after incorporating the results from these new sanitation studies, we still find that a CLTS intervention would pass a benefit-cost test in many plausible situations. However, the benefit-cost metrics (NPV, BCR, and ERR) are much lower than those reported in the prior benefit-cost literature of CLTS interventions. It is possible that other WASH or non-WASH could be more economically attractive investments than CLTS interventions. Furthermore, the sensitivity analysis shows that while CLTS effectiveness has a major effect on net benefits, other contextual factors that may be outside of the control of those designing interventions are also important. Model parameters that describe baseline conditions—the assumed GNI per capita among those in the study areas to calculate the VSL, the time spent on open defecation, the proportion of children under five with diarrhea seeking medical care, and the cost of inpatient

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<sup>26</sup> We note that the baseline diarrhea and case fatality rates were not listed in the top ten most sensitive parameters. However, this is probably because we assume age-specific rates as individual parameters rather than assuming a total baseline diarrheal or case fatality rate, which lessens the influence of these specific parameters on the results.

care-- all have large effects on the benefits of the intervention at the regional level. From our perspective too much attention has been placed on improving estimates of the effectiveness of the CLTS intervention compared to obtaining better information on these other parameters.

Second, the size of the diarrhea reduction for households adopting a latrine, the life of the latrine, and the nature of the externality relationship are influential variables in the benefit-cost model. It is somewhat ironic that despite all of the effort and expensive RCTs deployed to improve estimates of the effectiveness of CLTS, there remains such tremendous uncertainty about the extent to which these interventions reduce diarrheal disease rates. As discussed in Section 3, there are many reasons for these inconclusive and variable results, but a key conclusion of our analysis is that point estimates of the average reduction alone may not be sufficient for careful economic analysis of this intervention; a better understanding of what drives smaller and larger reductions (including the shape and scope of the sanitation externality) is sorely needed.

Third, the importance of the positive sanitation externality remains unclear. Based on our calculations, and if the relationships proposed by Andres et al.'s analysis are accurate, the presence of a positive sanitation externality has only a modest effect on benefit-cost outcomes, and may not be the game changer that many people in the public health community seem to assume. Even more important than the externality relationship itself is the extent to which high uptake of latrines can be achieved using CLTS, because this determines whether or not the positive externality “kicks in.”

Fourth, since CLTS is not a household-level intervention, the results of a CLTS BCA should be reported at a community or regional level. CLTS and sanitation studies only report differences in means of their outcome variables at a relatively small (experimental) scale. In order to better analyze the impact of CLTS and other sanitation interventions, the authors of RCTs should provide policy analysts more information about entire distribution of outcome variables in treatment villages.

Fifth, we believe that there is little more to be learned from global “desk-top” benefit-cost calculations of sanitation interventions. The results of such calculations yield a wide range of outcomes that are dependent on local conditions, or model assumptions about them. Transferring benefit estimates from one study to the regional, national, or global level might make sense if the results showed that CLTS interventions were economically attractive under all plausible assumptions about crucial parameters, but this is not the case. Analysts need to do the hard work required to identify localities where the benefits of CLTS interventions will most likely exceed the costs, and preferably by a large margin. This will require primary data collection to estimate the most important parameters in the analyst's benefit-cost model, such as the income level and corresponding value of a statistical life, the baseline latrine coverage rates, the time spent walking to open defecation sites, and several parameters related to cost of illness.

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**Table 1.** Summary of Prior Sanitation Intervention Benefit-Cost Analyses

Reference	Source	Intervention	BCR	Benefits	Costs
Hutton and Haller (2004)	WHO	Infrastructure to meet water and sanitation MDG	~6.5-11.7	<ul style="list-style-type: none"> <li>• <b>Individual Direct Health Benefits (~5%):</b> <ul style="list-style-type: none"> <li>○ Reduced expenditures from illness</li> </ul> </li> <li>• <b>Individual Indirect Health Benefits (~15%):</b> <ul style="list-style-type: none"> <li>○ Value of fewer days lost to being sick, caring for children, and missing school</li> <li>○ Value from reduced mortality</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Investment costs</b></li> <li>• <b>Recurrent costs</b> <ul style="list-style-type: none"> <li>○ Operation, maintenance, and surveillance</li> <li>○ Education</li> </ul> </li> </ul>
Hutton et al. (2007)	<i>Journal of Water and Health</i>	OR Infrastructure to provide universal access	5-46	<ul style="list-style-type: none"> <li>• <b>Individual Non-Health Benefits (~70-80%):</b> <ul style="list-style-type: none"> <li>○ Time savings (minimum wage)</li> </ul> </li> <li>• <b>Health System Benefits (~5-15%):</b> <ul style="list-style-type: none"> <li>○ Reduced expenditures on cases of diarrheal disease</li> </ul> </li> </ul>	
Whittington et al. (2009)	<i>Foundations and Trends® in Microeconomics</i>	CLTS	2.7-3	<ul style="list-style-type: none"> <li>• <b>Health-related impacts (~80%):</b> <ul style="list-style-type: none"> <li>○ Reduced premature deaths</li> <li>○ Reduced expenditure from illness</li> </ul> </li> <li>• <b>Access time impacts (~15%):</b> <ul style="list-style-type: none"> <li>○ (30% of daily wage rate)</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Capital cost</b></li> <li>• <b>Operation and Maintenance costs</b> <ul style="list-style-type: none"> <li>○ Replacement and cleaning materials</li> </ul> </li> <li>• <b>Times costs</b> <ul style="list-style-type: none"> <li>○ Community meetings and maintain a latrine</li> </ul> </li> <li>• <b>Program costs</b> <ul style="list-style-type: none"> <li>○ Implementation of CLTS</li> </ul> </li> </ul>
Winara et al. (2011)	World Bank Water and Sanitation Program	Urban/rural CLTS	1.7-2.3	<ul style="list-style-type: none"> <li>• <b>Individual Direct Health Benefits (~15-30%):</b> <ul style="list-style-type: none"> <li>○ Reduced expenditures from illness</li> </ul> </li> <li>• <b>Individual Indirect Health Benefits (~20-40%):</b> <ul style="list-style-type: none"> <li>○ Income from fewer sick days, fewer days caring for children, and from missing fewer days of school</li> <li>○ Value from reduced mortality</li> </ul> </li> <li>• <b>Domestic water-related impacts (~10-25%):</b> <ul style="list-style-type: none"> <li>○ Household treatment of water</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Investment costs</b> <ul style="list-style-type: none"> <li>○ Capital</li> <li>○ Program</li> </ul> </li> <li>• <b>Recurrent costs</b> <ul style="list-style-type: none"> <li>○ Operations</li> <li>○ Maintenance</li> </ul> </li> </ul>
Heng et al. (2012)	World Bank Water and Sanitation Program		0.84-1.4	<ul style="list-style-type: none"> <li>• <b>Access Time (~20-40%):</b> <ul style="list-style-type: none"> <li>○ (30% minimum wage for adults 15+ and 15% ≤15)</li> </ul> </li> </ul> <p><b>Non-Quantified Impacts</b></p> <ul style="list-style-type: none"> <li>• <b>Intangibles:</b> <ul style="list-style-type: none"> <li>○ Satisfaction with latrines and safety concerns</li> </ul> </li> <li>• <b>External Environment</b> <ul style="list-style-type: none"> <li>○ Satisfaction with external environment</li> </ul> </li> </ul> <p><b>National Impacts</b></p> <ul style="list-style-type: none"> <li>○ Impacts on tourism and businesses</li> </ul>	

Rijsberman and Zwane (2012)	Copenhagen Consensus Center	CLTS++	4 - 7	<ul style="list-style-type: none"> <li>• <b>Health-related impacts:</b> <ul style="list-style-type: none"> <li>○ Premature deaths, costs of treating diseases</li> <li>○ Productive time lost due to people falling ill</li> </ul> </li> <li>• <b>Domestic water-related impacts:</b> <ul style="list-style-type: none"> <li>○ Household treatment of water</li> </ul> </li> <li>• <b>Access time impacts:</b> <ul style="list-style-type: none"> <li>○ Time savings</li> <li>○ Absence from school and work.</li> </ul> </li> <li>• <b>Tourism impacts:</b> <ul style="list-style-type: none"> <li>○ Potential loss of tourism revenues.</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Capital cost</b></li> <li>• <b>Program Costs</b> <ul style="list-style-type: none"> <li>○ Implementation of CLTS</li> </ul> </li> </ul>
Whittington et al. (2012)	<i>World Development</i>	Total Sanitation	0.6 -10	<ul style="list-style-type: none"> <li>• <b>Health-related impacts (~85%):</b> <ul style="list-style-type: none"> <li>○ Reduced premature deaths</li> <li>○ Reduced expenditure due to illness</li> </ul> </li> <li>• <b>Access time impacts (~15%):</b> <ul style="list-style-type: none"> <li>○ (30% of daily wage rate)</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Capital cost</b></li> <li>• <b>Operation and Maintenance costs</b> <ul style="list-style-type: none"> <li>○ Replacement and cleaning materials</li> </ul> </li> <li>• <b>Times costs</b> <ul style="list-style-type: none"> <li>○ Community meetings and maintenace</li> </ul> </li> <li>• <b>Program costs</b> <ul style="list-style-type: none"> <li>○ Implementation of CLTS</li> </ul> </li> </ul>
Hutton (2015)	Copenhagen Consensus Center	Elimination of open defecation	4.5 – 7.3	<ul style="list-style-type: none"> <li>• <b>Health (~5%)</b> <ul style="list-style-type: none"> <li>○ Averted cases of illness</li> </ul> </li> <li>• <b>Health economic (~25)</b> <ul style="list-style-type: none"> <li>○ Income from fewer sick days, fewer days caring for children, and from missing fewer days from school</li> <li>○ Value from reduced mortality</li> </ul> </li> <li>• <b>Time Benefit (~70%)</b> <ul style="list-style-type: none"> <li>○ (30% minimum wage for adults 15+ and 15% for ≤15)</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>CapEx</b> <ul style="list-style-type: none"> <li>○ Investment costs</li> </ul> </li> <li>• <b>CapManEx</b> <ul style="list-style-type: none"> <li>○ Maintenance</li> </ul> </li> <li>• <b>OpEx</b> <ul style="list-style-type: none"> <li>○ Recurrent costs</li> </ul> </li> </ul>
Larsen (2016)	Copenhagen Consensus Center	Private improved sanitation	1.1 – 2.6	<ul style="list-style-type: none"> <li>• <b>Health (~50%):</b> <ul style="list-style-type: none"> <li>○ Reduction in diarrheal disease</li> <li>○ Reduction in diarrheal disease mortality</li> </ul> </li> <li>• <b>Time savings (~50%)</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>Capital costs of latrine</b></li> <li>• <b>Capital costs of intervention</b></li> <li>• <b>Operation and maintenance costs</b></li> <li>• <b>Program costs</b></li> </ul>
Sklar (2017)	Copenhagen Consensus Center	Pit latrines with septic tanks	0.5-2	<ul style="list-style-type: none"> <li>• <b>Health (~55%):</b> <ul style="list-style-type: none"> <li>○ Averted diarrheal disease deaths and DALYs</li> </ul> </li> <li>• <b>Education (~3%):</b> <ul style="list-style-type: none"> <li>○ Averted lost school days</li> </ul> </li> <li>• <b>Productivity (~25%):</b> <ul style="list-style-type: none"> <li>○ Averted lost work days</li> <li>○ Time saved for caretakers</li> <li>○ Time savings</li> </ul> </li> <li>• <b>Healthcare (~15%):</b> <ul style="list-style-type: none"> <li>○ Avoided costs of hospital/clinic visits and stays</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Hardware</b> <ul style="list-style-type: none"> <li>○ Pit Latrine hardware</li> <li>○ Septic Tank hardware</li> </ul> </li> <li>• <b>O &amp; M:</b> <ul style="list-style-type: none"> <li>○ Pit Emptying</li> </ul> </li> </ul>

Whittington et al. (2017)	Copenhagen Consensus Center	CLTS	0.5-3	<ul style="list-style-type: none"> <li>• <b>Health (~67%):</b> <ul style="list-style-type: none"> <li>○ Averted diarrheal disease deaths and DALYs</li> </ul> </li> <li>• <b>Time savings (~33%):</b> <ul style="list-style-type: none"> <li>○ (50% of the daily wage rate)</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Capital cost</b></li> <li>• <b>Operation and Maintenance costs</b> <ul style="list-style-type: none"> <li>○ Replacement and cleaning materials</li> </ul> </li> <li>• <b>Times costs</b> <ul style="list-style-type: none"> <li>○ Community meetings and maintain a latrine</li> </ul> </li> <li>• <b>Program costs</b> <ul style="list-style-type: none"> <li>○ Implementation of CLTS</li> </ul> </li> </ul>
Larsen (2018a)	Copenhagen Consensus Center	Rural Household subsidy/ (behavior change campaign)	8.1-9.7 / (1.4-2.8)	<ul style="list-style-type: none"> <li>• <b>Health (40-60%):</b> <ul style="list-style-type: none"> <li>○ Averted diarrheal disease deaths</li> <li>○ Averted diarrheal disease cases</li> </ul> </li> <li>• <b>Time savings (40-60%):</b> <ul style="list-style-type: none"> <li>○ (50% of the daily wage rate for people &gt;5)</li> </ul> </li> <li>• <b>(Health ~35%):</b> <ul style="list-style-type: none"> <li>○ Averted diarrheal disease deaths and DALYs</li> </ul> </li> <li>• <b>(Time savings ~65%):</b> <ul style="list-style-type: none"> <li>○ (50% of the daily wage rate))</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Capital cost</b></li> <li>• <b>Emptying Pit</b></li> <li>• <b>Cleaning</b></li> <li>• <b>Operation and Maintenance</b></li> <li>• <b>Program</b></li> <li>• <b>(Promotion)</b></li> <li>• <b>(Preference for OD)</b></li> <li>• <b>(Cleaning)</b></li> </ul>
Larsen (2018b)	Copenhagen Consensus Center	Rural Household subsidy/ (behavior change campaign)	7-8.3 / (0.8-2.9)	<ul style="list-style-type: none"> <li>• <b>Health (40-60%):</b> <ul style="list-style-type: none"> <li>○ Averted diarrheal disease deaths</li> <li>○ Averted diarrheal disease cases</li> </ul> </li> <li>• <b>Time savings (40-60%):</b> <ul style="list-style-type: none"> <li>○ (50% of the daily wage rate for people &gt;5)</li> </ul> </li> <li>• <b>(Health ~30%):</b> <ul style="list-style-type: none"> <li>○ Averted diarrheal disease deaths and DALYs</li> </ul> </li> <li>• <b>(Time savings ~70%):</b> <ul style="list-style-type: none"> <li>○ (50% of the daily wage rate))</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• <b>Capital cost</b></li> <li>• <b>Emptying Pit</b></li> <li>• <b>Cleaning</b></li> <li>• <b>Operation and Maintenance</b></li> <li>• <b>Program</b></li> <li>• <b>(Promotion)</b></li> <li>• <b>(Preference for OD)</b></li> <li>• <b>(Cleaning)</b></li> </ul>
Hutton et al. (2018)	UNICEF	Swachh Bharat Mission (Gramin)	<1 -12.4	<ul style="list-style-type: none"> <li>• <b>Health (~30-40%):</b> <ul style="list-style-type: none"> <li>○ Medical costs averted</li> <li>○ Averted diarrheal disease deaths</li> </ul> </li> <li>• <b>Time savings (~35%):</b> <ul style="list-style-type: none"> <li>○ (Minimum wage rate in rural areas for non-income earning adults, 50% of minimum wage for school age children, and no value given to time of children ≤5 years)</li> <li>○ Reduced time lost due to sickness</li> </ul> </li> <li>• <b>Property values (~25-35%)</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>Capital cost</b> <ul style="list-style-type: none"> <li>○ Construction</li> <li>○ Household time</li> </ul> </li> <li>• <b>Operations cost</b> <ul style="list-style-type: none"> <li>○ Water, soap, cleaning materials, and labor</li> </ul> </li> <li>• <b>Program cost</b></li> <li>• <b>Maintenance cost</b> <ul style="list-style-type: none"> <li>○ Emptying, repair, and renovation</li> </ul> </li> </ul>



**Table 2.** Estimates of Cases of Diarrhea Avoided, Premature Deaths Averted, and Hours Saved – from CLTS Intervention, totals over 10-year planning horizon

	Low-Uptake Village	Medium-Uptake Village	High-Uptake Village	All Villages (n = 200)
<b>Without Externality</b>				
<i>Statistical Cases Avoided Total*</i>	52	155	360	28,634
<5	23	69	160	13,744
5-14	10	29	66	3,436
≥15	19	57	134	11,454
<i>Premature Deaths Averted Total</i>	.024	.07	.16	14.2
<5	.016	.05	.11	9.6
5-14	.002	.005	.01	1.15
≥15	.006	.015	.04	3.4
<i>Hours Saved Total</i>	12,260	26,630	73,970	6,069,954
5-14	6,130	13,315	36,985	3,034,977
≥15	6,130	13,315	36,985	3,034,977
<b>With Externality</b>				
<i>Statistical Cases Avoided Total*</i>	52	155	481	35,715
<5	23	69	214	15,873
5-14	10	29	89	6,614
≥15	19	57	178	13,228
<i>Premature Deaths Averted Total</i>	.024	.07	.22	16.4
<5	.016	.05	.15	11.11
5-14	.002	.005	.02	1.32
≥15	.006	.015	.05	4
<i>Hours Saved Total</i>	12,260	26,630	73,970	6,069,954
5-14	6,130	13,315	36,985	3,034,977
≥15	6,130	13,315	36,985	3,034,977

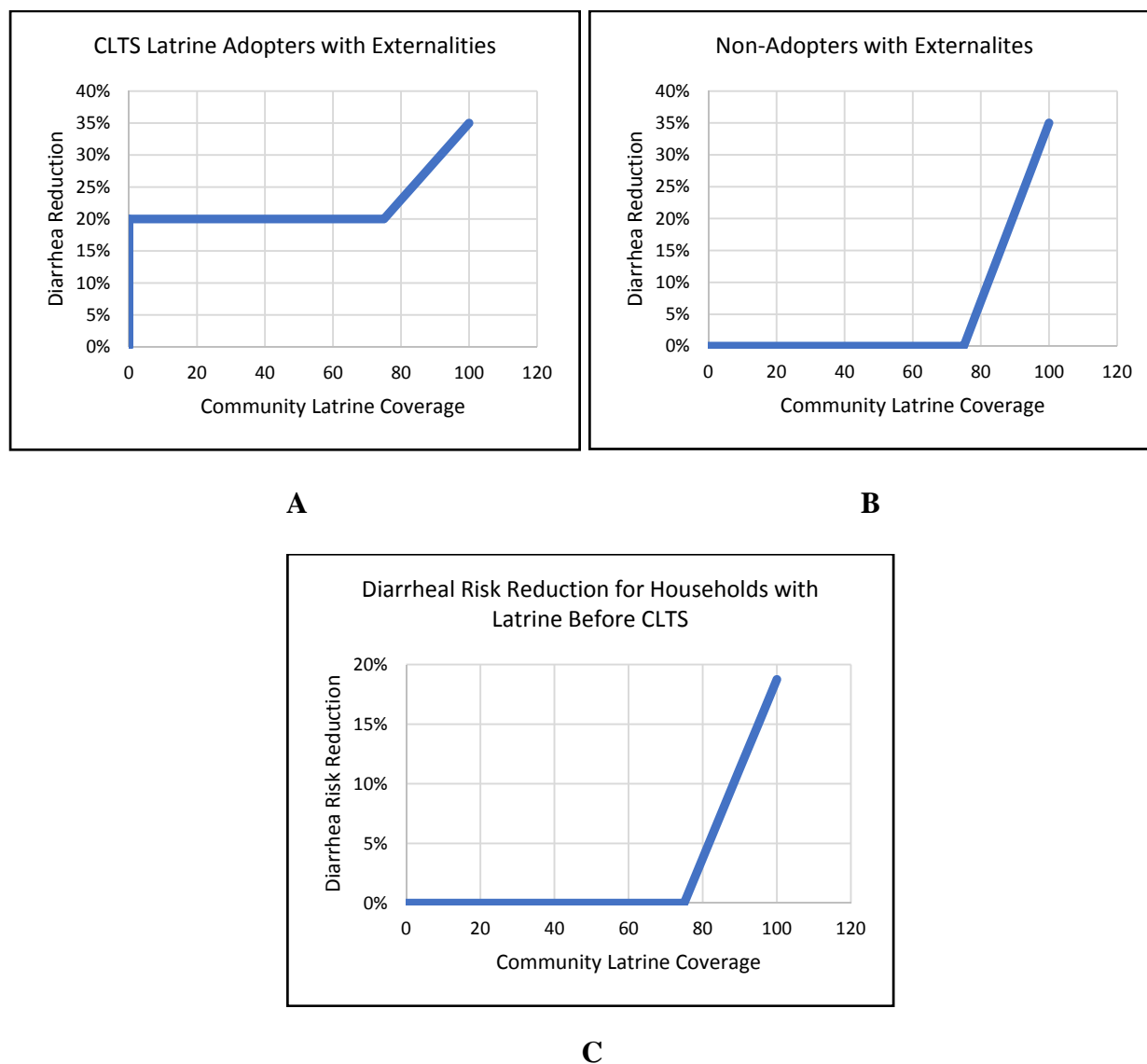
\*We note here that the statistical cases avoided refers to non-fatal diarrhea cases.

**Table 3.** Summary of Results of Benefit-Cost Analysis (2016 Int'l \$): Low, Medium, and High-Uptake Villages for Three Benefit-Cost Metrics (Net Present Value, Benefit-Cost Ratio, and Economic Rate of Return (with & w/o positive sanitation externality))

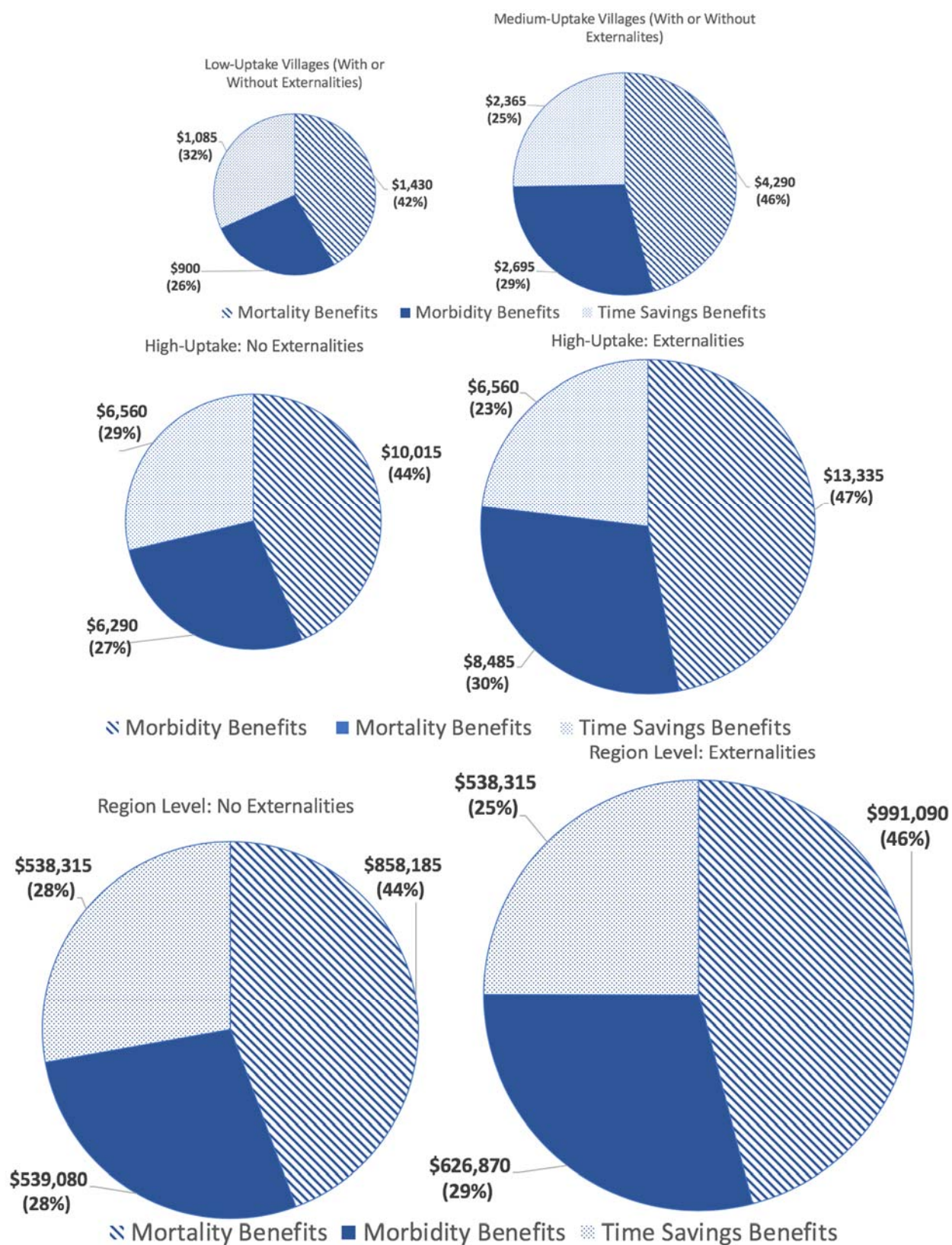
	Low-Uptake Village	Medium-Uptake Village	High-Uptake Village	All Villages (n = 200)
No Externalities				
Benefits	\$3,415	\$9,350	\$22,865	\$1,935,580
Mortality Benefits	\$1,430	\$4,290	\$10,015	\$858,185
Morbidity Benefits	\$900	\$2,695	\$6,290	\$539,080
Time Savings	\$1,085	\$2,365	\$6,560	\$538,315
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	(\$2,395)	\$2,770	\$14,200	\$609,790
BC ratio	0.6	1.4	2.7	1.5
ERR	-7%	11%	35%	12%
Externalities				
Benefits	\$3,415	\$9,350	\$28,380	\$2,156,275
Mortality Benefits	\$1,430	\$4,290	\$13,335	\$991,090
Morbidity Benefits	\$900	\$2,695	\$8,485	\$626,870
Time Savings	\$1,085	\$2,365	\$6,560	\$538,315
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	(\$2,395)	\$2,770	\$19,750	\$830,485
BC ratio	0.6	1.4	3.4	1.6
ERR	-7%	11%	49%	16%

**Table 4.** Benefit-Cost Results for Base, Poor Effectiveness, and Enhanced Effectiveness Cases at the Regional Level, for Three Benefit-Cost Metrics (Net Present Value, Benefit-Cost Ratio, and Economic Rate of Return (with & w/o positive sanitation externality))

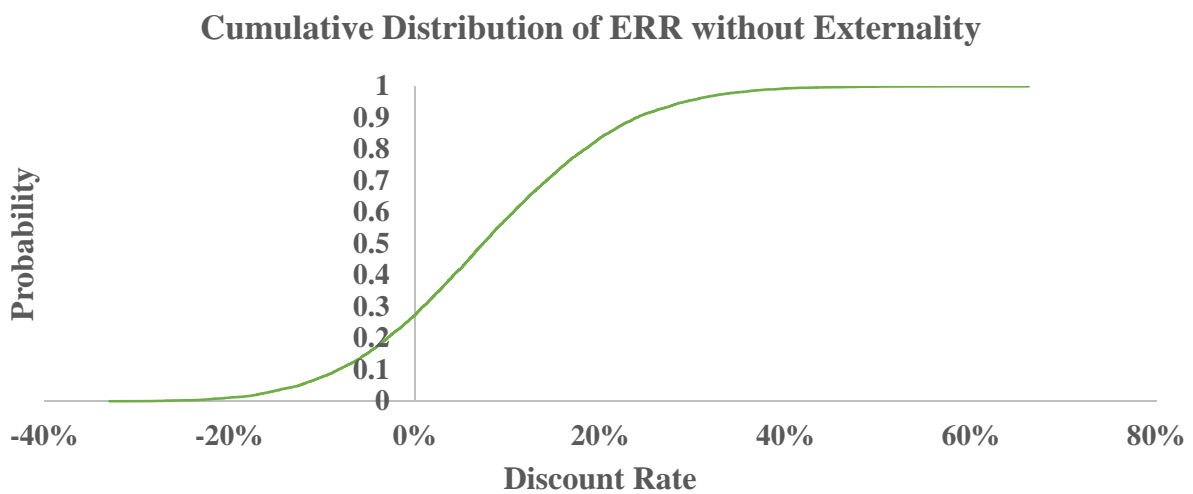
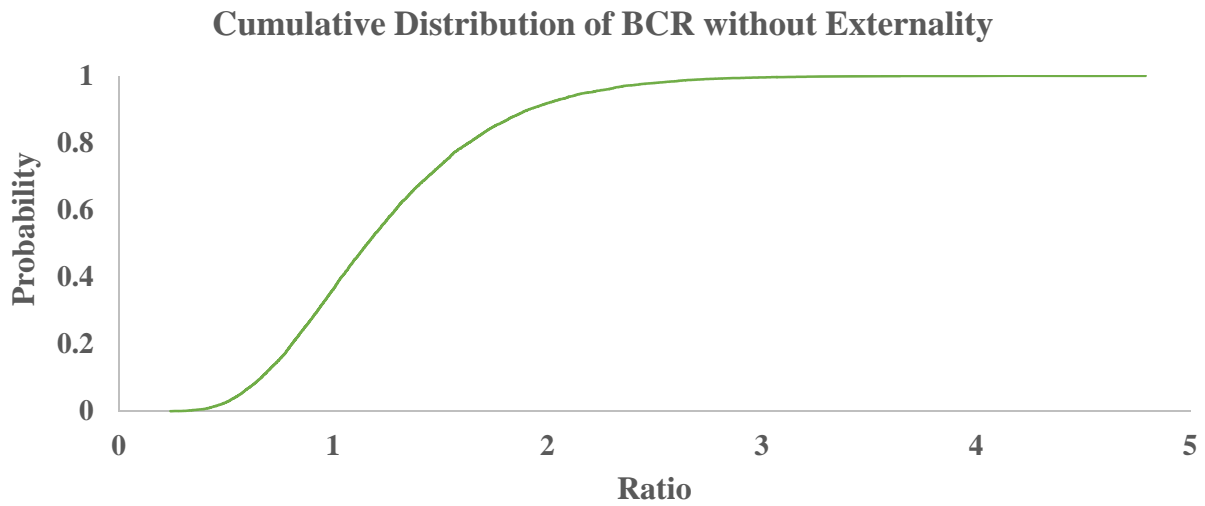
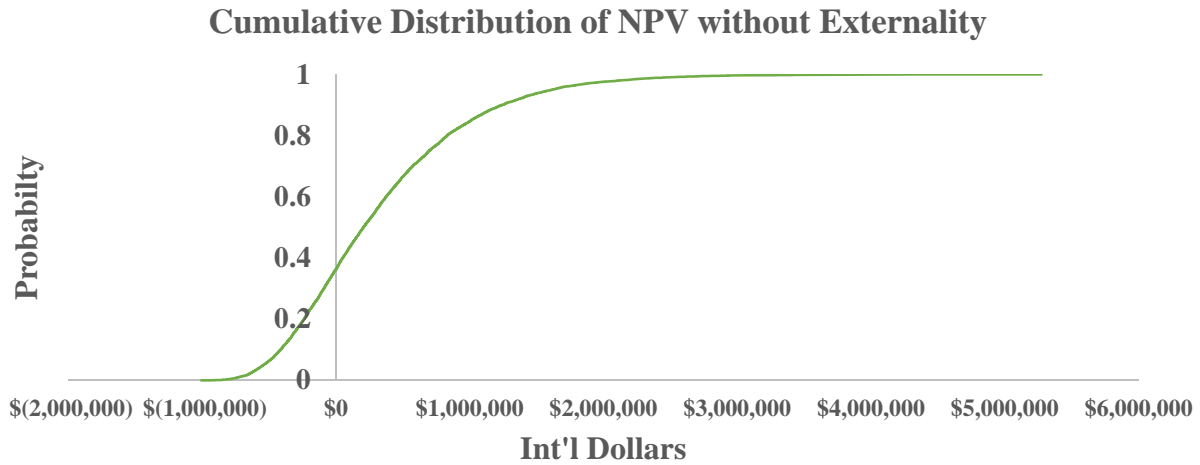
	Base Case (200 villages)	Poor Effectiveness (200 villages)	Enhanced Effectiveness (200 villages)
No Externalities			
Benefits	\$1,935,580	\$1,428,025	\$2,397,005
Mortality Benefits	\$858,185	\$629,335	\$1,058,425
Morbidity Benefits	\$539,080	\$395,325	\$664,865
Time Savings	\$538,315	\$403,360	\$673,715
Costs	\$1,325,790	\$1,259,160	\$1,386,660
Program Costs	\$980,000	\$980,000	\$980,000
Time Costs	\$107,265	\$107,265	\$107,265
Capital Costs	\$161,175	\$118,195	\$198,780
O&M Costs	\$77,350	\$53,700	\$100,615
Net Benefits	\$609,790	\$168,865	\$989,520
BC ratio	1.5	1.1	1.7
ERR	12%	6%	17%
Externalities			
Benefits	\$2,156,275	\$1,538,365	\$2,772,190
Mortality Benefits	\$991,090	\$695,785	\$1,284,365
Morbidity Benefits	\$626,870	\$439,220	\$814,110
Time Savings	\$538,315	\$403,360	\$673,715
Costs	\$1,325,790	\$1,259,160	\$1,386,660
Program Costs	\$980,000	\$980,000	\$980,000
Time Costs	\$107,265	\$107,270	\$107,265
Capital Costs	\$161,175	\$118,195	\$198,780
O&M Costs	\$77,350	\$53,695	\$100,615
Net Benefits	\$830,485	\$279,205	\$1,385,530
BC ratio	1.6	1.2	2
ERR	16%	8%	23%



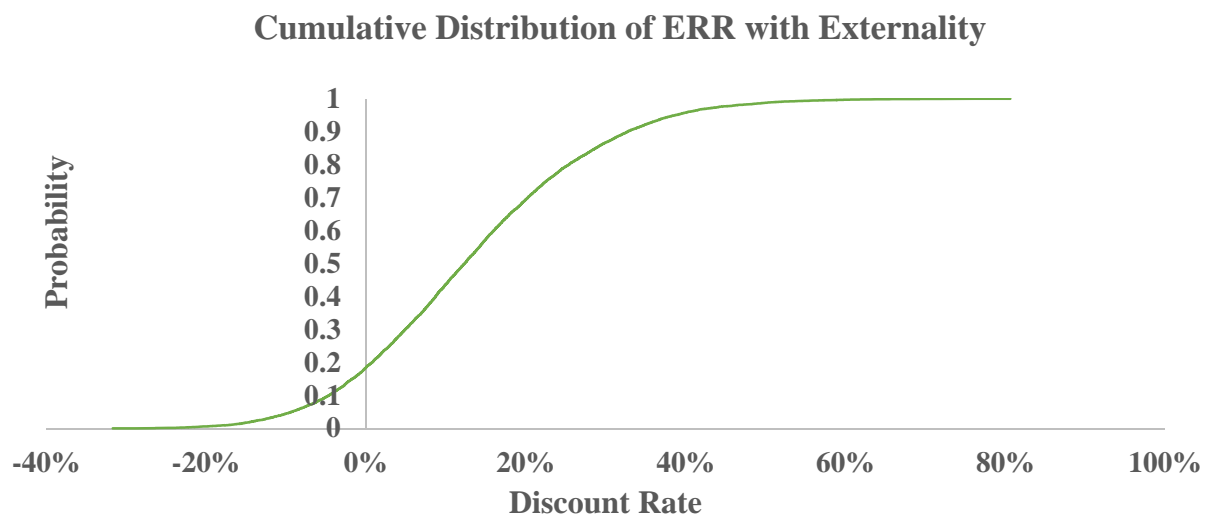
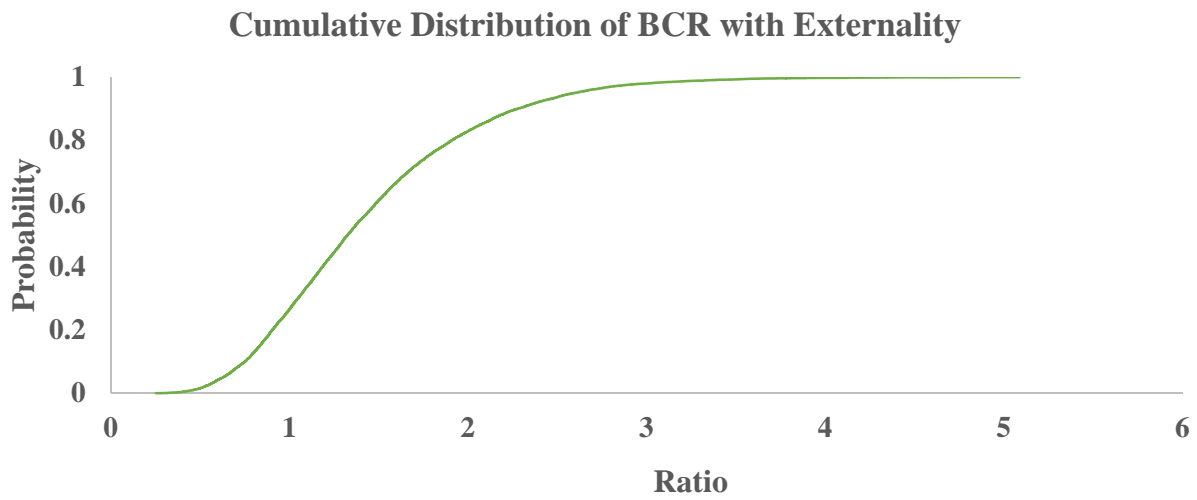
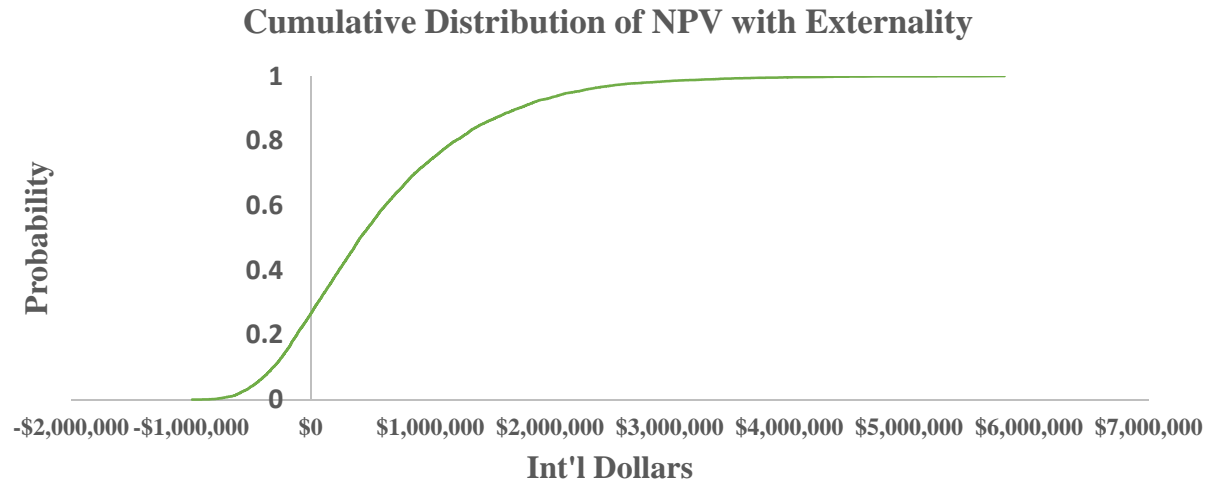
**Figure 1.** Assumed Diarrhea Risk Reduction with Positive Sanitation Externality (as a Function of Community Latrine Coverage) among A) New Adopters; B) Non-Adopters; and C) Pre-Intervention Adopters



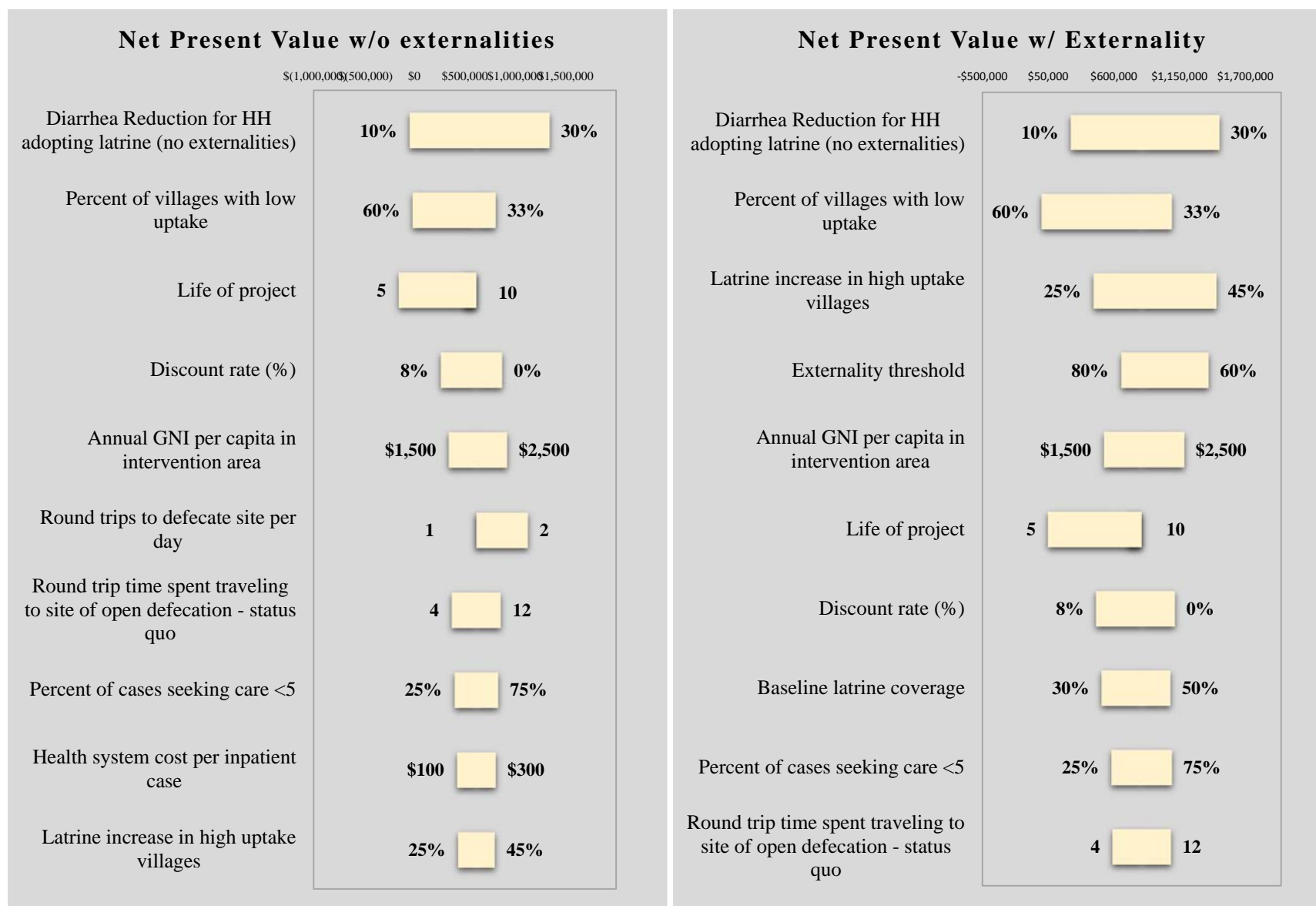
**Figure 2.** Distribution and Size of Benefits from the CLTS Intervention Per Village Types and at the Regional Level



**Figure 3.** Cumulative distribution of results from Monte Carlo simulation (10,000 draws) of CLTS intervention without externalities: Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Economic Internal Rate of Return (ERR)



**Figure 4.** Cumulative distribution of results from Monte Carlo simulation (10,000 draws) of CLTS intervention with externalities: Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Economic Internal Rate of Return (ERR)



**Figure 5.** Sensitivity analyses: Effect of selected parameters on Net Present Value (NPV) with and without Externality (holding other parameters at base case values).



## **Appendix A: Description of the Benefit-Cost Model**

### *Equations for calculations of benefits without the positive sanitation externality*

Consistent with the majority of previous BCAs of sanitation interventions, our estimates of the benefits of the CLTS campaign have two components: 1) health improvements, and 2) time savings. The health benefits from the CLTS intervention result from the reductions in mortality (premature deaths averted) and morbidity (non-fatal cases of diarrhea avoided) that ensue from the lower incidence of diarrheal disease. The economic value of the reductions in mortality risk are calculated using a value of a statistical life (VSL) derived from a benefit transfer approach proposed by Robinson et al. (2019). The value of reduced morbidity risk is calculated using an estimate of the cost of illness (COI) as a proxy for WTP. Time savings are valued according to guidance in Whittington and Cook (2019). Furthermore, we follow the guidance in Robinson et al. (2018) and Robinson and Hammitt (2018) by adjusting the VSL and the wage component of COI to account for real income growth.

The present value of the benefit stream in the hypothetical region in Sub-Saharan Africa is:

$$PVB = \sum_{j=1}^J \sum_{i=1}^I N_j * PV HH B_{ij} \quad (1)$$

where

$PVB$  = total present value of the benefits to all households in the 200 villages in the hypothetical region;

$N_j$  = number of villages of type  $j$ ; and

$PV HH B_{ij}$  = present value of the benefits for household  $i$  in village type  $j$ .

The model assumes heterogeneous responses to the CLTS intervention both across villages and within villages. The benefit a household receives depends on whether its household members construct and use a new latrine, whether members of households that already own a latrine start using a latrine more intensively after the intervention, how long households continue to use their latrines, and whether

households in the village receive a positive sanitation externality. The proportion of households in each of these groups varies according to the magnitude of the treatment effect from the CLTS intervention in the three village types (i.e. small, medium, and high-uptake). Village-level benefits in each of these three types of villages are calculated by summing the benefits for each household  $i$ .

The present value of the household benefits for household  $i$  in village type  $j$  is:

$$PV_{HH} B_{ij} = \sum_{t=1}^T \sum_{k=1}^3 B_{ijtk} * (1 + r)^{-t}, \quad (2)$$

where

$B_{ijtk}$  = value of the benefits for household  $i$  in village type  $j$  in year  $t$  for all household members in age group  $k$ ,

$r$  = real discount rate, and

$T$  = planning horizon

The benefits for each household  $i$  in village type  $j$  are depend on whether the household owns, uses, and maintains a latrine in year  $t$  and the impact of the CLTS intervention on the number of household members in each age group.

The benefits to each household in the region are calculated by adding the benefits from reduced diarrhea mortality (premature deaths averted), reduced diarrhea morbidity (nonfatal cases of diarrhea averted), and the time savings from no longer needing to walk somewhere outside the house to defecate. The benefits for all people in age group  $k$  in household  $i$  in village type  $j$  and year  $t$  are given by:

$$B_{ijtk} = P_k * \text{Premature deaths averted}_{ijtk} * VSL_t + P_k * \text{Nonfatal cases averted}_{ijtk} * COI_k + P_k * \text{Time savings}_{ijtk} * VOT_k * WAGE_t, \quad (3)$$

where

$P_k$  = number of people in age group  $k$  in household,

*Premature deaths averted* $_{ijtk}$  = number of deaths avoided due to the intervention's effect on diarrhea risk, in household  $i$  in village type  $j$  and year  $t$ , for each member of age group  $k$ ;

$VSL_t$  = value of a statistical life in year  $t$ ,

*Nonfatal cases averted* $_{ijtk}$  = number of nonfatal diarrhea cases averted due to the intervention's effect on diarrhea risk, in household  $i$  in village type  $j$  and year  $t$ , for each member of age group  $k$ ,

$COL_k$  = the cost of illness for a member of age group  $k$ ,

*Time savings* $_{ijtk}$  = number of hours saved from no longer walking to a defecation place due to the intervention, in household  $i$  in village type  $j$  and year  $t$ , for each member of age group  $k$ ,

$VOT_k$  = value of time for a member of age group  $k$ , expressed as a fraction of the unskilled wage rate in the region in the informal sector, and

$WAGE_t$  = the average unskilled hourly wage in year  $t$ .

Latrine abandonment is factored into this equation by adjusting the number of households with a latrine in each year  $t$ .

Using equation 3, individual benefits are aggregated by age group (younger than five, between five and fourteen, and fifteen and older) for each household, and then summed over the three age groups. The economic value of time savings for children under 5 years of age are assumed to be zero (Whittington and Cook, 2019).

Premature deaths avoided and non-fatal diarrhea cases avoided in household  $i$  in village type  $j$  and year  $t$ , for each member of age group  $k$  are shown in equations (4) and (5), respectively:

$$Premature\ deaths\ averted_{ijtk} = LAT_{ijt} * PP_{jtk} * DIA_{ik} * CFR_k * DR,$$

(4)

$$Nonfatal\ cases\ averted_{ijtk} = LAT_{ijt} * PP_{jtk} * DIA_{ik} * DR, \quad (5)$$

Where...

$LAT_{ijt}$  = one if household  $i$  in village type  $j$  has built or owns a latrine due to the intervention in year  $t$ , and is zero otherwise,

$PP_{jtk}$  = is the percentage of individuals in village type  $j$  in year  $t$  in age group  $k$  that use a latrine,

$DIA_{ik}$  = diarrhea incidence rate for a person in household  $i$  in age group  $k$ ,

$CFR_k$  = diarrhea case fatality rate for a person in age group  $k$ , and

$DR$  = diarrhea risk reduction experienced by members of a household with a latrine. We subscript equations (4) and (5) by year  $t$  to account for latrine abandonment.

The latrine indicator ensures that health benefits only accrue to household that build a latrine due to the CLTS intervention and still use their latrine in year  $t$ . The percentage of individuals using a latrine in each village in each year in each age group ensures that benefits only accrue to individuals using a latrine. Among households that have built and the individuals using a latrine, then, premature deaths averted are calculated with a multiplicative function of age-specific diarrhea incidence and case fatality rates, and the diarrhea risk reduction due to the intervention. Nonfatal diarrhea cases averted are calculated using the same equations but removing the case fatality variable.<sup>27</sup>

An avoided case of diarrhea for an individual in age group  $k$  is valued using the COI:

$$COI_k = SEEK_k * (HHC + POC_k * COC + PIC_k * CIN) + VLT_k * WAGE_t * [SEEK_k * POC_k * HLO_k + SEEK_k * PIC_k * HLI_k + (1 - SEEK_k) * HLNC_k], \quad (6)$$

where ...

$SEEK_k$  = percentage of diarrhea cases for which individuals in age group  $k$  seek medical attention,

$HHC$  = household financial cost per case among those seeking medical attention,

$POC_k$  = percentage of diarrhea patients seeking medical care in age group  $k$  that receive outpatient care,

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<sup>27</sup> This assumes that people that die from diarrhea also incur the full cost of illness.

$PIC_k$  = percentage of diarrhea patients seeking medical care in age group  $k$ , that receive inpatient care,

$COC$  = cost of outpatient care,

$CIN$  = cost of inpatient care,

$HLO_k$  = number of working hours lost due to being sick or caring for a sick person in age group  $k$  for those receiving outpatient care,

$HLI_k$  = number of working hours lost due to being sick or caring for a sick person in age group  $k$  for those receiving inpatient care,

$HLNC_k$  = number of working hours lost due to being sick or caring for a sick person in age group  $k$  for those not receiving care,

We assume that the diarrhea patients not seeking care have no medical expenses and that the only economic cost for these individuals is the time lost to the illness. All other terms ( $WAGE_t$  and  $VLT_k$ ) are as defined previously.

The cost of illness consists of the treatment costs and the lost productivity<sup>28</sup> due to being sick or caring for a sick child. The treatment costs are calculated as the sum of the average costs incurred by those seeking medical care and the proportion of those seeking care that receive inpatient or outpatient care. These costs may be paid by households themselves, the public sector, or donors. Lost productivity is calculated by adding the work hours not working due to sickness or due to caring for children for patients in each category of care (inpatient, outpatient, or none).

Time savings in household  $i$  in village type  $j$  and year  $t$ , for each member of age group  $k$ , are calculated as:

$$Time\ Savings_{ijtk} = [LAT_{ijt} * USE_{ijt} + BLAT_i * (USE_{ij} - BUSE_i)] * \frac{TRVL}{60} * TDEF * 365, \quad (7)$$

---

<sup>28</sup> We estimate the loss in productivity as the loss of income that an individual would have earned by working had they not gotten sick.

where

$BLAT_i$  = one for household  $i$  that owned a latrine before the intervention began, and is zero otherwise,

$BUSE_i$  = one if at least some members of household  $i$  use a latrine to defecate before the CLTS

intervention, and is zero otherwise,

$USE_{ijt}$  = one if at least some members of household  $i$  use a latrine to defecate after the CLTS

intervention, and is zero otherwise,

$TRVL$  = time spent walking to and from a place to defecate per trip, in minutes,

$TDEF$  = number of times a person defecates per day, (60 is used to convert travel time to hours, and 365 to convert daily to annual time savings).

The first term of equation (7) applies to members of households that have newly adopted, use, and maintain a latrine due to the CLTS intervention, while the second term applies to those who already had a latrine but started using it more intensively after the CLTS intervention. The other terms in the equation describe the hours saved per year from not needing to walk to and from defecation sites outside the household.

#### *Equations for calculations of benefits including the positive sanitation externality*

Several adjustments are required to incorporate a positive sanitation externality into the benefit-cost model. First, a new estimate for the diarrhea risk reduction among households adopting latrines is specified:

$$DR - EX^L = \begin{cases} DR + (MR - DR) * \left( \frac{\sum_{i=1}^I LAT_{ijt}}{HH} - TH \right) / (1 - TH), & \text{if } \frac{\sum_{i=1}^I LAT_{ijt}}{HH} \geq TH, \\ DR, & \text{if } \frac{\sum_{i=1}^I LAT_{ijt}}{HH} < TH \end{cases}, \quad (8)$$

where ...

$DR-EX^L$  = diarrhea reduction (including the externality) for households that newly adopted latrines after the CLTS intervention,

$MR$  = maximum diarrhea reduction that applies if all households in a village own a latrine,

$\sum_{i=1}^I LAT_{ijt}$  = total number of households in village type  $j$  that have built or own a latrine due to the CLTS intervention in year  $t$ ,

$HH$  = total number of households per village (100), and

$USE_{ijt}$  = one if at least some members of household  $i$  use a latrine to defecate before and after the CLTS intervention, and zero otherwise, and

$TH$  = threshold level of community coverage required to experience a positive externality.

The first part of this piecewise linear function requires calculating the latrine coverage level in a village in each village type. When this percentage of households with a latrine is greater than or equal to the threshold above which an externality is produced, the village experiences a positive sanitation externality that increases linearly with coverage up to the maximum achievable protection ( $MR$ ). Otherwise, the diarrhea reduction is simply that assumed for the case without an externality ( $DR$ ), as shown in Figure 1A. Due to latrine disuse and abandonment, villages could lose the externality benefits if coverage in year  $t$  falls below the threshold.

The diarrheal reduction for households without latrines is shown in equation (9), and the premature deaths and cases averted for these households are presented in equations (10) and (11):

$$DR - EX^{NL} = \begin{cases} MR * \left( \frac{\sum_{i=1}^I LAT_{ijt}}{HH} - TH \right) / (1 - TH), & \text{if } \frac{\sum_{i=1}^I LAT_{ijt}}{HH} \geq TH \\ 0\%, & \text{if } \frac{\sum_{i=1}^I LAT_{ijt}}{HH} < TH \end{cases} \quad (9)$$

$$Premature \text{ deaths averted}_{ijtk}^{NL} = NLAT_{ijt} * DIA_{ik} * CFR_k * DR - EX^{NL} \quad (10)$$

$$Nonfatal \text{ cases averted}_{ijtk}^{NL} = NLAT_{ijt} * DIA_{ik} * DR - EX^{NL}, \quad (11)$$

where  $DR-EX^{NL}$  = diarrhea reduction for households that do not have latrines following the intervention,

$NLAT_{ijt}$  = one for household  $i$  in village type  $j$  that has not constructed a latrine, in year  $t$ , and zero otherwise.

This calculation assumes that households without latrines experience a positive sanitation externality if there is overall coverage in the village above the threshold required to generate community-level protection, and that the protection again increases linearly with coverage up to the maximum achievable protection ( $MR$ ). Below the threshold, the risk reduction is simply zero (Figure 1B).

Finally, households already owning latrines prior to the intervention also experience reductions (albeit smaller ones) in diarrhea mortality (premature deaths averted) and morbidity (nonfatal diarrhea cases averted) above the threshold coverage. The diarrheal reduction for these households is shown in equation (12); premature deaths averted and nonfatal cases averted for these households are then analogous to those in equations (10) and (11), only they use the different protection rate  $DR - EX^{BL}$  and the binary indicator  $BLAT_{ij}$  from above:

$$DR - EX^{BL} = \begin{cases} \left(1 - \frac{1-MR}{1-DR}\right) * \left(\frac{\sum_{i=1}^I LAT_{ijt}}{HH} - TH\right) / (1 - TH), & \text{if } \frac{\sum_{i=1}^I LAT_{ijt}}{HH} \geq TH \\ 0\%, & \text{if } \frac{\sum_{i=1}^I LAT_{ijt}}{HH} < TH \end{cases} \quad (12)$$

where  $DR-EX^{BL}$  = diarrhea reduction for households that do not have latrines following the intervention.

This calculation again assumes that households who previously owned latrines experience a positive sanitation externality when coverage in the village rises above the threshold required to generate community-level protection. In this case, since households have already received protection  $DR$  from private latrine ownership, the additional protection increases linearly with coverage up to a maximum



achievable protection of  $1 - (1 - MR / (1 - DR))$ . Below the threshold, the additional risk reduction is simply zero (Figure 1C).

### *Equations for Costs Calculations*

Our estimates for the costs of implementing a CLTS intervention consist of estimates for administrative, logistic, and human resource costs. These include costs for transportation, educational materials, and administrative overhead, as well as the time of government officials, project facilitators, local leaders, and village residents required to implement a CLTS campaign. If a household decides to build a latrine after the CLTS intervention, it will incur latrine construction and maintenance costs, which are included as well.

The total costs of a CLTS intervention are calculated as the sum of the household-level costs in each village type  $j$  multiplied by the total number of villages of each type  $j$ :

$$PVC = \sum_{j=1}^J \sum_{i=1}^I N_j * PV_{HH} C_{ij}, \quad (13)$$

where

$PVC$  = present value of the cost of the CLTS intervention for the 200 villages in the hypothetical region in Sub-Saharan Africa,

$PV_{HH} C_{ij}$  = present value of cost per household  $i$  in village type  $j$ , and  $N_j$ ,

The present value of the costs per household  $i$  in village type  $j$  is then:

$$PV_{HH} C_{ij} = \frac{Program}{HH} + Capital_{ij} + Village\ time_{ij} + \sum_{t=1}^T O\&M_{ijt} * (1 + r)^{-t}, \quad (14)$$

where

$Program$  = total program (implementation) cost per village, including the management, training, facilitation, and the time costs of local actors required for a CLTS intervention,

$Capital_{ij}$  = capital cost for latrine construction incurred by household  $i$  in village type  $j$ ,

*Village time<sub>ij</sub>* = cost of time spent by household *i* in CLTS activities in village type *j*,

*O&M<sub>ijt</sub>* = operation and maintenance costs for household *i* in village type *j* in year *t* (a household must pay *O&M* as long as it continues to use a latrine).

The first three costs are one-time expenditures incurred in the first year of the CLTS program. CLTS program costs in each village are calculated as:

$$Program = Management + Training + Facilitation + Local Actor, \quad (15)$$

where *Management* includes non-infrastructure fixed costs, e.g., office supplies and transportation, as well as time costs for government and program managers. *Training* includes materials, accommodation, per diems, facilities, and time spent in training to capacitate facilitation staff.

*Facilitation* includes the transportation, material, and time costs of actually planning and implementing CLTS pre-triggering, triggering, and follow-up sessions. Finally, *Local actor* costs are for the value of time spent by members of village committees on CLTS promotion and village-level monitoring.

In classical (“pure”) CLTS interventions households are responsible for building or purchasing a latrine with their own resources. Capital costs for latrines constructed by a household *i* in village type *j* are calculated as the sum of materials and time spent by a person assumed to be older than fifteen years of age:

$$Capital_{ij} = LAT_{ij} * (CAP + CNST * WAGE * VOT_{k=3}), \quad (16)$$

where *CAP* = capital cost of a latrine,

*CNST* = time in hours required for constructing a latrine,

*VOT<sub>k=3</sub>* = value of time for people fifteen or older.

The major CLTS activity is the triggering session. During triggering, which occurs in the first year, village residents are led through a number of exercises designed to engender community behavior

change. The sessions take place when a facilitator or health official is able to schedule a meeting.

Many residents may be busy and unable to attend. Additional follow-up meetings or monitoring activities may also occur. Time costs for a household  $i$  in village type  $j$  are calculated as:

$$Village\ Time_{ij} = NAT_{ijk} * P_k * VLT_k * WAGE * (TRGT + CLTS), \quad (17)$$

where ...

$NAT_{ijk}$  = one if a person from age group  $k$  in household  $i$  and village type  $j$  participated in CLTS activities, and zero otherwise,

$TRGT$  = time in hours spent in a triggering session, and

$CLTS$  = time spent in hours in non-triggering CLTS meetings and activities.

This expression considers the number of people from each age group in a household who participate in the CLTS triggering and other activities, and the amount of time spent. This time is then multiplied by an age-specific value of time. As with the time benefits calculations, our analysis only includes the time costs for children older than five and for adults.

The final cost is for operation and maintenance. This includes the time and expense required for upkeep of a latrine. Households must regularly clean latrines and replace or repair parts of the latrine and its superstructure. Since these costs occur over the lifetime of the latrine they are calculated on an annual basis and discounted appropriately. O&M costs per household in each village type are calculated as:

$$O\&M_{ijt} = LAT_{ijt} * OPEX, \quad (18)$$

where  $OPEX$  is the annual expenditure on operation and maintenance activities, as a percentage of initial capital costs.

## Appendix B: Parameter Value Assumptions

Parameters	Base	Low	High	Source	Parameters	Base	Low	High	Source
Number of villages	200			Authors' estimate	% of cases seeking treatment receiving outpatient care <5	65%	50%	70%	Kotloff et al. (2013)
Low-uptake villages	80	120	66	Authors' estimate	% of cases seeking treatment receiving outpatient care ≥5	94%	91%	97%	Lamberti et al (2012)
Medium-uptake villages	80	60	66	Authors' estimate	Health system cost per outpatient case	\$10	\$5	\$15	Aikins et al. (2010) and Sigei et al. (2015)
Large-uptake villages	40	20	68	Authors' estimate	% of cases seeking treatment receiving inpatient care <5	35%	30%	50%	Kotloff et al. (2013)
Households per village	100			Crocker et al. (2016a) and Harris et al. (2017)	% of cases seeking treatment receiving inpatient care ≥5	6%	2%	10%	Lamberti et al (2012)
Average children <5 per household	1			DHS	Health system cost per inpatient case	\$200	\$100	\$300	Ngabo et al. (2016), Aikins et al. (2010), and Sigei et al. (2015)
Average children 5-14 per household	2			DHS	Working hours lost for outpatient /not seeking care <5	8	4	12	Lamberti et al. (2012)
Average people ≥15 per household	2			DHS	Working hours lost for inpatient <5	12	8	16	Lamberti et al. (2012)
Average baseline diarrheal incidence <5	2.4	2	2.8	2016 Global Burden of Disease	Working hours lost for outpatient/not seeking care ≥5	16	8	24	Lamberti et al. (2012)
Baseline diarrheal incidence <5 for HH w/o a latrine	2.64	2.2	3.1	Based on incidence, latrine coverage, and diarrhea reduction	Working hours lost for inpatient ≥5	24	16	32	Lamberti et al. (2012)
Baseline diarrheal incidence <5 for HH w a latrine	2.11	1.76	2.46	Based on incidence, latrine coverage, and diarrhea reduction	Value of time (% of wage) for ≥15	50%	25%	75%	Whittington and Cook (2019)
Average baseline diarrheal incidence 5-14	0.5	0.4	0.6	2016 Global Burden of Disease	Value of time (% of wage) for 5-14	25%	0%	50%	Whittington and Cook (2019)
Baseline diarrheal incidence 5-14 for HH w/o a latrine	.55	.44	.66	Based on incidence, latrine coverage, and diarrhea reduction	Value of time spent caring for <5 (% of wage)	50%	25%	75%	Whittington and Cook (2019)
Baseline diarrheal incidence 5-14 for HH w a latrine	.44	.35	.53	Based on incidence, latrine coverage, and diarrhea reduction	Market wage per hour (2016 International Dollars)	0.25	0.2	0.3	Pouliot et al. (2013), Matsumoto et al. (2006), Appiah et al. (2009), Yemiru et al. (2010), Babulo et al. (2008), and Ngabo et al. (2016)
Average baseline diarrheal incidence ≥15	1	0.9	1.1	2016 Global Burden of Disease weighted by DHS data	Discount rate	3%	0%	8%	Authors assumption, Wilkinson et al. 2016, and Claxton et al. 2019
Baseline diarrheal incidence ≥15 for HH w/o a latrine	1.1	.99	1.21	Based on incidence, latrine coverage, and diarrhea reduction	Round trip time spent on open defecation	8	4	12	World Bank ESI and BDS-Center for Development Research (2016)

Baseline diarrheal incidence $\geq 15$ for HH w a latrine	.88	.79	.97	Based on incidence, latrine coverage, and diarrhea reduction	Round trips to defecate site per day	1	1	2	Whittington et al (2009).
Diarrheal case fatality rate $< 5$	0.07%	0.05%	0.09%	2016 Global Disease Burden	Usage of new latrine in low-uptake villages	60%	50%	65%	Barnard et al. (2013), Anteneh and Kumie. (2010), and Garn et al. (2017)
Diarrheal case fatality rate 5-14	0.02%	0.01%	0.03%	2016 Global Disease Burden	Usage of new latrine in medium-uptake villages	65%	60%	70%	Barnard et al. (2013), Anteneh and Kumie. (2010), and Garn et al. (2017)
Diarrheal case fatality rate $\geq 15$	0.03%	0.02%	0.05%	2016 Global Burden of Disease weighted by DHS data	Usage of new latrine in high-uptake villages	85%	75%	95%	Barnard et al. (2013), Anteneh and Kumie. (2010), and Garn et al. (2017)
Increase in latrine for low-uptake	5%	0%	10%	Authors' assumption	Baseline latrine usage	45%	30%	60%	Sinha et al. 2017, Crocker et al. 2016b, Anteneh and Kumie 2010, and Barnard 2013
Increase in latrine for medium-uptake	15%	10%	20%	Authors' assumption	Management cost per village	\$1,500	\$1,250	\$1,750	Crocker et al. (2017b) derived from average
Increase in latrine for high-uptake	35%	25%	45%	Authors' assumption	Training cost per village	\$700	\$400	\$1,000	Crocker et al. (2017b) derived from average
Baseline latrine coverage	45%	30%	60%	DHS and CLTS studies	Facilitation costs per village	\$2,500	\$1,500	3,500	Crocker et al. (2017b) derived from average
Diarrhea reduction for households adopting latrines	20%	10%	30%	Wolf et al. (2018) and CLTS studies	Local actor costs per household	\$200	\$100	\$300	Crocker et al. (2017b) derived from average
Maximum diarrhea reduction with externalities	35%	25%	45%	Authors' estimate	Percent in CLTS in low-uptake village	35%			Authors assumption
US VSL	\$9,400,000			Robinson et al. (2018)	Percent in CLTS in medium-uptake village	45%			Authors assumption
US GNI per Capita	\$57,878			World Bank (2018)	Percent in CLTS in high-uptake villages	60%			Authors assumption
Annual GNI per capita in intervention area	\$2,000	\$1,500	\$2,500	Based on World Bank (2018) GNI per capita	Triggering time per person	4	3	6	Crocker et al. (2017B)
VSL in intervention area	\$60,380	\$39,215	\$84,385	Authors assumption	Follow up time per participating person	20	15	25	Crocker et al. (2017B)
GNI per capita growth	2%	0%	4%	Author assumptions	Planning horizon for the latrine	10			Meyer et al. (2018)/author assumption
Latrine abandonment	10%	5%	15%	Authors' assumption	Capital cost of a latrine	\$50	\$35	\$65	Cole et al. (2012) and Crocker et al. (2017b)
% of cases seeking care $< 5$	50%	25%	75%	Mean number of cases for $< 5$ seeking care from DHS and MIS	Operation and maintenance expenses for toilet (% of cost of toilet)	10%	5%	15%	Author assumption
% of cases seeking care $\geq 5$	5%	3%	9%	Ratio of severe and moderate diarrhea in older 5/under 5	Time constructing toilet (hours)	30	25	35	BDS-Center for Development Research 2016, Crocker et al. (2017)
HH cost per case seeking care	\$4	\$2	\$6	Rheingans et al. (2012)	Externality threshold	60%	75%	80%	Wolf et al. 2015, Andres et al. 2014, and Jung et al. 2017

## Appendix C: Assumed Associations between Selected Parameters, for Monte Carlo Sensitivity Analysis

Baseline Condition Parameters	Association	Other Parameters	Association
Baseline latrine coverage	-0.5 Average Baseline diarrheal incidence <5, -0.5 Average Baseline diarrheal incidence 5-14, -0.5 Average Baseline diarrheal incidence ≥15	Annual GNI per capita in intervention area	0.7 unskilled market wage
Baseline latrine usage	-0.5 Average Baseline diarrheal incidence <5, -0.5 Average Baseline diarrheal incidence 5-14, -0.5 Average Baseline diarrheal incidence ≥15	HH cost per case seeking care	0.5 market unskilled market wage
Diarrheal case fatality rate <5	0.5 Average Baseline diarrheal incidence <5,	Health system cost per outpatient case	0.5 market unskilled market wage
Diarrheal case fatality rate 5-14	0.5 Average Baseline diarrheal incidence 5-14	Health system cost per inpatient case	0.5 market unskilled market wage
Diarrheal case fatality rate ≥15	0.5 Average Baseline diarrheal incidence ≥15	Training cost per village	0.5 market unskilled market wage
% of cases seeking treatment receiving inpatient care <5	0.5 Average Baseline diarrheal incidence <5,	Facilitation costs per village	0.5 market unskilled market wage
% of cases seeking treatment receiving inpatient care >5	0.5 Average Baseline diarrheal incidence 5-14, 0.5 Average Baseline diarrheal incidence ≥15	Local actor costs per household	0.5 market unskilled market wage
Working hours lost for inpatient <5	0.5 Average Baseline diarrheal incidence <5,	Value of time (% of wage) for 15+	0.5 market unskilled market wage
Working hours lost for inpatient >5	0.5 Average Baseline diarrheal incidence 5-14, 0.5 Average Baseline diarrheal incidence ≥15	Value of time (% of wage) for 5-14	0.5 market unskilled market wage
Working hours lost for outpatient/not seeking care <5	0.5 Average Baseline diarrheal incidence <5,	Value of time spent caring for <5	0.5 market unskilled market wage
Working hours lost for outpatient/not seeking care >5	0.5 Average Baseline diarrheal incidence 5-14, 0.5 Average Baseline diarrheal incidence ≥15		
% of cases seeking care <5	0.5 Average Baseline diarrheal incidence <5,		
% of cases seeking care >5	0.5 Average Baseline diarrheal incidence 5-14, 0.5 Average Baseline diarrheal incidence ≥15		

#### Appendix D: Summary of Results of Benefit-Cost Analysis Including Only Time Savings Benefits

	Low-Uptake Villages	Medium-Uptake Villages	High-Uptake Villages	All Villages
No Externalities				
Benefits	\$1,090	\$2,365	\$6,560	\$538,310
Mortality Benefits	\$0	\$0	\$0	\$0
Morbidity Benefits	\$0	\$0	\$0	\$0
Time Savings	\$1,090	\$2,365	\$6,560	\$538,310
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	(\$4,720)	(\$4,215)	(\$1,800)	(\$787,480)
BC ratio	0.2	0.4	0.8	0.4
ERR	-23%	-15%	-2%	-14%

\*We only include the results without an externality since there are no externalities in a scenario where we assume no health benefits.

# Appendix E: Summary of BCA Results with Monetized YLDs to Value Morbidity Benefits\*

	Low-Uptake Villages	Medium-Uptake Villages	High-Uptake Villages	All Villages
No Externalities				
Benefits	\$3,375	\$9,215	\$22,550	\$1,909,045
Mortality Benefits	\$1,430	\$4,290	\$10,015	\$858,185
Morbidity Benefits	\$855	\$2,560	\$5,975	\$512,550
Time Savings	\$1,090	\$2,365	\$6,560	\$538,310
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	(\$2,435)	\$2,635	\$14,185	\$583,260
BC ratio	0.6	1.4	2.7	1.45
ERR	-7%	11%	34%	12%
Externalities				
Benefits	\$3,375	\$9,215	\$28,075	\$2,129,985
Mortality Benefits	\$1,430	\$4,290	\$13,335	\$991,090
Morbidity Benefits	\$855	\$2,560	\$8,180	\$600,580
Time Savings	\$1,090	\$2,365	\$6,560	\$538,315
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	(\$2,435)	\$2,635	\$19,705	\$804,190
BC ratio	0.6	1.4	3.35	1.6
ERR	-7%	11%	49%	15%

\*We assume the YLD equals Int'l \$1,285 in the first year of the project and based on our base case VSL (Int'l \$60,380). For the DALYs averted we calculate two separate values for children  $\leq 5$  and people  $> 5$  by calculating a weighted average of mild, moderate, and severe cases of diarrhea for these two age groups. We assume that about 65% of the cases for  $\leq 5$  are mild, 34.5% are moderate, and .5% are severe. For  $> 5$  we assume that 95% of cases are mild, 4.95% are moderate, and .05% are severe. Therefore, the DALYs averted per case of non-fatal diarrhea for children  $\leq 5$  is .002 (calculated with a weight of .11 and an average case lasts 5 days), while for those  $> 5$  the DALYs averted per case of non-fatal diarrhea is .0006 (calculated with a weight of .08 and an average case lasts 2.8 days).



Appendix F: Summary of Benefit-Cost Results using a Value of Statistical Life (VSL) of 2016 Int'l \$200,000

	Low-Uptake Villages	Medium-Uptake Villages	High-Uptake Villages	All Villages
W/o Externalities				
Benefits	\$6,090	\$17,340	\$41,500	\$3,533,330
Mortality Benefits	\$4,100	\$12,280	\$28,650	\$2,455,940
Morbidity Benefits	\$900	\$2,695	\$6,290	\$539,080
Time Savings	\$1,090	\$2,365	\$6,560	\$538,310
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	\$4,900	\$10,760	\$33,135	\$2,207,540
BC ratio	1.1	2.6	5.0	2.7
ERR	4%	32%	72%	33%
With Externalities				
Benefits	\$6,090	\$17,340	\$53,725	\$4,022,125
Mortality Benefits	\$4,100	\$12,280	\$38,680	\$2,856,940
Morbidity Benefits	\$900	\$2,695	\$8,485	\$626,870
Time Savings	\$1,090	\$2,365	\$6,560	\$538,315
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	\$4,900	\$10,760	\$45,360	\$2,696,335
BC ratio	1.1	2.6	6.4	3.0
ERR	4%	32%	106%	45%

**Appendix G:** Summary of Benefit-Cost Results using a Value of Statistical Life (VSL) of 2016 Int'l \$320,000

	Low-Uptake Villages	Medium-Uptake Villages	High-Uptake Villages	All Villages
No Externalities				
Benefits	\$8,535	\$24,705	\$58,695	\$5,006,890
Mortality Benefits	\$6,545	\$19,645	\$45,845	\$3,929,500
Morbidity Benefits	\$900	\$2,695	\$6,290	\$539,080
Time Savings	\$1,090	\$2,365	\$6,560	\$538,310
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	\$2,725	\$18,125	\$50,330	\$3,681,100
BC ratio	1.5	3.8	7.0	3.8
ERR	12%	50%	104%	50%
Externalities				
Benefits	\$8,535	\$24,705	\$76,930	\$5,736,290
Mortality Benefits	\$6,545	\$19,645	\$61,885	\$4,571,105
Morbidity Benefits	\$900	\$2,695	\$8,485	\$626,870
Time Savings	\$1,090	\$2,365	\$6,560	\$538,315
Costs	\$5,810	\$6,580	\$8,365	\$1,325,790
Program Costs	\$4,900	\$4,900	\$4,900	\$980,000
Time Costs	\$535	\$535	\$535	\$107,265
Capital Costs	\$270	\$805	\$1,880	\$161,175
O&M Costs	\$100	\$340	\$1,050	\$77,350
Net Benefits	\$2,725	\$18,125	\$68,565	\$4,410,500
BC ratio	1.5	3.8	9.2	4.3
ERR	12%	50%	155%	69%