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Benefit-Cost Analysis

Economic Costs and Benefits of Cholera Vaccination Intervention Options for Rural Haiti

COPENHAGEN CONSENSUS CENTER

Haïti Priorise
Un plan de développement alternatif

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Haïti Priorise

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Academic Abstract

This paper, written for Priorise Haiti, presents a cost-benefit comparison of four cholera vaccination interventions in rural Haiti. The four vaccination variations are: 1) a mass vaccination campaign providing two doses of the vaccine; 2) a mass vaccination campaign providing one dose of the vaccine; 3) a school-based vaccination campaign providing two doses of the vaccine to children only; and 4) a school-based vaccination campaign providing one dose of the vaccine to these same children.

We adapted a model that had previously been applied for evaluating cholera vaccination interventions in other settings, incorporating a different health valuation measure, as well as new data. Specifically, this analysis of four cholera vaccination interventions in rural Haiti values health benefits using the concept of the value of an averted Disability Adjusted Life Year (DALY) for both mortality and morbidity. Our previous model of the costs and benefits of cholera interventions used the value of a statistical life (VSL) to estimate the economic value of mortality risk reductions and the cost-of-illness method to measure the economic value of morbidity risk reductions (Jeuland and Whittington 2009). In conducting the analysis for Haiti, we also updated the model with available data on cholera incidence and case mortality rates from cholera in rural Haiti and other data from recently published research.

We performed a sensitivity analysis on the cost-benefit results by adjusting the discount rate and the assumed value of an averted DALY. Our results show that there is a strong economic case for investing in cholera vaccination campaigns. We also performed a one-way sensitivity analysis to identify those parameters with the largest impact on the four interventions. The net benefits of the four interventions are most sensitive, in order of sensitivity, to the assumed economic value of an averted DALY, the cholera case fatality rate, and the discount rate.

We also conducted Monte Carlo simulations allowing all the model parameters to vary over uniform distributions between assumed low and high values. The results of these simulations show

that the one-dose school vaccination intervention has the tightest distribution of net benefits. Under particular local conditions, any of the four interventions may not deliver positive net benefits, and decision makers should consider the appropriateness of each intervention carefully, given local realities.

We believe that the citizens of Haiti are morally entitled to remedial actions by the United Nations, as it was United Nations peacekeepers who first introduced cholera to the country. The most effective strategy for combatting cholera is considered to be a combination of vaccination campaigns as well as water and sanitation interventions. However, our analysis did not estimate the costs and benefits of a combined water, sanitation, and vaccination intervention.

Policy Abstract

Overview

Cholera first emerged as a public health threat in Haiti in 2010, in the aftermath of a massive earthquake, and spread quickly throughout the country. Since that time, hundreds of thousands of people have been infected, and nearly 10,000 people are estimated to have died due to the illness. According to the Pan American Health Organization's (PAHO) *Atlas of Cholera Outbreak in Hispaniola, 2010-2016*, Haiti had 34,838 new cholera cases and 374 deaths from cholera between January and October 2016. The situation has prompted a range of interventions to address the cholera epidemic, including a series of vaccination efforts. However, cholera still remains a burden on the people of Haiti. The vaccination interventions described in this paper would build upon previous vaccination initiatives, including follow-up with individuals in rural areas who have already been vaccinated.

Implementation Considerations

We estimate the costs for a cholera vaccination campaign based on the financial costs of producing, transporting, and administering the vaccine, as well as related programmatic costs. Vaccinated individuals also incur time and monetary costs for traveling to the vaccination center, potentially queuing for the vaccine, and the time requirements associated with the vaccination protocol. We include these costs as well. This analysis uses a constant marginal cost per dose, a common approach in cost-effectiveness literature because cost data are limited (Mogasale et al. 2016). We assume the constant marginal cost per dose includes both the purchase price and the delivery cost (Jeuland et al. 2009). In other words, we assume that the costs of the vaccination interventions examined exhibit constant returns to scale, which means that the total financial cost of a vaccination intervention increases (decreases) at a constant proportion to the increase (decrease) of the coverage of the intervention. For example, the total financial cost of a vaccination intervention that reached 100% of a target population would be double the financial cost of a vaccination intervention that reached 50% of the target population. Additionally, we assume the cost of delivering a second dose of vaccine is the same as the cost of delivering the first dose in both the mass vaccination interventions and in the school vaccination interventions. We acknowledge that the marginal cost of *producing* the oral cholera vaccine will exhibit increasing returns to scale, but the available cost data and global supply constraints preclude us making more refined assumptions about the purchase price of the oral cholera vaccine to the Haitian government or international donors.

Cholera vaccination programs have occurred regularly in Haiti since 2012. These campaigns can continue with the support of international donors, local and international NGOs, and the Haitian government. In 2012, two NGOs ran Haiti's first cholera vaccination campaign, which reached almost 100,000 people. In 2013, the Haitian government ran its own vaccination campaign as part of its strategy for eliminating cholera. This campaign also reached more than 100,000 people. Most recently, WHO/PAHO, UNICEF, GAVI, the Vaccine Alliance, and other partners supported a campaign that reached more than 700,000 people. As of 2017, more than 1 million Haitians have received vaccinations against cholera. However, the oral cholera vaccines used in Haiti provide only short-lived protection against cholera (approximately 3 years), making continuing vaccination important so long as the disease persists in Haiti.

In addition to the evidence of effectiveness documented in international vaccine trials, a number of studies have suggested that the campaigns in Haiti have afforded vaccinated individuals with protection against infection. In a 2016 study, researchers recorded information for all patients presenting at a local cholera treatment center for one month. The treatment center was located in an area where a previous vaccination campaign was administered. The researchers found that of all the patients presenting with cholera, 99% were from outside the vaccinated area and the others were never vaccinated (Severe et al. 2016). In a different location, a government surveillance program in an urban slum claimed that no culture-confirmed cholera cases occurred between September 2013 and August 2016 among persons who received interventions of both 1) household water chlorination, and 2) cholera vaccination (Ivers 2017).

Ideally, additional vaccination campaigns would start as soon as possible. However, the cholera vaccine supply is limited. Haitian officials would need to work with the International Coordinating Group (ICG) that manages the global Oral Cholera Vaccine stockpile to organize a new intervention. In 2015, the global demand for the cholera vaccine was greater than the available supply. The WHO pre-qualified Euvichol in late 2015, and global production of cholera vaccines is expected to increase. The planned additional production is estimated to double the global supply. Therefore, in order to implement a vaccination campaign, Haitian officials would need to coordinate with and have the support of the ICG.

Rationale for Intervention

The benefits from a cholera vaccination campaign are from the health gains to both the vaccinated population as well as the unvaccinated population. Unvaccinated individuals receive some protection against cholera infection from herd immunity. The protection from the vaccine reduces both morbidity and mortality from cholera infection. For the purpose of this analysis, these health benefits are calculated as the product of 1) the number of DALYs averted per month over the duration of the protection offered by the vaccine, and 2) an assumed value per DALY averted. The result of this multiplication is an estimate of a monthly monetary benefit of the improved health outcomes to households.

All Haitians susceptible to cholera in a vaccinated area are beneficiaries of the vaccination intervention. While both vaccinated and unvaccinated populations benefit from the campaigns, the benefits to the vaccinated group are higher than the benefits to the unvaccinated group. Therefore, in the school campaigns, children benefit more than adults. However, to facilitate comparison of the different interventions, we still present the results of our benefit-cost calculation for the two school vaccination interventions on a monthly per household basis.

All the interventions analyzed for Haiti Priorise that result in health outcomes use the same method for valuing averted DALYs. We believe that this method likely underestimates the economic benefits of cholera vaccination interventions. Since cholera was introduced by the United Nations peacekeepers, it is likely that most Haitians believe their reference condition is a world without cholera. Therefore, when analyzing cholera-related interventions, one should theoretically use a willingness-to-accept compensation approach to value the resulting health benefits (Knetsch et al. 2012; Whittington et al. 2017). Since estimates for willingness-to-accept compensation to forgo a reduction in a loss are typically larger than measures for willingness to pay for the same magnitude reduction in risk, we believe that the benefits of cholera interventions are much larger than the estimates obtained by the use of the Copenhagen Consensus protocol for valuing health outcomes suggest.

The only positive health externalities included in the analysis are the herd immunity effect of the vaccinations. Due to the herd immunity effect, it may not be necessary to vaccinate 100% of the Haitian population to eliminate cholera infections, although evidence on the nature of the herd protection effect of the vaccine is limited to data from a single setting (Bangladesh). If vaccination campaigns are combined with investments to improve water and sanitation conditions, it may be possible to completely eliminate cholera from Haiti.

Our model does not capture any macroeconomic effects from the cholera vaccination interventions. An example of the benefits of reducing cholera could be an increase in tourism, as travelers' may be unwilling to visit Haiti due to the ongoing cholera epidemic. Nor does our model include the fact that cholera cases may increase with extreme weather events. Other factors not incorporated in our model include: 1) people's fear or anxiety due to the cholera epidemic, and 2) the value friends or family members place on the lives saved from the vaccination campaigns.

Cost Benefit Table

Summary Table

Interventions	Benefit ($/hh-month)	Cost ($/hh-month)	BCR	Quality of Evidence
Mass Vaccination with Two Doses	US$0.80	US$0.38	2.1	Medium
Mass Vaccination with One Dose	US$0.66	US$0.19	3.5	Limited
School Vaccination with Two Doses	US$0.39	US$0.09	4.5	Medium
School Vaccination with One Dose	US$0.26	US$0.04	5.9	Limited

Notes: All figures assume a 5% discount rate

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1. Introduction

Cholera is an infectious disease caused by exposure to the bacterium *Vibrio cholerae O1* or *O139*, resulting in acute dehydration and sometimes death. The illness first emerged as a public health threat in Haiti in late 2010, in the aftermath of a massive earthquake. Cholera spread quickly through the country. Since that time, hundreds of thousands of people have been infected, and nearly 10,000 people are confirmed to have died due to the illness. Several interventions have been implemented to address the cholera epidemic, including a series of vaccination efforts. This paper describes the economic costs and benefits of four cholera vaccination interventions that could build on these previous cholera vaccination initiatives (including additional follow-up vaccinations of individuals who have already been vaccinated). In Haiti and other countries affected by cholera, multilateral aid organizations remain interested in the potential of oral cholera vaccines for reducing risks of the outbreaks of this illness (Jeuland et al. 2009). Due to limited vaccination supplies and an increasing global demand for oral cholera vaccines, any vaccination plan for Haiti would require coordination with international partners and GAVI, the Vaccine Alliance (Desai et al. 2016).

This paper has been prepared for the Copenhagen Consensus Haiti Priorise Project. The analysis provides estimates of the economic costs and benefits of four cholera vaccination interventions in rural Haiti: 1) a mass vaccination campaign providing two doses of the vaccine to each individual vaccinated; 2) a mass vaccination campaign providing one dose of the vaccine; 3) a school-based vaccination campaign providing two doses of the vaccine to children only; and 4) a school-based vaccination campaign providing one dose of the vaccine to children only. The mass and school-based interventions were selected for two main reasons. First, previous analyses have indicated that these interventions could have positive economic effects. Second, examination of the costs and benefits of these interventions illustrate the important tradeoff between higher coverage and therefore cases avoided, on the one hand, and cost and logistical challenges, on the other (Jeuland and Whittington 2009, and Jeuland et al. 2009). In particular, a school-based vaccination program is easier to implement because many vaccines are already provided through similar vaccination programs and information campaigns and needs are relatively modest. Mass vaccination campaigns, on the other hand, require greater planning and additional awareness-raising if high rates of participation are to be achieved. In addition to these differences, the nonlinear relationship between vaccination coverage and effectiveness that arises from herd protection has important economic implications (Cook et al. 2009; Jeuland et al. 2009). However, a key limitation of our analysis in this respect is the fact that per-vaccine costs are not assumed to vary with program scale (that is, we assume constant marginal costs of vaccination). This assumption is consistent with prior work in the literature that is constrained by a lack of data on the relationship between costs and coverage. It also reflects the global supply constraints on the number of oral cholera vaccines currently available.

In the next, second section of the paper, we describe the history of the cholera outbreak in Haiti and provide information regarding current baseline health conditions. In the third section, we describe the cholera vaccine and ongoing campaigns that have already vaccinated many Haitians. In the fourth section, we briefly describe the four vaccination campaign interventions. In the fifth section, we present the equations we use to calculate the costs and benefits of each of the four interventions. We also present the data and assumed parameters we use in these equations. The sixth section presents the results of the benefit-cost calculations and sensitivity analyses. In the seventh section, we offer our interpretation of the results of these analyses.

2. Background

Cholera was brought to Haiti by the United Nations peacekeepers following a massive earthquake (magnitude 7.0) that hit Haiti in 2010. Shortly after this disaster, the United States Centers for Disease Control (CDC) assessed the situation and found that while “the current water, sanitation, and hygiene infrastructure in Haiti would certainly facilitate transmission of cholera (and many other illnesses), cholera is not circulating in Haiti, and the risk of cholera introduction to Haiti is low” (CDC 2010). Unfortunately, on October 19, 2010, the Ministère De Santé Publique Et De La Population (MSPP) was alerted to an increase in acute diarrhea patients in two Departments. By November 19, an outbreak caused by *V. cholerae* serogroup *O1*, biotype *Ogawa*, was confirmed with cases in all of Haiti’s ten departments and the country’s first cholera outbreak was declared

(Barzilay et al. 2013; U.N General Assembly 2016). Within a matter of days nearly 130 people had died and an additional 2,000 people had been hospitalized.

After Hurricane Tomas hit the island in early November, 2010, cholera spread further across all departments of the country, affecting many more people. As of October 2016, according to *PAHO's Atlas of Cholera Outbreak in Hispaniola, 2010-2016*, 798,272 people (roughly 7% of the Haitian population) had been infected with cholera and 9,517 had died from the disease.

The CDC, in cooperation with the MSPP, investigated the source of the outbreak and the mechanism for its rapid spread across the country. The investigation found that "untreated drinking water" was the primary source for cholera (Tappero and Tauxe 2011, p. 2088), but did not explain the new and sudden appearance of the disease-causing bacterium in the country. A separate genome sequencing analysis determined that the cholera strains in Haiti were genetically almost identical to Nepalese isolates (Hendriksen et al. 2011). The outbreak was eventually traced to a contingent of UN peacekeepers from Nepal.

Although UN peacekeepers inadvertently introduced cholera into Haiti, it would not have spread as quickly "without simultaneous water and sanitation and health care system deficiencies" (Cravioto et al. 2011, p. 29). The National Plan for the Elimination of Cholera in Haiti 2013-2022 acknowledges that:

> The lack of good hygiene practices among most of the population, and particularly among groups without access to basic health services, was among the factors that furthered the rapid spread of the disease. In addition, even before the earthquake in January 2010 and the cholera outbreak in October of that same year, 46% of the Haitian population had no access to health care. (MSPP 2013, p. 6).

The risk posed by lack of safe water, sanitation and health care is further evidenced by the difference in the epidemic's progression in Haiti and the neighboring Dominican Republic, where access to such services is higher. While water and sanitation interventions would surely reduce the risks of a resurgence of cholera, such investments are expensive, implementation is complicated, and infrastructure construction takes time. Water and sanitation investments are thus unlikely to provide adequate short term protection against new cholera outbreaks.

While the number of cholera cases and deaths from cholera has steadily decreased since the initial outbreak, seasonal factors, future hurricanes, or other natural disasters could trigger new outbreaks. Predicting the future of the epidemic in Haiti is particularly difficult as there is a limited history of cholera in country and the Caribbean region. There are no data indicating what proportion of the population has developed natural immunity to the disease and how long this immunity might last (Tappero and Tauxe 2011). In fact, in early 2012, the MSPP identified "a resurgence in cholera cases ... during the months of May, November and December" (MSPP 2013, p. 13). More recently, between January and April 2016, "150 new deaths occurred, an increase of 18 per cent over the same period in 2015" (U.N General Assembly 2016, p. 6). It is also unknown whether cholera has become endemic in Haiti by establishing reservoirs in the country's rivers, estuaries, and coastal regions (Rinaldo et al. 2012, p. 6602).[1] If so, seasonal fluctuations, severe weather patterns, or natural disasters could all induce new outbreaks.

Interventions designed to control cholera in Haiti must consider the reality that the cholera organism quickly evolves, rendering full eradication difficult without extensive improvements in water quality and sanitation (Morris 2011; Kirpich 2015). Interventions such as vaccinations can provide temporary relief from the disease and complement long-term efforts to improve poor water and sanitation conditions. For this reason, the WHO advocates for the use of cholera vaccination (especially among preschool- and school-aged children) along with traditional community engagement, water and sanitation programs, and other strategies for combatting this illness (WHO 2010). Haiti's Minister of Public Health, Dr. Daphne Benoit has expressed a similar view (PAHO 2016), and the *National Plan for the Elimination of Cholera in Haiti* has called for implementing vaccination campaigns, particularly targeting rural communities lacking access to adequate health facilities.

To summarize the progression of the cholera epidemic in Haiti over time and space, from when it started in 2010 up to October 2016, we use data collected from the *Atlas of Cholera Outbreak in*

[1] Two studies, Alam et al. 2014 and Alam et al. 2015, have found *V. cholerae O1* in the aquatic environment and assert that: "Regardless of whether toxigenic *V. cholerae O1* have established true environmental reservoirs or the surface water was contaminated by those infected with cholera, the presence of toxigenic *V. cholerae O1* in the surface water represents a potential ongoing source of exposure."

Hispaniola, 2010-2016, the Demographic Health Survey 2012 (DHS), and the MSPP's Statistical Report 2014 and 2013 (Rapport Statistique 2014 and Rapport Statistique 2013). These data suggest that there is a real risk of an upsurge of cholera infections in the future.

Over the first two years of the epidemic, the cumulative weekly number of new cholera cases and deaths from cholera rose quickly, and then began to level off (Figures 1 and 2). However, both the number of cases and the number of deaths have continued to rise through the end of 2016. Since 2012, every year has seen periods with spikes in the numbers of cases and deaths (Figures 3 and 4). Data from the 2012 DHS confirm that cholera is widespread across rural Haiti (these cases were self-reported and not clinically confirmed). According to the 2012 DHS respondents, 4-32% of households across the ten departments reported that a household member had contracted a non-fatal case of cholera, while 0.6-2.7% of households reported that a household member had died of cholera (Figure 5 and 6). The total cases by department for 2013 and 2014 are shown in Figure 7 (Data from the MSPP 2014 and 2013 Statistical Report).

Another important feature of these trends is the apparent decline in the cholera case fatality rate (CFR) since the beginning of the epidemic. As of April 2011, cumulative case-fatality rates ranged from 0.8% to 7.7% across the ten departments (Farmer et al. 2011). Nationally, the official case-fatality rate decreased from a high of 1.7% to an estimated 1%, on par with CFRs in many other countries with endemic cholera (Jeuland et al. 2009).

3. Oral Cholera Vaccines and Prior Cholera Vaccination Efforts in Haiti

The National Plan for the Elimination of Cholera in Haiti 2013-2020 calls for using the oral cholera vaccine (OCV) to protect Haitians from the illness. As of December 2015, the WHO had prequalified three OCVs that have proved safe and effective against preventing cholera. The commercial names of these three vaccines are: Dukoral, Shanchol, and Euvichol. Dukoral was first produced by Crucell, a Swedish manufacturer. In some recent studies, the procurement cost for this vaccine is reported as US$5 per dose, though prices quoted elsewhere vary considerably (Mogasale et al.

2016). A manufacturer in Vietnam improved the production process with support from the International Vaccine Institute and other international partners. The main improvements included lowering manufacturing costs and removing the need for buffer or water co-administration, resulting in decreased storage costs and requirements (Baik et al. 2015). The technology was then transferred to Shantha Biotechnics Limited, an Indian manufacturer that produces Shanchol, which was pre-qualified in 2011, and has often been sold for US$1.85 per dose (Mogasale et al. 2016). The technology was subsequently transferred to a South Korean manufacturer that produces Euvichol, which was prequalified in 2015.

Shanchol and Euvichol are made of similar inputs and use a similar manufacturing process that ensures that both OCVs contain the same killed cells of *V. cholerae*, undergo similar quality assurance, and are presented in glass vials.[2] Initial findings testing the non-inferiority of Euvichol revealed that both Euvichol and Shanchol provide similar levels of protection (Baik et al. 2015). For the purpose of our analysis in this paper, we assumed that Shanchol would be administered in rural Haiti, since the vaccine has been used since 2009 and researchers have already conducted a number of evaluations of its effectiveness in several different countries, including Haiti. Over two million doses of the Shanchol vaccine have been administered globally since 2009.

In 2012, soon after Shanchol received prequalification from the WHO, the Groupe Haïtien d'Etude du Sarcome de Kaposi et des Infections Opportunistes (GHESKIO) and Partners in Health/Zamni Lasante (PIH) ran the first demonstration project using OCVs in response to the ongoing epidemic. The project successfully reached almost 100,000 people, living in one urban community in Port-au-Prince and in rural communities in the Artibonite valley. Specifically, the rural arm of the campaign reached 45,417 persons with at least one dose of OCV, and 91% of these were confirmed to have received a second dose in the follow-up vaccination phase (Ivers et al. 2013). A two-week study in the urban arm identified only 18 cases of cholera among the 52,357 vaccinated people (corresponding to an incidence of 0.034%) (Severe et al. 2016). Furthermore, a government

[2] Each dose of Euvichol or Shanchol contains 300 Lipopolysaccharide ELISA Unit (LEU) of *V. cholerae O1* Inaba Cairo 48 (Heat inactivation), 600 LEU of *V. cholerae O1* Inaba Phil 6973 El Tor (Formalin inactivation), 300 LEU of *V. cholerae O1* Ogawa Cairo 50 (Formalin inactivation), 300 LEU of *V. cholerae O1* Ogawa Cairo 50 (Heat inactivation), and 600 LEU of *V. cholerae O139* 4260B (Formalin inactivation) (Baik et al. 2015).

surveillance program in an urban slum claimed that no culture-confirmed cholera cases occurred between September 2013 and August 2016 among persons who received interventions of both 1) household water chlorination, and 2) cholera vaccination (Ivers 2017). The results of this initial campaign offer suggestive evidence that vaccination can be used to effectively protect populations in Haiti against cholera infection.

After the successful demonstration project, MSPP conducted small-scale annual vaccination campaigns, and between 2013 and late 2016 vaccinated approximately 480,000 people, which is roughly 4% of the Haitian population (GAVI 2016). Support for these efforts has been provided by GAVI, the Vaccine Alliance. Most recently, in response to Hurricane Matthew in November 2016, MSPP ran a large-scale campaign that reached more than 729,000 people, with support from the WHO, UNICEF, and the International Federation of the Red Cross, as well as other organizations (Beaubien 2016; Mitchell 2016). However, several million people in Haiti have still not been vaccinated. Additionally, as the duration of the effectiveness of the vaccine is assumed to fall within the range of 2–4 years, many individuals will need to be revaccinated to ensure continued protection against infection (Jeuland and Whittington 2009).

4. Description of Four Vaccination Interventions

Our analysis considers two types of campaigns (mass and school-based) that each deliver two doses, as recommended, or a single dose. In all cases, we consider that vaccination would also provide indirect protection to unvaccinated individuals through herd effects, consistent with the literature (Ali et al. 2005; Longini et al. 2007; Jeuland et al. 2009). We calculate overall protection to cholera as a function of vaccine effectiveness and the extent of the herd protection. While the literature shows that one dose of vaccine offers less protection than two doses, studies for a one-dose regime do not estimate the herd effects (Qadri et al. 2016, Azman et al. 2015, and Azman et al. 2016). Our analysis assumes that one-dose vaccination interventions will result in herd protection, but that the herd effect will be lower in vaccination campaigns that use one dose than in campaigns that use two doses. We adjust the extent of the herd effect in the one-dose interventions by the relative effectiveness of the vaccine in one-dose interventions to the effectiveness of the vaccine in two-dose interventions. We emphasize that this relationship is highly uncertain.

4.1 Mass Vaccination with Two Doses

A mass vaccination campaign attempts to vaccinate the entire population living in the targeted location, but some individuals will typically choose not to participate. We assume a participation rate of 65%, based on demand studies conducted in several other settings with endemic cholera (Jeuland et al. 2009, Kim et al. 2008, Lucas et al. 2007, and Cook et al. 2012). Before administering the vaccination, households would need to be informed as to where and when the vaccine will be administered. In the two-dose campaign, a follow-up vaccine would be required about two weeks after the first dose, and household members would incur additional time and travel costs to return to a vaccination site. This intervention requires significant administrative efforts to manage the information and logistical requirements. Household members would need to make two roundtrips to the vaccination site and possibly spend time waiting in queues or being observed for adverse reactions to the vaccine at the time of each visit.

4.2 Mass Vaccination with a Single Dose

The mass vaccination campaign with one dose mirrors the previously described campaign. When only one dose is provided, the administrative and logistical costs are significantly lower. On the other hand, a single dose of the vaccine provides a lower level of protection to both vaccinated and unvaccinated individuals.

4.3 School Vaccination with Two Doses

A school-focused vaccination intervention targets only children, who often exhibit higher rates of cholera incidence (Deen et al. 2008). We assume this intervention tries to reach children who are younger than school-age through awareness-raising activities. This intervention would provide the recommended two doses to both school-aged and below school-aged (but vaccine-eligible) children.

4.4 School Vaccination with a Single Dose

The school vaccination campaign with one dose mirrors the previously described campaign. By only providing one dose, the campaign is once again able to reduce administrative and logistical costs. On the other hand, a single dose of the vaccine provides a lower level of protection to vaccinated and unvaccinated individuals. Overall, the single-dose school-based vaccination intervention offers the lowest benefits because it reaches fewer people than the mass vaccination interventions and only achieves the reduced protection associated with a single dose. But it also has the lowest total costs.

5. Calculation of the Costs and Benefits for the Four Cholera Vaccination Interventions

This paper utilizes a similar approach to calculate the benefits and costs of cholera vaccination interventions as was used in Jeuland and Whittington, 2009 and Jeuland et al. 2009. The underlying theoretical framework is similar to that presented in our Haïti Priorise water and sanitation paper for rural Haiti (Jeuland et al. 2017). The categories of benefits and costs are explained in more detail below.

5.1 Benefits[3]

The health benefits from all four cholera vaccination interventions result from reductions in morbidity and mortality from cholera infection. The total monthly benefits per household for each of the interventions are calculated as the product of (1) the Copenhagen Consensus supplied estimate for the value of a DALY as a multiple of GDP per capita, and (2) the number of DALYs averted by the intervention per household per month:

$$B^{C} = V^{DALY} * DALY^{a} \quad (1)$$

Where:

B^{C}	= total monthly per household benefit from the cholera intervention;
V^{DALY}	= Copenhagen Consensus estimate of the economic value of a DALY; and
$DALY^{a}$	= fraction of a DALY averted per household per month by implementation of the cholera intervention.

[3] We have expressed household benefits on a monthly basis to facilitate comparison with the benefit-cost results for rural WASH interventions in our companion paper for Haïti Priorise. This will not affect the BCRs. Annual benefits and costs of the cholera vaccination interventions can be obtained simply by multiplying the monthly benefits and costs by 12.

The fraction of a DALY averted per household per month is calculated as a product of (1) an overall discounted vaccine effectiveness rate for the entire population over the duration of protection, (2) the number of people per household, (3) the cholera incidence in cases per person per year, divided by 12 to convert it into a monthly rate, and (4) the sum of the reduction in mortality and morbidity, the latter of which is divided by 365 to obtain an annual amount of days spent sick, from the intervention:

$$DALY_a = N_E*H*(C_I/12)*[(1-CFR_C)*(C_D/365)*DALY_C+CFR_C*PV(LE)] \qquad (2)$$

Where:

N_E	= overall (direct and indirect) rate of protection from the vaccine campaign;
H	= number of people per household;
C_I	= cholera incidence in cases per year;[4]
CFR_C	= case fatality rate from cholera cases;
C_D	= duration of cholera cases in days;
$DALY_C$	= DALY weight for cholera infection; and
$PV(LE)$	= present value of years of lives lost from cholera-related deaths;

Up-to-date data on mortality rates from cholera by age group are unavailable for rural Haiti. We assume that the weighted present value of the life expectancy in years lost due to cholera-related deaths equals the weighted present value of the life expectancy in years lost due to diarrhea-related deaths. Therefore, to calculate a weighted present value of the life expectancy in years lost due to cholera-related deaths, we use diarrhea-related mortality data from the Global Burden of Disease 2015. The value is a sum of the years of life lost by age group[5] weighted by the mortality rates by age group:

$$PV(LE) = \frac{1}{M}\sum_{i=1}^{17} M_i * \left(1 - e^{(-r*LE_i)}\right)/r \qquad (3)$$

Where:

[4] The incidence rate is adjusted for the school vaccination campaigns as cholera rates are assumed to be higher in children.

[5] The total population was divided into 17 different groups by age. Sixteen are calculated as the total number of people in 5-year age groups from 0-79 and the last group includes all Haitians 80 years old and above.

$PV(LE)$	= present value of years of lives lost from diarrhea related deaths;
M	= total number of annual deaths from diarrhea;
i	= one of the aggregated age groups;
M_i	= total number of annual deaths in age group i;
LE_i	= expected additional life years of age group i; and
r	= discount rate.

The overall rate of protection from a vaccination intervention is an increasing function of coverage, as discussed in previous studies of vaccine protection (Jeuland and Whittington 2009; Jeuland et al. 2009; Ivers et al. 2015). Adjustments for a one-dose vaccine administration were made based on results presented in Azman et al. (2015). The overall protection rate is calculated as the weighted average of (1) the direct vaccine effectiveness for those vaccinated, calculated as function of the short term vaccine effectiveness, the estimated extent of the herd effect, and the percent of the population vaccinated, multiplied by the number of people vaccinated; (2) the indirect vaccine effectiveness for those unvaccinated is calculated as a function of the estimated extent of the herd effect and the percent of the population vaccinated, which is then multiplied by the total number of people not vaccinated by the intervention; and (3) an adjustment factor to account for the fact that the health benefits from cases avoided in future years are discounted relative to those realized in the year of vaccination:

$$N_E = (E_V*V_{COV}+(1-V_{COV})*E_U*[(1+(1/r)-(1/(r*(1+r)^{L-1})/L] \qquad (4)$$

Where:

E_V	= direct effectiveness of the cholera vaccine (among those who are vaccinated);
V_{COV}	= vaccination coverage rate as a percent of the population;
E_U	= indirect effectiveness of the cholera vaccine (among those who are unvaccinated);
r	= discount rate; and
L	= duration of protection offered by the vaccine.

The Copenhagen Consensus Haiti Prioritise Project has instructed the authors of all of the sector papers to estimate the economic value of the health benefits as the product of the DALYs (Disability Adjusted Life Years) avoided and a multiple of GDP per capita. The Copenhagen

Consensus Project requires analysts to value a DALY at three different multiples of GDP per capita (1 time, 3 times, and 8 times).

When considering this measure of benefits, it is important to recognize that if the true economic value of a DALY avoided is in fact approximated by the per capita GDP in a country, this would include the entire stream of benefits associated with improved health because both avoided mortality and morbidity outcomes are included in the calculation of avoided DALYs. In other words, this estimate already includes avoided cost-of-illness expenses and all of the benefits that stem from reduced illness (including increased education or productivity). Back-of-the-envelope calculations using the 1x and 3x multiples of GDP per capita for Haiti suggest that the implied VSL for an average statistical life (in terms of life years remaining) would be within the same order of magnitude as the values obtained from research studies aimed at quantifying the value of a statistical life as a function of income (Hammitt & Robinson 2011).

5.2 Costs

We calculate the total cost of each vaccination intervention as the sum of 1) the cost of purchasing, delivering the vaccines, and administering the vaccination program; and 2) the time and money households spend acquiring the vaccines.

$$S = (S_c + S_T)*V_i \tag{5}$$

Where:

S	= total cost of the vaccination;
S_c	= constant marginal cost per dose of purchasing and delivering the vaccine and administering the vaccination program;
S_T	= cost per dose to a household of acquiring the vaccines; and
V_i	= total number of vaccines required for vaccine intervention i.

We assume that the cost of per dose of purchasing the vaccines is constant regardless of the number of doses purchased. We do not specify who pays for these purchase costs. We assume that the constant marginal cost per dose of delivering the vaccine and administering the program is the same for both the mass vaccination campaigns and the school vaccination campaigns. We make this assumption because cost data are limited (Mogasale et al. 2016). Also, the mass vaccination interventions likely exhibit both 1) economies of scale as fixed program costs are spread across more individuals; and 2) diseconomies of scale as the marginal delivery cost of vaccinating successively larger numbers of a target population increases because households become harder and harder to reach. On the other hand, the school vaccination campaigns are designed to reach smaller numbers of people and may have larger fixed program costs per vaccinated individual. However, the school vaccination interventions could be included in already-established routine immunizations and could thus have lower average delivery costs than mass vaccination interventions (Mogasale et al. 2016).

In the base case we thus assume that the combined cost of purchasing and delivering an oral cholera vaccine is US$2 per dose: US$1 for purchase and US$1 for delivery.[6] This is at the low end of the range of purchase prices reported in the recent cost literature for Shanchol (Mogasale et al. 2016). We acknowledge that the marginal cost of producing the oral cholera vaccine will exhibit increasing returns to scale, but the available cost data and global supply constraints preclude us from making more refined assumptions about the purchase price of the oral cholera vaccine to the Haitian government or international donors.

The second component of the total cost of the intervention is the time and money households spend on acquiring one dose of the vaccine, which we estimate based on an assumed time needed to obtain a dose of vaccine multiplied by one half the unskilled wage rate (to reflect the likely lower opportunity cost of time for many of those choosing to be vaccinated, which includes children and non-working adults). We only include the time costs incurred by a household to obtain a dose of vaccine. We do not include any financial cost that a household may incur obtaining the vaccine e.g. transport costs.

$$S_T = T_D * \frac{W_u}{2*8} \tag{6}$$

Where:

[6] This estimate is reasonable as the South Korean manufacturers of Euvichol, the recently WHO pre-qualified oral cholera vaccine, stated a target price of $1 per dose of the vaccine (HANSHEP 2014).

T_D = time in hours that a household spends to acquire a dose of the cholera vaccine;
W_u = unskilled daily wage rate;
8 = number of working hours in a day; and
$\frac{1}{2}$ = ratio of the cost of time spent acquiring the vaccine to the unskilled wage rate.

To calculate the per household costs of a vaccination campaign, we first assume a population coverage rate. For example, in the mass campaign intervention we assume the vaccination coverage rate is 65%, and that 65% of the members of a household are vaccinated. We then multiply the number of people vaccinated per household by the number of doses received per person to obtain the total number of doses received per household. We then multiply the number of doses received per household by the cost per dose described in the previous paragraph to obtain a cost per household.

$$S_H = V_{COV} * H * D_i * (S_c + S_T) \tag{7}$$

Where:

S_H = per household cost of the vaccine intervention;
V_{COV} = vaccination coverage rate as a percent of the population;
H = number of people per household;
D_i = number of doses administered to the average household member in vaccination intervention i;
S_c = constant marginal cost per dose; and
S_T = cost to the household to acquire the vaccine per dose.

For the school vaccination campaigns, the household costs are based on the average number of children per household (obtained from the DHS 2012 survey) multiplied by number of doses received per vaccinated child to obtain the total number of doses received per household. We again multiply the number of doses received per household by the total cost per dose to obtain a cost per household.

In order to calculate a monthly per household cost, we multiply the total household cost by a capital recovery factor to obtain an annual cost per household for the intervention. The annual capital recovery factor is a function of the discount rate and the expected lifetime of protection offered by the vaccine:

$$CRF = (r*(1+r)^L)/((1+r)^L-1) \quad (8)$$

Where:

CRF	= capital recovery factor;
r	= discount rate; and
L	= duration of protection offered by the vaccine.

The annual cost is then divided by 12 to obtain a monthly cost per household.

In summary, the monthly costs per household are calculated according to the equation below:

$$S = V_{COV}*H*D_i*(S_c+S_T)*CRF/12 \quad (9)$$

Where:

V_{COV}	= vaccination coverage rate as a percent of the population;
H	= number of people per household;
D_i	= number of doses administered per person in vaccine intervention i;
S_c	= cost of purchasing, administering, and delivering the vaccines per dose;
S_T	= cost for acquiring the vaccines per dose; and
CRF	= capital recovery factor;

The same equations are used for each of the interventions. The values of some of the parameters differ across the four cholera vaccination interventions analyzed.

5.3 Parameter Values and Data Sources

Data on baseline cholera incidence in rural Haiti are limited. New cholera cases and deaths fluctuate seasonally and with weather patterns. Additionally, as more and more people become infected, and as vaccination campaigns continue, it is unknown how immune responses will change. Despite several large campaigns with OCVs in Haiti since 2012, data on administration and logistical costs have not been reported. Our analyses therefore rely on data from the DHS 2012 survey, the Global Burden of Disease 2015, and assumptions from other related peer-reviewed studies. The parameter values and data sources used in our analyses are presented in Table 1.

To the extent possible, we have adjusted the parameter estimates and assumptions to ensure that the benefit and cost calculations presented in this paper are in real (i.e. net of inflation) 2014 US dollars. For example, the Copenhagen Consensus Project's GDP per capita estimates for Haiti which we use in the economic valuation of DALYs are in 2014 dollars.[7]

6. Results of Benefit-Cost Calculations

6.1 Mass Vaccination with Two Doses

6.1.1 Benefits, Costs, and Benefit-Cost Ratio

The results of the benefit-cost calculations for the mass vaccination campaign with two doses are presented in Table 2 assuming a discount rate of 3% and a DALY value of 3 times GDP per capita. The total monthly benefits per household from the mass vaccination campaign with two doses is US$1.18. The monthly cost per household, over the duration of protection offered by the vaccine, is US$0.54, of which only 4% is due to the household’s time to acquire the vaccines its members received. The net benefits in this base case are US$0.63 and the benefit-cost ratio is 2.2.

Table 3 presents the results of a sensitivity analysis that shows how changes in the discount rate and the assumed value of a DALY affect the estimates of benefits and costs. The monthly household benefits range from $0.11 to $3.14 across the nine cases. The costs are unaffected by the assumed DALY value. The per household monthly costs range from US$0.34 to US$0.54 depending on the discount rate. The total net benefits range from -US$0.23 to US$2.59 per household per month and the benefit-cost ratio ranges from 0.3 to 5.8 per household per month for the nine cases.

[7] We will continue to refine these calculations to ensure that all estimates are expressed in 2014 US dollars to the extent possible.

6.2 Mass Vaccination with One Dose

6.2.1 Benefits, Costs, and Benefit-Cost Ratio

The results of the benefit-cost calculations for the mass vaccination campaign with one dose are presented in Table 4 assuming a discount rate of 3% and a DALY value of 3 times GDP per capita. The total monthly household benefits from the mass vaccination campaign with one dose is US$0.96. The monthly cost per household is US$0.27, of which only 4% is due to the household's time to acquire the vaccines its members received. The net benefits in this base case are US$0.69 and the benefit-cost ratio is 3.6.

Table 5 presents the results of a sensitivity analysis that shows how changes in the discount rate and value of a DALY affect the estimates of benefits and costs. The monthly household benefits range from $0.09 to $2.57 across the nine cases. The per household monthly costs range from US$0.17 to US$0.27 depending on the discount rate. The total net benefits range from -US$0.08 to US$2.30 per household per month and the benefit-cost ratio ranges from 0.5 to 9.5 per household per month for the nine cases.

6.3 School Vaccination with Two Doses

6.3.1 Benefits, Costs, and Benefit-Cost Ratio

The results of the benefit-cost calculations for the school vaccination campaign with two doses are presented in Table 6 assuming a discount rate of 3% and a DALY value of 3 times GDP per capita. The total monthly household benefits from the school vaccination campaign with two doses is US$0.57. The monthly cost per household is US$0.13, of which only 8% is due to the household's time to acquire the vaccines its members received. The net benefits in this base case are US$0.45 and the benefit-cost ratio is 4.6.

Table 7 presents the results of a sensitivity analysis that shows how changes in the discount rate and value of a DALY affect the estimates of costs and benefits. The monthly household benefits range from $0.05 to $1.52 across the nine cases. The per household monthly costs range from

US$0.08 to US$0.13 depending on the discount rate. The total net benefits range from -US$0.02 to US$1.40 per household per month and the benefit-cost ratio ranges from 0.7 to 12.2 per household per month for the nine cases.

6.4 School Vaccination with One Dose

6.4.1 Benefits, Costs, and Benefit-Cost Ratio

The results of the benefit-cost calculations for the school vaccination campaign with one dose are presented in Table 8 assuming a discount rate of 3% and a DALY value of 3 times GDP per capita. The total monthly household benefits from the school vaccination campaign with one dose is US$0.38. The monthly cost per household is US$0.06, which is fully comprised of the discounted monthly cost of the vaccine doses received per household. The net benefits in this base case are US$0.32 and the benefit-cost ratio is 6.1.

Table 9 presents the results of a sensitivity analysis that shows how changes in the discount rate and value of a DALY affect the estimates of costs and benefits. The monthly household benefits range from $0.04 to $1.01 across the nine cases. The per household monthly costs range from US$0.04 to US$0.06 depending on the discount rate. The total net benefits range from US$0.00 to US$0.95 per household per month and the benefit-cost ratio ranges from 1 to 16.2 per household for the nine cases.

6.5 Sensitivity Analyses

6.5.1 One Sensitivity Analyses

One-way sensitivity analyses show that the net benefits of the cholera interventions are most sensitive to the economic value of an averted DALY, the cholera case fatality rate, and the discount rate (Figures 8a-d). The net benefits of the two school vaccination interventions are more sensitive to the population coverage of the vaccination intervention than the net benefits of the two mass vaccination interventions because the school vaccination interventions reach a smaller percentage of the Haitian population and marginal herd immunity effects are larger at low levels of coverage. The net benefits of the two mass vaccination interventions are more sensitive to the marginal price of a dose of vaccine. The costs of the school interventions could be lower than we assume because cholera vaccination could perhaps be included in routine, and thus lower cost, school-based immunization programs. The duration of protection offered by the vaccine and the household size are less important to the overall results.

6.5.2 Multi-Parameter Sensetivity Analysis

We also conducted multi-parameter Monte Carlo simulations, allowing the model parameters to vary over uniform distributions between their assumed low and high values (Figure 9). There are several findings of interest. First, the distribution of net benefit outcomes for the one-dose school vaccination intervention is tighter than the distributions for the other three interventions. This is logical because the one-dose school intervention offers fewer vaccines and has lower benefits and costs than the other three interventions.

Second, the cumulative distributions of net benefits for the two mass vaccination interventions are shifted to the right of the two school vaccination interventions. This is because the additional health benefits offered by increasing coverage still generally exceed the additional costs of vaccinating more people in these programs that reach a larger percentage of the population. Third, the proportion of simulations with negative net benefits is highest with the two-dose mass vaccination intervention. Fourth, when comparing the school vaccination interventions, the distribution of net benefits from the two-dose intervention is mostly to the right of the one-dose school intervention because the benefits of greater protection provided by the two-dose school campaign usually exceed the costs of the additional vaccinations. In contrast, the distribution of net benefits for the two-dose mass vaccination effort does not so clearly dominate that for the single-dose mass campaign. This is because the additional benefits are smaller when coverage rates increase to the high levels achieved in these campaigns, such that the incremental herd protection benefits become smaller. Nonetheless, all four interventions will fail to deliver positive net benefits in some situations. Hence decision makers should consider the appropriateness of each intervention carefully, given local realities.

7 Conclusion

In this final section, we discuss how we believe the Eminent Panel should interpret the results of our benefit-cost calculations of the four vaccination campaigns presented in this paper. The results for the most plausible cases for the four interventions (3% discount rate and economic value of a DALY = 3 times GDP per capita) show that the benefits will be at least twice the costs. The sensitivity analyses show that the benefit-cost ratios for the one-dose school vaccination campaign are highest (6.3 compared to 4.8 for the two-dose school vaccination campaign, 3.6 for the one-dose mass vaccination campaign, and 2.2 for the two-dose mass vaccination campaign). The school vaccination with the one-dose intervention design most consistently produces positive net benefits among the four interventions analyzed. Only in the case where the discount rate is 12% and the economic value of a DALY is 1 times GDP per capita, are the net benefits approximately zero. In all of the other eight cases the net benefits are positive. The next highest ranked interventions in terms of their BCRs are 1) the one-dose mass vaccination campaign, and 2) the two-dose school campaign. However, the results for these two interventions for the cases with the high discount rate and low economic value of a DALY show that the benefits are less than the costs.

Our results thus suggest that there is a strong economic case for pursuing the cholera vaccination campaigns. We find that the one-dose campaigns can provide significant net benefits. This is an important finding because the global supply of cholera vaccines is limited and current vaccination campaigns in Haiti are providing Haitians with only one dose of the vaccine. The results also support the strategy of vaccinating a larger percentage of the population with one dose of vaccine rather than a smaller group with the standard two-dose regime.

However, there are several limitations to our analysis. First, we emphasize that there has been no research on whether herd protection effects are similar in one-dose and two-dose vaccination interventions. We included herd protection in all analyses; our assumption that these indirect effects are proportional to the relative direct effectiveness of a one dose regime compared to a two-dose regime is however highly uncertain. As such, the advantage of the one-dose interventions versus two-dose interventions may be overestimated.

Second, this analysis did not allow for varying program and delivery costs of the vaccine campaigns as coverage targets change due to lack of data. If increasing the coverage target of a campaign has increasing marginal costs, the net benefits and benefit-cost ratios per household would decrease. A related point is that under these two assumptions (that overall protection is a declining function of vaccine coverage rates, while costs are independent of program size), the BCR will always tend to favor more limited program size, because costs increase faster than benefits as program size increases. Yet larger programs will generate higher total benefits, and thus may continue to generate positive marginal net benefits relative to smaller programs, particularly for high values of avoiding a DALY.

Third, the protocol required by the Copenhagen Consensus Haiti Priorise Project for estimating the economic benefits of health improvements does not take account of households' own preferences for avoiding cholera infection. While the simplicity of valuing a DALY as a multiple of GDP per capita may be perceived as helpful for comparison between health interventions, it is important to recognize that Haitians may consider their reference condition to be a world without cholera, because cholera was only introduced to Haiti in 2010. Therefore, when valuing reductions in cholera, an estimate of willingness to accept compensation to forgo a reduction in a loss is more appropriate than a measure of willingness to pay for reductions in risk of cholera infection. This equivalent variation measure of the reduction in an economic loss will yield a higher economic value than a willingness-to-pay compensating variation measure of a health gain of comparable magnitude. Therefore, we believe the economic benefits of cholera interventions are potentially larger than the Copenhagen Consensus protocol measures suggest.

Fourth, regardless of the results of the benefit-cost analysis, the moral dimension of the cholera problem in Haiti should be considered. We believe that the citizens of Haiti are entitled to remedial actions funded by the United Nations. The current WHO cholera vaccine strategy (described in its 2010 cholera vaccine position paper) and the Haitian government's strategy is to combine both water and sanitation efforts along with vaccination campaigns to control or eliminate cholera. While our analysis did not model benefits and costs for combining water and sanitation interventions along with cholera vaccination campaigns, both interventions are likely to have a greater effect on controlling the disease than either alone and the Eminent Panel should consider recommending both for simultaneous funding.

Summary Table

Interventions	Discount	Benefit	Cost	BCR	Quality of Evidence
Mass Vaccination with Two Doses	3%	US$1.18	US$0.54	2.2	Medium
	5%	US$0.80	US$0.38	2.1	
	12%	US$0.34	US$0.34	1.0	
Mass Vaccination with One Dose	3%	US$0.96	US$0.27	3.6	Limited
	5%	US$0.66	US$0.19	3.5	
	12%	US$0.28	US$0.17	1.6	
School Vaccination with Two Doses	3%	US$0.57	US$0.13	4.6	Medium
	5%	US$0.39	US$0.09	4.5	
	12%	US$0.16	US$0.08	2.1	
School Vaccination with One Dose	3%	US$0.38	US$0.06	6.1	Limited
	5%	US$0.26	US$0.04	5.9	
	12%	US$0.11	US$0.04	2.8	

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References

Alam, M. T., Weppelmann, T. A., Weber, C. D., Johnson, J. A., Rashid, M. H., Birch, C. S., Brumback, B. A., De Rochars, V. M., Glenn, J., & Ali, A. (2014). Monitoring Water Sources for Environmental Reservoirs of Toxigenic Vibrio cholerae O1, Haiti. *Emerging Infectious Diseases*, *20*(3), 363. https://dx.doi.org/10.3201/eid2003.131293.

Alam, M. T., Weppelmann, T. A., Longini, I., De Rochars, V. M., Morris, J. G. Jr, & Ali, A. (2015) Increased isolation frequency of toxigenic Vibrio cholerae O1 from environmental monitoring sites in Haiti. PLoS One 2015;10(4):e0124098. pmid:25853552

Ali, M., Emch, M., von Seidlein, L., Yunus, M., Sack, D. A., Rao, M., Holmgren, J., & Clemens, J. D. (2005). Herd immunity conferred by killed oral cholera vaccines in Bangladesh: a reanalysis. *The Lancet, 366*(9479), 44-49. doi:10.1016/S0140-6736(05)66550-6

Azman, A. S., Parker, L. A., Rumunu, J., Tadesse, F., Grandesso, F., Deng, L. L., Lino, R. L., Bior, B. K., Lasuba, M., Page, A. L., Ontweka, L., Llosa, A. E., Cohuet, S., Pezzoli, L., Sodnijou, D. V., Abubakar, A., Debes, A. K., Mpairwe, A. M., Wamala, J. F., Jamet, C., Lessler, J., Sack, D. A., Quilici, M. L., Ciglenecki, I., & Luquero, F. J. (2016). Effectiveness of one dose of oral cholera vaccine in response to an outbreak: a case-cohort study. *The Lancet Global Health, 4*(11), e856-e863. doi:http://dx.doi.org/10.1016/S2214-109X(16)30211-X

Azman, A. S., Luquero, F. J., Ciglenecki, I., Grais, R. F., Sack, D. A., & Lessler, J. (2015). The impact of a one-dose versus two-dose oral cholera vaccine regimen in outbreak settings: a modeling study. *PLoS Med, 12*(8), e1001867.

Baik, Y. O., Choi, S. K., Olveda, R. M., Espos, R. A., Ligsay, A. D., Montellano, M. B., Yeam, J. S., Yang, J. S., Park, J. Y., Kim, D. R., Desai, S. N., Singh, A. P., Kim, I. Y., Kim, C. W., & Park, S. N. (2015). A randomized, non-inferiority trial comparing two bivalent killed, whole cell, oral cholera vaccines (Euvichol vs Shanchol) in the Philippines. *Vaccine, 33*(46), 6360-6365. doi:http://dx.doi.org/10.1016/j.vaccine.2015.08.075

Barzilay, E. J., Schaad, N., Magloire, R., Mung, K. S., Boncy, J., Dahourou, G. A., Mintz, E. D., Steenland, M. W., Vertefeuille, J. F., & Tappero, J. W. (2013). Cholera surveillance during the Haiti epidemic—the first 2 years. *New England Journal of Medicine, 368*(7), 599-609.

Beaubien, J. (2016, November 08). Haiti Launches Largest-Ever Cholera Vaccination Campaign. Retrieved February 7, 2017, from http://www.npr.org/sections/goatsandsoda/2016/11/08/501155987/haiti-launches-largest-ever-emergency-cholera-vaccination-campaign

Cook, J., Jeuland, M., Maskery, B., Lauria, D., Sur, D., Clemens, J., & Whittington, D. (2009). Using private demand studies to calculate socially optimal vaccine subsidies in developing countries. *Journal of Policy Analysis and Management, 28*(1), 6-28.

Cook, J., Jeuland, M., Maskery, B., & Whittington, D. (2012). Giving stated preference respondents "time to think": results from four countries. *Environmental and Resource Economics, 51*(4), 473-496.

Cravioto, A., Lanata, C., Lantagne, D., & Nair, G. (2011). Final Report of the Independent Panel of Experts on the Cholera Outbreak in Haiti. United Nations. 1–32.

Deen, J. L., Von Seidlein, L., Sur, D., Agtini, M., Lucas, M. E., Lopez, A. L., Kim, D. R., Ali, M., & Clemens, J. D. (2008). The high burden of cholera in children: comparison of incidence from endemic areas in Asia and Africa. *PLoS Negl Trop Dis, 2*(2), e173.

Desai, S. N., Pezzoli, L., Martin, S., Costa, A., Rodriguez, C., Legros, D., & Perea, W. (2016). A second affordable oral cholera vaccine: implications for the global vaccine stockpile. *The Lancet Global Health, 4*(4), e223-e224. doi:http://dx.doi.org/10.1016/S2214-109X(16)00037-1

Farmer, P., Almazor, C. P., Bahnsen, E. T., Barry, D., Bazile, J., Bloom, B. R., Bose, N., Brewer, T., Calderwood, S. B., Clemens, J. D., Cravioto, A., Eustache, E., Jerome, G, Gupta, N., Harris, J. B., Hiatt, H. H., Holstein, C., Hotez, P. J., Ivers, L. C., Kerry, V. B., Koenig, S. P., LaRocque, R. C., Leandre, F., Lambert, W., Lyon, E., Mekalanos, J. J., Mukherjee, J. S., Oswald, C., Pape, J., Prosper, A. G., Rabinovich, R., Raymonville, M., Rejouit, J., Ronan, L, J., Rosenberg, M. L., Ryan., E. T., Sachs, J. D., Sack, D. A., Surena, C., Suri, A. A., Ternier, R., Waldor, M. K., Walton, D., & Weigel, J. L (2011). Meeting Cholera's Challenge to Haiti and the World: A Joint Statement on Cholera Prevention and Care. PLoS Negl Trop Dis 5(5): e1145. doi:10.1371/ journal.pntd.0001145

GAVI. (2016, November 8). *Cholera vaccination campaign kicks off in Haiti.* Retrieved March 5, 2017, from http://www.gavi.org/library/news/gavi-features/2016/cholera-vaccination-campaign-kicks-off-in-haiti/

Haiti Pre-decision Brief: CDC Responds to Cholera Outbreak in Haiti. (2010). Atlanta, United States. Centers for Disease Control (CDC). Retrieved January 6, 2017, from https://www.cdc.gov/cholera/haiti/pre-decision-brief.html

Hammitt, J., & Robinson, L. (2011). The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations. *Journal of Benefit-Cost Analysis* 2(1): 1-29.

Harnessing Non-State Actors for Better Health for the Poor (HANSHEP) (2014). *Global Health Investment Fund invests in Low-Cost Oral Cholera Vaccine*. Retrieved April 18, 2017, from http://www.hanshep.org/news-and-events/global-health-investment-fund-invests-in-low-cost-oral-cholera-vaccine

Hendriksen, R. S., Price, L. B., Schupp, J. M., Gillece, J. D., Kaas, R. S., Engelthaler, D. M., Bortolaia, V., Pearson, T., Waters, A. E., Upadhyay, B. P., Shrestha, S. D., Adhikari, S., Shakya, G., Keim, P. S., & Aarestrup, F. M. (2011). Population genetics of Vibrio cholerae from Nepal in 2010: evidence on the origin of the Haitian outbreak. *MBio, 2*(4), e00157-00111.

Institute for Health Metrics and Evaluation (IHME) (2015). GBD Results Tool. Seattle, WA: IHME, University of Washington. Available from http://ghdx.healthdata.org/gbd-results-tool. (Accessed December 25, 2016)

Ivers, L. C., Hilaire, I. J., Teng, J. E., Almazor, C. P., Jerome, J. G., Ternier, R., Boncy, J., Buteau, J., Murray, M. B., Harris, J. B., & Franke, M. F. (2015). Effectiveness of reactive oral cholera vaccination in rural Haiti: a case-control study and bias-indicator analysis. *The Lancet Global Health, 3*(3), e162-e168.

Ivers, L. C., Teng, J. E., Lascher, J., Raymond, M., Weigel, J., Victor, N., Jerome, J. G., Hilaire, I. J., Almazor, C. P., Ternier, R., Francois, J., Guillaume, F. D., & Farmer, P. E. (2013). Use of Oral Cholera Vaccine in Haiti: A Rural Demonstration Project. *The American Journal of Tropical Medicine and Hygiene*, *89*(4), 617–624. http://doi.org/10.4269/ajtmh.13-0183

Ivers, L. C. (2017). Eliminating Cholera Transmission in Haiti. *New England Journal of Medicine, 376*(2), 101-103. doi:doi:10.1056/NEJMp1614104

Jeuland, M., Cook, J., Poulos, C., Clemens, J., & Whittington, D. (2009). Cost-Effectiveness of New-Generation Oral Cholera Vaccines: A Multisite Analysis. *Value in Health, 12*(6), 899-908. doi:http://dx.doi.org/10.1111/j.1524-4733.2009.00562.x

Jeuland, M., Lucas, M., Clemens, J., & Whittington D. (2009) A cost-benefit analysis of cholera vaccination programs in Beira, Mozambique. The World Bank Economic Review 23(2): 235–267.

Jeuland, M., & Whittington, D. (2009). Cost–benefit comparisons of investments in improved water supply and cholera vaccination programs. *Vaccine, 27*(23), 3109-3120. doi:http://dx.doi.org/10.1016/j.vaccine.2009.02.104

Jeuland, M., Radin, M., & Whittington, D. (2017). Economic Costs and Benefits of Three Water and Sanitation Interventions in Rural Haiti. *Copenhagen Consensus Haiti Priorise Project.*

Knetsch J. L., Riyanto, Y. E., & Zong, J. (2012). Gain and loss domains and the choice of welfare measure of positive and negative changes. *J. Benefit-Cost Anal.* 3(4):1—18.

Kim, D., Canh, D. G., Poulos, C., Thoa, L. T., Cook, J., Hoa, N. T., Nyamete, A., Thuy, D. T. D., Deen, J., Clemens, J., Thiem, V. D., Anh, D. D., & Whittington, D. (2008). Private demand for cholera vaccines in Hue, Vietnam. *Value in Health, 11*(1), 119-128.

Kirpich, A., Weppelmann, T. A., Yang, Y., Ali, A., Morris Jr, J. G., & Longini, I. M. (2015). Cholera transmission in Ouest Department of Haiti: dynamic modeling and the future of the epidemic. *PLoS Negl Trop Dis, 9*(10), e0004153.

Longini Jr, I. M., Nizam, A., Ali, M., Yunus, M., Shenvi, N., & Clemens, J. D. (2007). Controlling endemic cholera with oral vaccines. *PLoS Med, 4*(11), e336.

Lucas, M. E., Jeuland, M., Deen, J., Lazaro, N., MacMahon, M., Nyamete, A., Barreto, A., von Seidlein, L., Cumbane, A., Songane, F. F., & Whittington, D. (2007). Private demand for cholera vaccines in Beira, Mozambique. *Vaccine, 25*(14), 2599-2609.

Mogasale, V., Ramani, E., Wee, H., & Kim, J. H. (2016) Oral Cholera Vaccination Delivery Cost in Low- and Middle-Income Countries: An Analysis Based on Systematic Review. PLoS Negl Trop Dis 10(12): e0005124. doi:10.1371/journal. pntd.0005124

Morris, J. (2011). Cholera—Modern Pandemic Disease of Ancient Lineage-Volume 17, Number 11—November 2011-Emerging Infectious Disease journal-CDC.

PAHO's Atlas of Cholera Outbreak in la Hispaniola 2010-2016. (2016, October 29). Retrieved March 15, 2017, from http://new.paho.org/hq/images/Atlas_IHR/CholeraHispaniola/atlas.html

Mitchell, C. (2016, November 28). Haiti's Ministry of Health successfully vaccinates 729,000 persons against cholera. Retrieved March 12, 2017, from http://www.paho.org/hq/index.php?option=com_content&view=article&id=12771%3Ahaiti-ministry-of-health-vaccinates-729000-persons-against-cholera&Itemid=135&lang=en

Republic of Haiti: Ministry of Public Health and Population, National Directorate for Water Supply and Sanitation. National Plan for the Elimination of Cholera in Haiti, 2013–2022. Port-au-Prince: Republic of Haiti; 2013. http://new.paho.org/hq/index.php?option=com_docman&task=doc_download&gid=20326&Itemid=270&lang=eng/

Republic of Haiti: Ministry of Public Health and Population. (May 2015). Rapport Statistique 2014. https://mspp.gouv.ht/site/downloads/Rapport%20Statistique%20MSPP%202014%20version%20web.pdf

Republic of Haiti: Ministry of Public Health and Population. (May 2014). Rapport Statistique 2013. http://www.mspp.gouv.ht/site/downloads/Rapport%20Statistique%20MSPP%202013.pdf

Qadri, F., Wierzba, T. F., Ali, M., Chowdhury, F., Khan, A. I., Saha, A., Khan, I. A., Asaduzzaman, M., Akter, A., Khan, A., Begum, Y. A., Bhuiyan, T. R., Khanam, F., Chowdhury, M. I., Islam, T., Chowdhury, A. I., Rahman, A., Siddique, S. A., You, Y. A., Kim, D. R., Siddik, A. U., Saha, N. C., Kabir, A., Cravioto, A., Desai, S. N., Singh, A. P., & Clemens, J. D. (2016). Efficacy of a Single-Dose, Inactivated Oral Cholera Vaccine in Bangladesh. *New England Journal of Medicine, 374*(18), 1723-1732. doi:doi:10.1056/NEJMoa1510330

Rinaldo, A., Bertuzzo, E., Mari, L., Righetto, L., Blokesch, M., Gatto, M., Casagrandi, R., Murray, M., Vesenbeckh, & Rodriguez-Iturbe, I. (2012). Reassessment of the 2010–2011 Haiti cholera outbreak and rainfall-driven multiseason projections. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(17), 6602–6607. http://doi.org/10.1073/pnas.1203333109.

Severe, K., Rouzier, V., Anglade, S. B., Bertil, C., Joseph, P., Deroncelay, A., Mabou, M. M., Wright, P. F., Guillaume, F. D., & Pape, J. W. (2016). Effectiveness of Oral Cholera Vaccine in Haiti: 37-Month Follow-Up. *The American journal of tropical medicine and hygiene* 94(5): 1136-42.

Tappero, J. W., & Tauxe, R. V. (2011). Lessons Learned during Public Health Response to Cholera Epidemic in Haiti and the Dominican Republic. *Emerging Infectious Diseases*, *17*(11), 2087–2093. http://doi.org/10.3201/eid1711.110827

U.N General Assembly, 71st Session. "Provisional Agenda Item 69 (b): Report of the Special Rapporteur on Extreme Poverty and Human Rights," A/71/367, Official Records. (2016). New York.

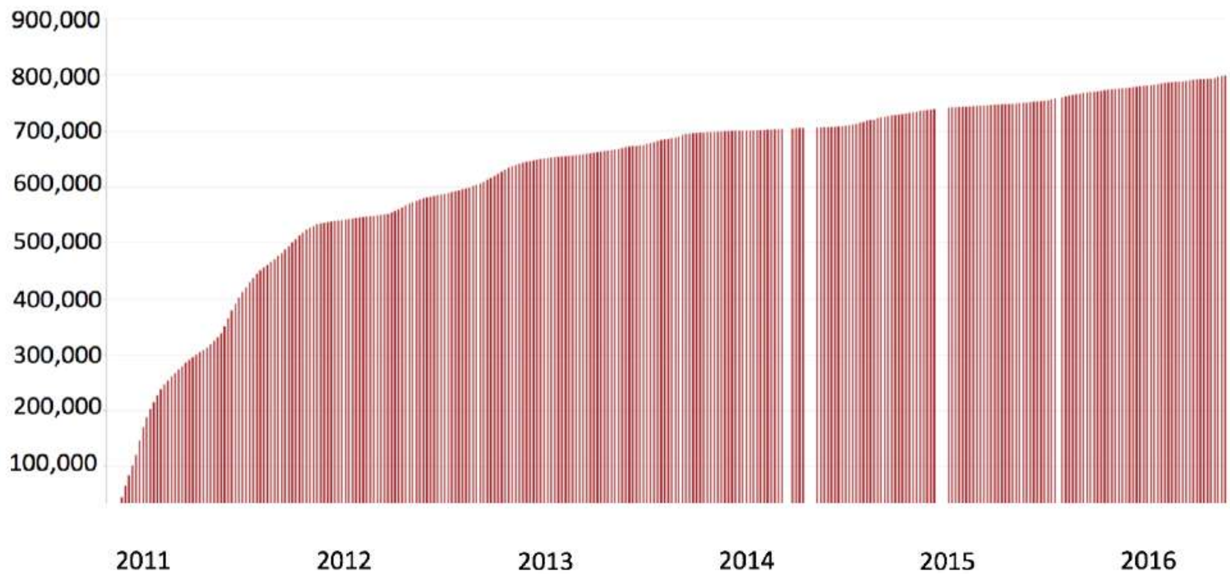
Whittington, D., Adamowicz, W., & Lloyd-Smith, P. (2017). Asking Willingness-to-Accept Questions in Stated Preference Surveys: A Review and Research Agenda. Forthcoming in *Annual Review of Resource Economics*.

World Health Organization (WHO) (2010) Cholera vaccines: WHO position paper. Weekly epidemiological record. World Health Organization, Geneva.

WHO Prequalified Vaccines. (2017). Retrieved March 1, 2017, from https://extranet.who.int/gavi/PQ_Web/

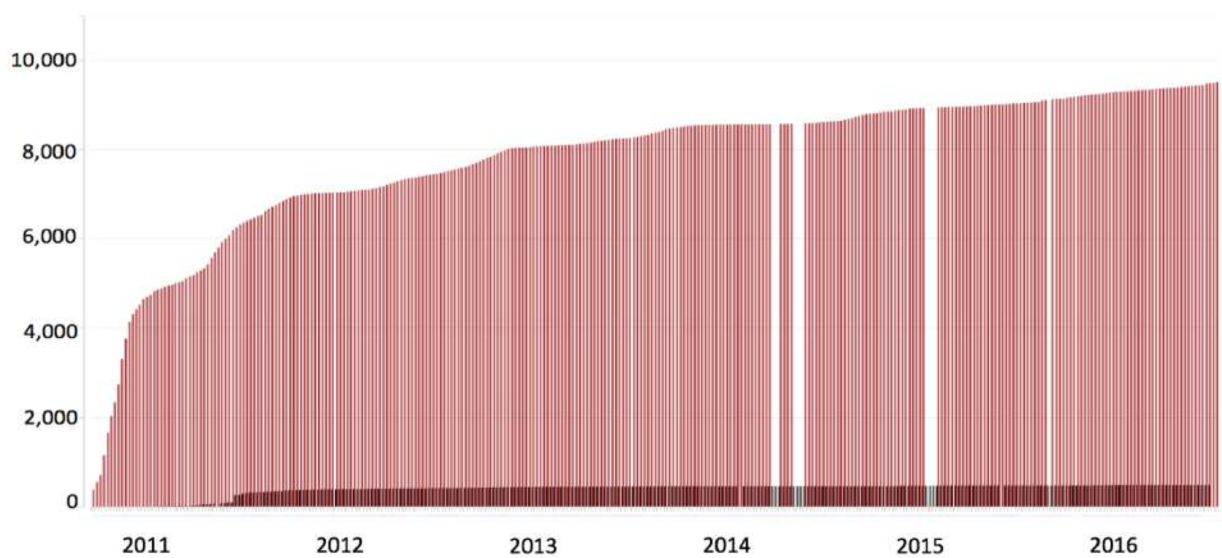
Graphs and tables

Figure 1: Cumulative Cases of Reported Cholera (Oct. 2010- Oct. 2016)



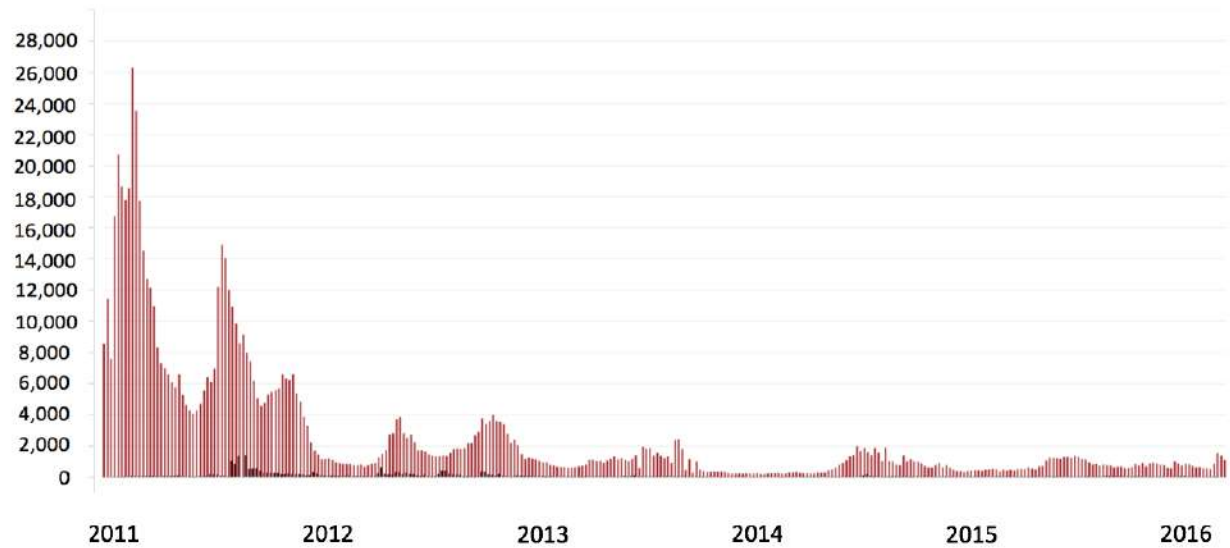
Source: Atlas of Cholera Outbreak in Hispaniola, 2010-2016

Figure 2: Cumulative Deaths from Cholera (Oct. 2010 - Oct. 2016)



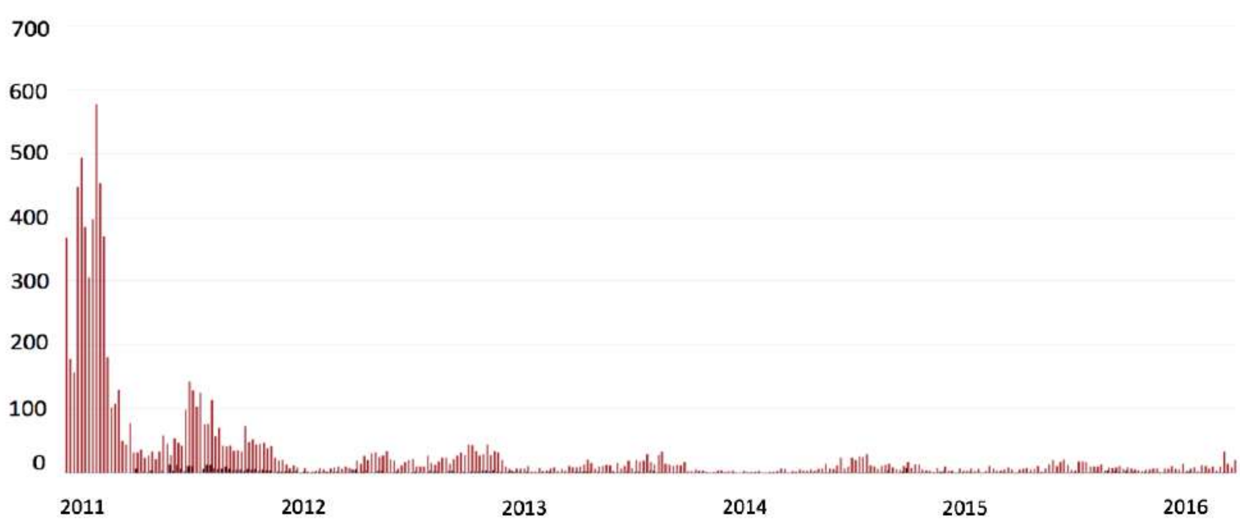
Source: Atlas of Cholera Outbreak in Hispaniola, 2010-2016

Figure 3: New Reported Cholera Cases by Week (Oct. 2010 – Oct. 2016)



Source: Atlas of Cholera Outbreak in Hispaniola, 2010-2016

Figure 4: New Reported Cholera Deaths by Week (Oct. 2010 – Oct. 2016)



Source: Atlas of Cholera Outbreak in Hispaniola, 2010-2016

Figure 5: Percent of Households Reporting Death from Cholera by Department (Oct. 2010 - Oct. 2016)

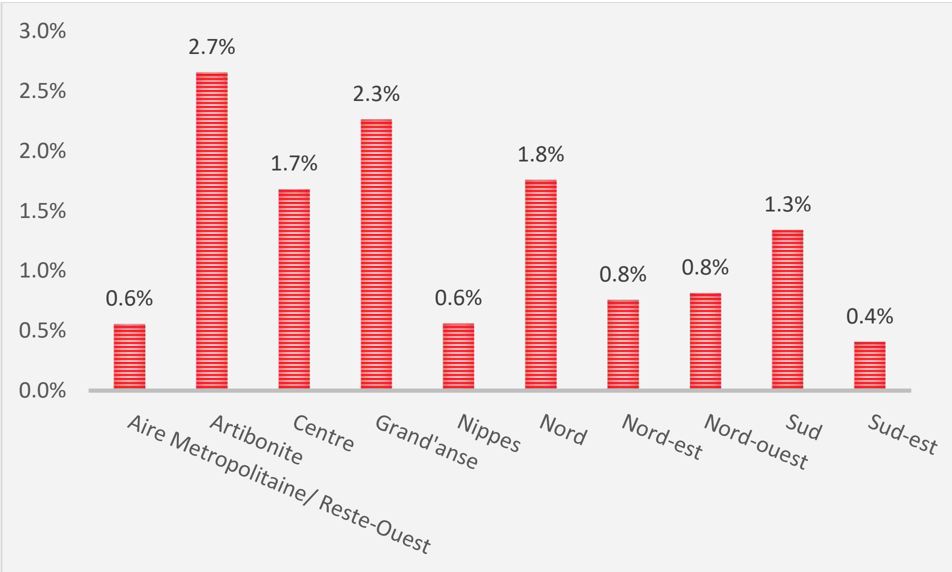


Figure 6: Households Reporting Non-Fatal Cases of Cholera by Departments (Oct. 2010 - Oct. 2016)

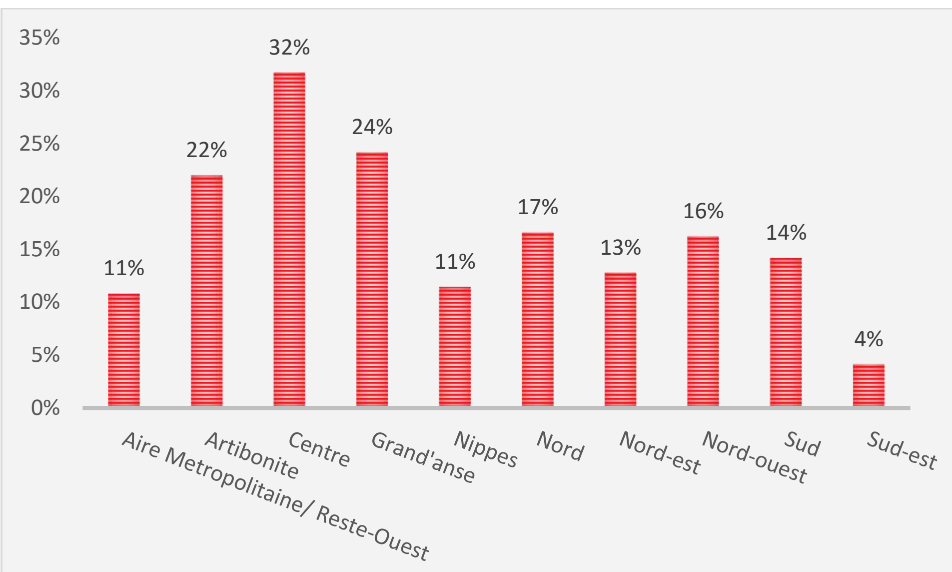
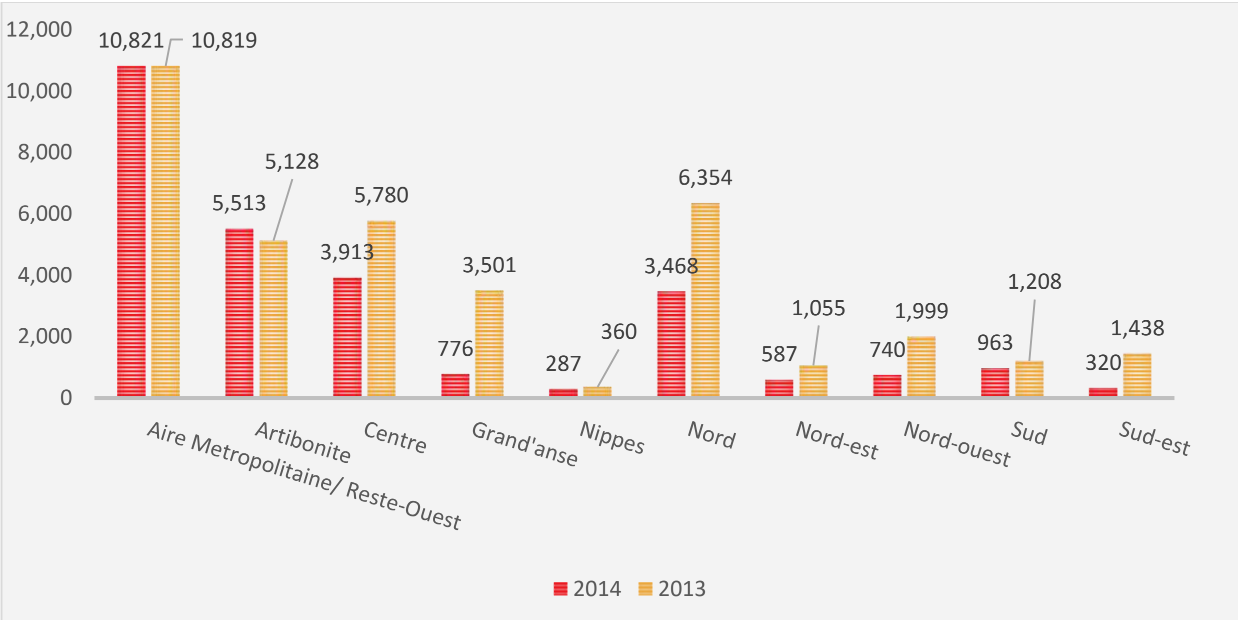


Figure 7: Cases of Cholera 2014 and 2013



Source: Statistical Report 2014 and 2013

Table 1: Parameter Values and Data Sources

Symbol	Parameter	Low	Mean	High	Notes
Common Parameters Across Interventions					
H	Household size	4.2	4.7	5.2	Haiti DHS 2012 data on rural household size across Departments
W_u	Market wage for unskilled labor ($/day)	0.50	1.25	2.00	Jeuland and Whittington (2009)
$\frac{W_u}{2}$	Value of time / market wage for unskilled labor	0.50	0.50	0.50	Given assumption as 50% of group average earnings under analysis
C_I	Cholera incidence (cases/pc-yr)	2.48	4.69	5.71	Calculated with a weighted average from the DHS 2012 self-reported cholera cases and the data from the MSPP Statistical Report 2014, and divided by the rural population.
$DALY_C$	Cholera DALY weight	0.08	0.105	0.27	Jeuland and Whittington 2009
C_D	Cholera case duration (days)	2	4	8	Jeuland, Whittington (2009)
CFR	Cholera case fatality rate (%)	0.50%	1.10%	3.00%	Assumptions take from Jeuland and Whittington (2009) and mean confirmed by the Statistical Report 2014

LE	Current life expectancy	42.7	55.1	59.1	The Haiti DHS 2012 data was used to calculate a sex ratio across the rural Departments for average life expectancy, and min and max is taken from two other countries in the World Bank Low Income Country classification and using the percentage decrease in life expectancy as assumed in Haiti (Sierra Leone and Nepal).
V_{DALY}	Value of averted DALY ($)	820.00	2460.00	6560.00	Given weights and given GDP
r	Real, net of inflation, discount rate (%)	0.03	0.05	0.12	Given assumption
	Fixed costs per campaign				Unknown
	Extend of herd protection for in Campaigns with two doses	60%	80%	100%	Jeuland et al. 2009
	Extend of herd protection for in Campaigns with two doses	22%	48%	81%	Authors' assumption based on proportionate effectiveness of receiving one dose of vaccine to two doses of vaccine
L	Lifetime of protection offered by the vaccine	2	3	4	Jeuland et al. 2009
S_D	Marginal cost per dose ($)	$0.70	$2.00	$3.30	Jeuland and Whittington 2009 and support by lower estimates in Mogasale et al. 2016
T_D	Time spent for one dose vaccine (hrs)	0.25	0.75	1.25	Jeuland and Whittington 2009
CRF	Annual capital recovery factor	$0.5	$0.4	$0.3	Function of discount rate and life of project.
	Mass Campaign				
E_V	Vaccine effectiveness – vaccinated 2 Doses (%)	72%	94%	99%	Mean of Ivers et al. (2015) and Azman et al. (2015)
E_U	Vaccine effectiveness – unvaccinated 2 Doses (%)	68%	86%	95%	Mean of Ivers et al. (2015) and Azman et al. (2015)
E_V	Vaccine effectiveness – vaccinated 1 Dose (%)	36%	77%	95%	Authors' assumptions, based on Azman et al. 2015, and Qandri et al. (2016).
E_U	Vaccine effectiveness – unvaccinated 1 Dose (%)	34%	70%	92%	Authors' assumptions, based on Azman et al. 2015, and Qandri et al. (2016).
V_{COV}	Vaccination coverage rate as a percent of the population	50%	65%	80%	Jeuland and Whittington 2009
	School Campaign				
C_I	Child cholera incidence (cases/1000-yr)	4.73	5.02	5.31	Rate is calculated by GBD rate of <14 proportion of diarrhea incidence multiplied by cholera cases, and then divided by the percent of the

					population that is under 14 according to the given data
E_V	Vaccine effectiveness - vaccinated 2 Dose (%)	64%	84%	80%	Mean of Ivers et al. (2015) and Azman et al. (2015)
E_U	Vaccine effectiveness – unvaccinated 2 Doses (%)	19%	35%	53%	Mean of Ivers et al. (2015) and Azman et al. (2015)
E_V	Vaccine effectiveness - vaccinated 1 Dose (%)	18%	48%	78%	Authors' assumptions, based on Azman et al. 2015, and Qandri et al. (2016).
E_U	Vaccine effectiveness – unvaccinated 1 Dose (%)	7%	22%	47%	Authors' assumptions, based on Azman et al. 2015, and Qandri et al. (2016).
V_{COV}	Coverage - as fraction of population	10%	15%	20%	Jeuland and Whittington 2009.

Table 2: Household Results for Mass Campaign with 2 Doses (with 3% Discount Rate, Value of DALY 3 x GDP per Capita)

	Household			
	Baseline	Mass Campaign with 2 Doses	Change	% of Total
Benefits (US$/HH per month)				
Health Benefits ($)	-	$1.18	+$1.18	100%
Costs (US$/HH per month)				
Capital Cost ($)	-	$0.52	-$0.52	96%
Time Cost ($)	-	$0.02	-$0.02	4%
Total Costs	-	$0.54	-$0.54	
Net Benefits	-	$0.63	$0.63	
B-C Ratio	-	2.17	2.17	

Source: Authors' calculations

Table 3: Household Results for Mass Campaign with 2 Doses Sensitivity Analysis

	Low DALY Value			Mean DALY Value			High DALY Value		
	Low Discount Rate	Mean Discount Rate	High Discount Rate	Low Discount Rate	Mean Discount Rate	High Discount Rate	Low Discount Rate	Mean Discount Rate	High Discount Rate
Total Benefits	$0.39	$0.27	$0.11	$1.18	$0.80	$0.34	$3.14	$2.14	$0.90
Total Costs	$0.54	$0.38	$0.34	$0.54	$0.38	$0.34	$0.54	$0.38	$0.34
Net Benefits	-$0.15	-$0.11	-$0.23	$0.63	$0.42	$0.00	$2.59	$1.76	$0.56
B-C Ratio	0.72	0.70	0.33	2.17	2.11	0.99	5.79	5.63	2.64

Source: Authors Calculations

Table 4: Household Results for Mass Campaign with 1 Dose (with 3% Discount Rate, Value of DALY 3 x GDP per Capita)

	Household			
	Baseline	Mass Campaign with 2 Doses	Change	% of Total
Benefits (US$/HH per month)				
Health Benefits ($)	-	$0.96	+$0.96	100%
Costs (US$/HH per month)				
Capital Cost ($)	-	$0.26	-$0.26	96%
Time Cost ($)	-	$0.01	-$0.01	4%
Total Costs	-	$0.27	-$0.27	
Net Benefits	-	$0.69	$0.69	
B-C Ratio	-	3.55	3.55	

Source: Authors' calculations

Table 5: Household Results for Mass Campaign with 1 Dose Sensitivity Analysis

	Low DALY Value			Mean DALY Value			High DALY Value		
	Low Discount Rate	Mean Discount Rate	High Discount Rate	Low Discount Rate	Mean Discount Rate	High Discount Rate	Low Discount Rate	Mean Discount Rate	High Discount Rate
Total Benefits	$0.32	$0.22	$0.09	$0.96	$0.66	$0.28	$2.57	$1.75	$0.74
Total Costs	$0.27	$0.19	$0.17	$0.27	$0.19	$0.17	$0.27	$0.19	$0.17
Net Benefits	$0.05	$0.03	-$0.08	$0.69	$0.47	$0.11	$2.30	$1.56	$0.57
B-C Ratio	1.18	1.15	0.54	3.55	3.45	1.62	9.48	9.21	4.33

Source: Authors Calculations

Table 6: Household Results for School Campaign with 2 Doses (with 3% Discount Rate, Value of DALY 3 x GDP per Capita)

	Household			
	Baseline	Mass Campaign with 2 Doses	Change	% of Total
Benefits (US$/HH per month)				
Health Benefits ($)	-	$0.57	+$0.57	100%
Costs (US$/HH per month)				
Capital Cost ($)	-	$0.12	-$0.12	92%
Time Cost ($)	-	$0.01	-$0.01	8%
Total Costs	-	$0.13	-$0.13	
Net Benefits	-	$0.45	$0.45	
B-C Ratio	-	4.6	4.6	

Source: Authors' calculations

Table 7: Household Results for School Campaign with 2 Doses Sensitivity Analysis

	Low DALY Value			Mean DALY Value			High DALY Value		
	Low Discount Rate	Mean Discount Rate	High Discount Rate	Low Discount Rate	Mean Discount Rate	High Discount Rate	Low Discount Rate	Mean Discount Rate	High Discount Rate
Total Benefits	$0.19	$0.13	$0.05	$0.57	$0.39	$0.16	$1.52	$1.04	$0.44
Total Costs	$0.13	$0.09	$0.08	$0.13	$0.09	$0.08	$0.13	$0.09	$0.08
Net Benefits	$0.07	$0.04	-$0.02	$0.45	$0.30	$0.09	$1.40	$0.95	$0.36
B-C Ratio	1.52	1.48	0.70	4.57	4.45	2.09	12.19	11.85	5.56

Source: Authors Calculations

Table 8: Household Results for School Campaign with 1 Dose (with 3% Discount Rate, Value of DALY 3 x GDP per Capita)

	Household			
	Baseline	Mass Campaign with 2 Doses	Change	% of Total
Benefits (US$/HH per month)				
Health Benefits ($)	-	$0.38	+$0.38	100%
Costs (US$/HH per month)				
Capital Cost ($)	-	$0.06	-$0.06	100%
Time Cost ($)	-	$0.00	-$0.00	0%
Total Costs	-	$0.06	-$0.06	
Net Benefits	-	$0.32	$0.32	
B-C Ratio	-	6.08	6.08	

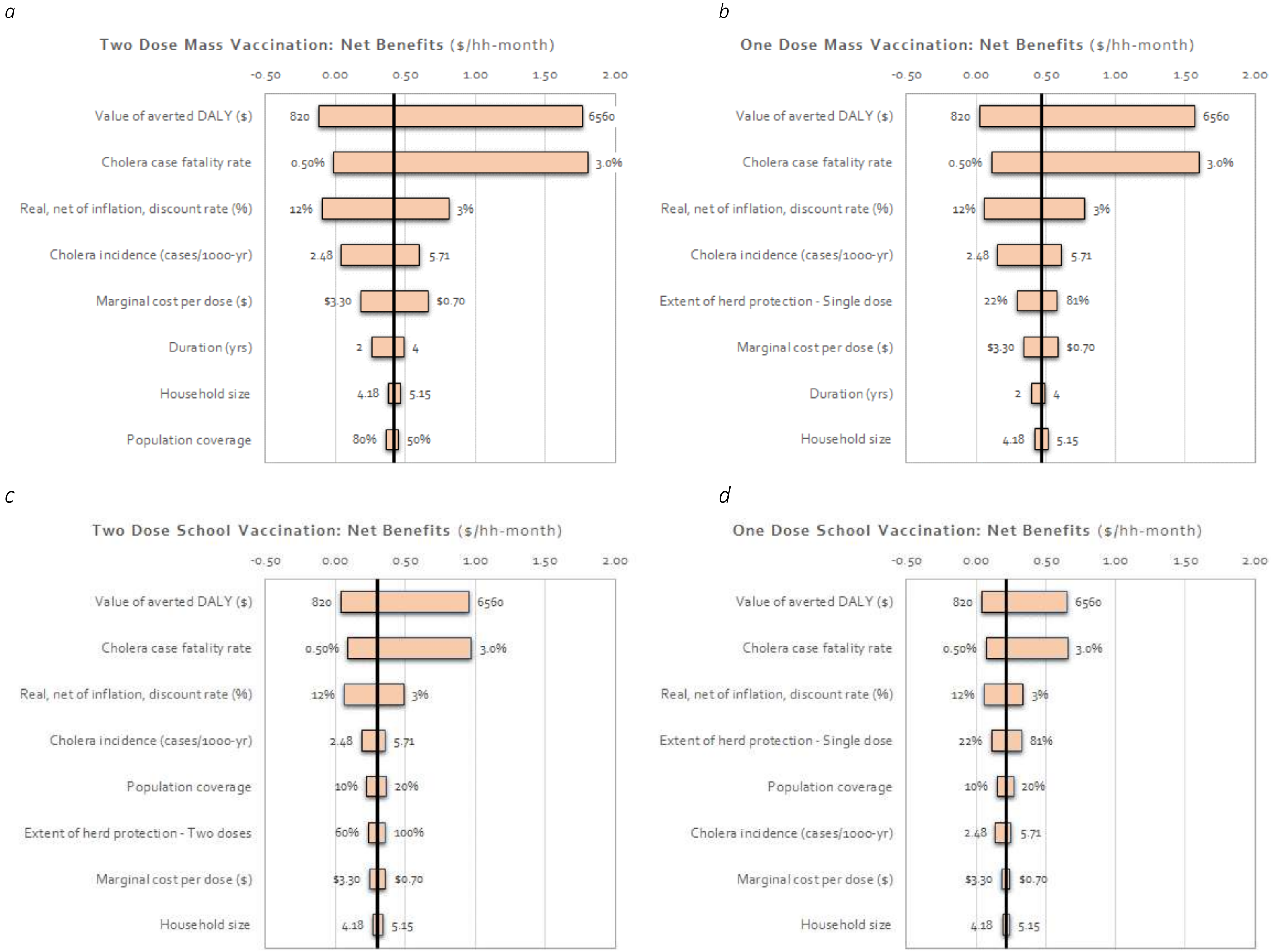
Source: Authors' calculations

Table 9: Household Results for School Campaign with 1 Dose Sensitivity Analysis

	Low DALY Value			Mean DALY Value			High DALY Value		
	Low Discount Rate	Mean Discount Rate	High Discount Rate	Low Discount Rate	Mean Discount Rate	High Discount Rate	Low Discount Rate	Mean Discount Rate	High Discount Rate
Total Benefits	$0.13	$0.09	$0.04	$0.38	$0.26	$0.11	$1.01	$0.69	$0.29
Total Costs	$0.06	$0.04	$0.04	$0.06	$0.04	$0.04	$0.06	$0.04	$0.04
Net Benefits	$0.06	$0.04	$0.00	$0.32	$0.22	$0.07	$0.95	$0.65	$0.25
B-C Ratio	2.03	1.97	0.93	6.08	5.91	2.78	16.22	15.76	7.40

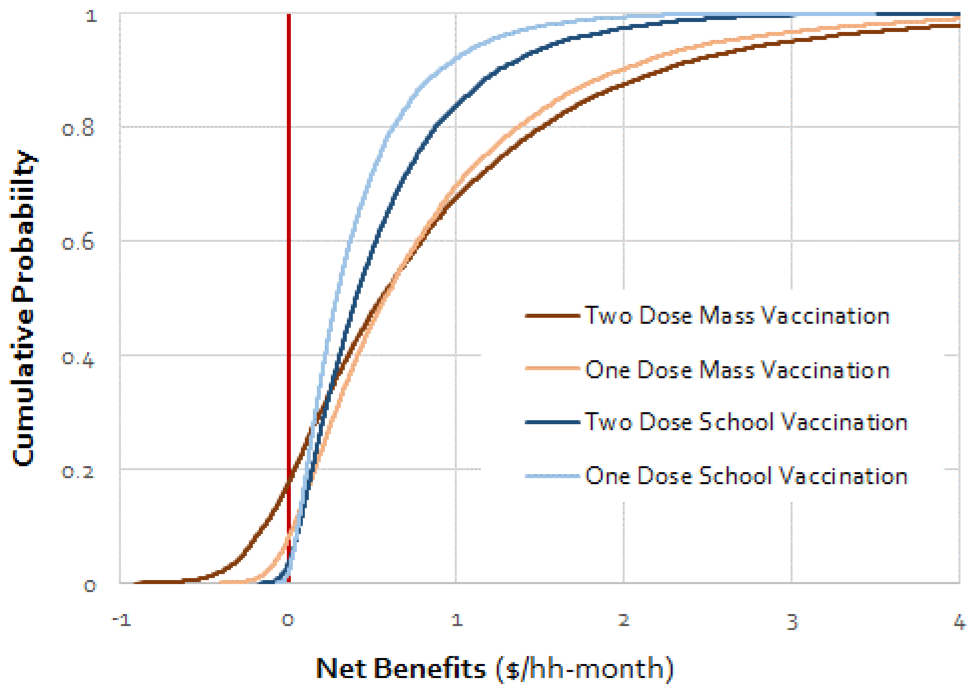
Source: Authors Calculations

Figure 8a-d: One-way sensitivity analysis for cholera vaccination program options



Source: Authors' calculation

Figure 9: Multiple parameter Monte Carlo analysis for cholera vaccination program options



Source: Authors' calculations

Haiti faces some of the most acute social and economic development challenges in the world. Despite an influx of aid in the aftermath of the 2010 earthquake, growth and progress continue to be minimal, at best. With so many actors and the wide breadth of challenges from food security and clean water access to health, education, environmental degradation, and infrastructure, what should the top priorities be for policy makers, international donors, NGOs and businesses? With limited resources and time, it is crucial that focus is informed by what will do the most good for each gourde spent. The Haïti Priorise project will work with stakeholders across the country to find, analyze, rank and disseminate the best solutions for the country. We engage Haitans from all parts of society, through readers of newspapers, along with NGOs, decision makers, sector experts and businesses to propose the best solutions. We have commissioned some of the best economists from Haiti and the world to calculate the social, environmental and economic costs and benefits of these proposals. This research will help set priorities for the country through a nationwide conversation about what the smart - and not-so-smart - solutions are for Haiti's future.

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