Chapter 29

Economics of Mass Deworming Programs

Amrita Ahuja, Sarah Baird, Joan Hamory Hicks, Michael Kremer, and Edward Miguel

INTRODUCTION

Soil-transmitted helminth (STH) and schistosomiasis infections affect more than 1 billion people, mainly in low- and middle-income countries, particularly school-age children. Although light infections can be fairly asymptomatic, severe infections can have significant health effects, such as malnutrition, listlessness, organ damage, and internal bleeding (Bundy, Appleby, and others 2017).[1]

Low-cost drugs are available and are the standard of medical care for diagnosed infections. Because diagnosis is relatively expensive, and treatment is inexpensive and safe, the World Health Organization (WHO) recommends periodic mass treatments in areas where worm infections are greater than certain thresholds (WHO 2015). A number of organizations, including the Copenhagen Consensus, GiveWell, and the Abdul Latif Jameel Poverty Action Lab, which have reviewed the evidence for, and comparative cost-effectiveness of, a wide range of development interventions, have consistently ranked deworming as a priority for investment.[2] However, Taylor-Robinson and others (2015) challenge this policy, accepting that those known to be infected should be treated but arguing that there is substantial evidence that mass drug administration (MDA) has no impact on a range of outcomes.[3]

This chapter discusses the economics of policy choices surrounding public investments in deworming and considers policy choices under two frameworks:

- *Welfare economics or public finance approach.* Individuals are presumed to make decisions that maximize their own welfare, but government intervention may be justified in cases in which individual actions create externalities for others. These externalities could include health externalities from reductions in the transmission of infectious disease, as well as fiscal externalities if treatment increases long-term earnings and tax payments. Evidence on epidemiological and fiscal externalities from deworming will be important for informing decisions under this perspective.
- *Expected cost-effectiveness approach.* Policy makers should pursue a policy if the statistical expectation of the value of benefits exceeds the cost. Future monetary benefits should be discounted back to the present. Policy makers may also value nonfinancial goals, such as weight gain or school participation; they should pursue a policy if the statistical expectation of the benefit achieved per unit of expenditure exceeds that of other policies that policy makers are considering.

Under either framework, the case for government subsidies will be stronger if demand for deworming is sensitive to price. If everyone would buy deworming medicine on their own, without subsidies, then subsidies would yield no benefits; they would generate a deadweight loss of taxation.

The first perspective focuses on individual goals and assumes that consumers will maximize their own welfare. It treats them as rational and informed, and it

Corresponding author: Joan Hamory Hicks, Senior Researcher, Center for Effective Global Action, University of California, Berkeley, jrhamory@berkeley.edu.

abstracts from intrahousehold conflicts. The second perspective does not make these assumptions and seeks simply to inform policy makers about expected benefit-cost ratios or cost-effectiveness metrics, rather than making welfare statements.

This chapter summarizes the public finance case for deworming subsidies, given the evidence on epidemiological externalities[4] and high responsiveness of household deworming to price. It reviews the evidence on the cost-effectiveness of mass school-based deworming and associated fiscal externalities. It argues that the expected benefits of following the WHO's recommendation of mass presumptive deworming of children in endemic regions exceed the costs, even given uncertainty about the magnitude and likelihood of impacts in given contexts.[5] This benefit is realized even when only the educational and economic benefits of deworming are considered. Finally, the chapter maintains that between the two leading policy options for treatment in endemic areas—mass treatment versus screening and treatment of those found to be infected—the former is preferred under both public finance and cost-effectiveness approaches. Definitions of age groupings and age-specific terminology used in this volume can be found in chapter 1 (Bundy, de Silva, and others 2017).

EPIDEMIOLOGICAL EXTERNALITIES

STHs—including hookworm, roundworm, and whipworm—are transmitted via eggs in feces deposited in the local environment, typically through open defecation or lack of proper hygiene after defecating. Schistosomiasis is spread through contact with infected fresh water. School-age children are particularly vulnerable to such infections and prone to transmitting infection (Bundy, Appleby, and others 2017). Treating infected individuals kills the parasites in their bodies and prevents further transmission. Three studies provide evidence on such epidemiological externalities from deworming school-age children and suggest these externalities can be substantial.

Bundy and others (1990) studied a program in the island of Montserrat, West Indies, where all children between ages 2 and 15 years were treated with albendazole, four times over 16 months, to eliminate STH infections. The authors found substantial reductions in infection rates for the targeted individuals (more than 90 percent of whom received treatment), as well as for young adults ages 16–25 years (fewer than 4 percent of whom were treated). These findings suggest large positive epidemiological externalities, although only one geographic unit was examined.

Miguel and Kremer (2004) studied a randomized school-based deworming program in rural western Kenya from 1998 through 1999, where students in treatment schools received albendazole twice a year; in addition, some schools received praziquantel for schistosomiasis infections annually. The authors found large reductions in worm infections among treated individuals, untreated individuals attending treatment schools, and individuals in schools located near treatment schools. The authors estimated an 18 percentage point reduction after one year in the proportion of moderate-to-heavy infections among untreated individuals attending treatment schools, and a 22 percentage point reduction among individuals attending a school within 3 kilometers of a treatment school.[6]

Ozier (2014) studied this same randomized program in Kenya but focused on children who were ages zero to two years and living in catchment areas of participating schools at the time of program launch. These children were not treated, but they could have benefited from positive within-community externalities generated by the mass school-based deworming. Indeed, 10 years after the program, Ozier estimated average test score gains of 0.2 standard deviation units for these individuals. Consistent with the hypothesis that these children benefited primarily through the reduced transmission of worm infections, the effects were twice as large among children with an older sibling in one of the schools that participated in the program.

Bobonis, Miguel, and Puri-Sharma (2006), in contrast, found small and statistically insignificant cross-school externalities of deworming and iron supplementation on nutritional status and school participation of children in India. The authors noted that this finding is unsurprising in this context, given both the lower prevalence and intensity of worm infections and the small fraction of treated individuals.

Together, these studies provide strong evidence for the existence of large, positive epidemiological externality benefits to mass treatment in endemic areas, especially in areas with higher infection loads.[7] Such externality benefits are important to consider in both the public finance and cost-effectiveness decision-making frameworks. Under the first perspective, such benefits cannot be fully internalized by household decision makers and thus provide a potential rationale for government subsidies. Under the second perspective, externalities increase the cost-effectiveness of the intervention by increasing the total benefit achieved for a given amount of expenditure.

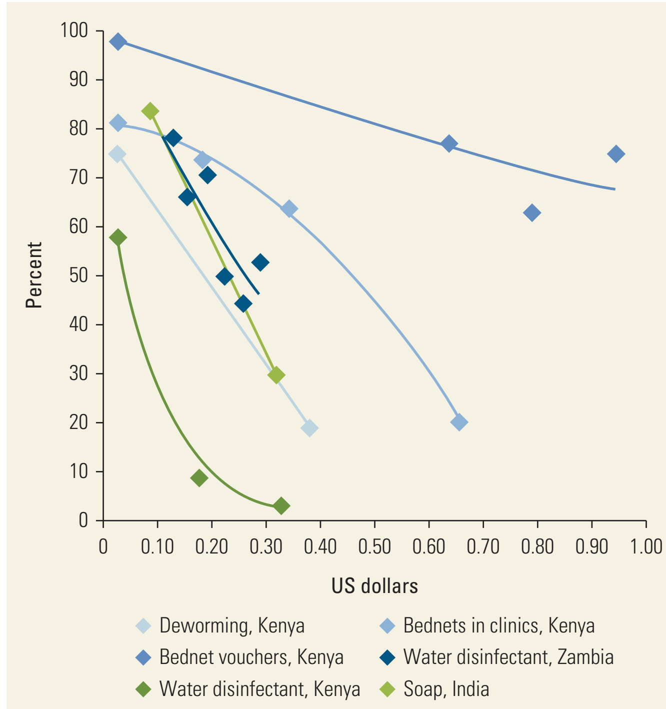
IMPACTS OF THE PRICE OF DEWORMING ON TAKE-UP

Assuming that a behavior generates positive externalities—or that under a cost-effectiveness approach, it is valued by policy makers—public finance theory emphasizes that the attractiveness of a subsidy depends on the ratio of marginal consumers (those who will change their behavior in response to a subsidy) to inframarginal consumers (those who would have engaged in the behavior even in the absence of a subsidy). The higher this ratio, the more attractive the subsidy.

Kremer and Miguel (2007) studied the behavioral response to a change in the price of deworming treatment in the Kenyan deworming program. Starting in 2001, a random subset of participating schools was chosen to pay user fees for treatment, with the average cost of deworming per child set at US$0.30, which was about 20 percent of the cost of drug purchase and delivery through this program. This cost-sharing reduced take-up (the fraction of individuals who received treatment) by 80 percent, to 19 percent from 75 percent.

This result is consistent with findings observed for other products for disease prevention and treatment of non-acute conditions, such as bednets for malaria and water treatment. Figure 29.1 displays how the demand for a range of health care products decreases as price increases.[8] Moreover, Kremer and Miguel (2007) found that user fees did not help target treatment to the sickest students; students with moderate-to-heavy worm infections were not more likely to pay for the medications. These results suggest low costs and large benefits from deworming subsidies, important for both the cost-effectiveness and welfare economics perspectives.

Figure 29.1 Response of Consumer Demand to Increase in the Price of Health Products



Source: Abdul Latif Jameel Poverty Action Lab 2011.

IMPACTS OF DEWORMING ON CHILD WEIGHT

In this and subsequent sections we examine the cost-effectiveness of mass deworming in affecting various outcomes potentially valued by policy makers. We focus primarily on economic outcomes rather than health outcomes because the impact of deworming on health is covered in chapter 13 in this volume (Bundy, Appleby, and others 2017). However, we would like to briefly expand upon that discussion to address the cost-effectiveness of deworming in improving child weight. Bundy, Appleby, and others (2017) discuss recent work of Croke and others (2016), who reviewed the literature on the impact of multiple-dose deworming on child weight. Overall, they estimated that MDA increases weight by an average of 0.13 kilograms, with somewhat larger point estimates among populations in which prevalence is greater than the WHO's 20 percent prevalence threshold for MDA, or the 50 percent threshold for multiple-dose MDA.[9] Assuming that an MDA program with two treatments per year costs US$0.60 per person (Givewell 2016), Croke and others (2016) estimated that the cost of deworming MDA per kilogram of weight gain is US$4.48. For comparison with another policy option, a review of school feeding programs by Galloway and others (2009) found that the average of the range associated with a 1 kilogram weight increase for school feeding from evidence from randomized controlled trials is US$182. This finding implies that per dollar of expenditure, mass deworming produces a weight increase 40.62 times that of school feeding. This finding on weight gain suggests that evidence of education and economic impact should not be rejected out of hand based on concern for lack of evidence about mechanisms by which such impacts could be achieved.

IMPACTS OF DEWORMING ON EDUCATION AND LABOR MARKETS

Evidence on the impact of deworming on education and labor market outcomes directly informs the cost-effectiveness perspective, while the fiscal externalities resulting from labor market impacts are important from a welfare economics perspective.

We review publicly available studies of the impact of mass deworming that do the following:

- Use experimental or quasi-experimental methods to demonstrate causal relationships
- Incorporate a cluster design to take into account the potential for infectious disease externalities
- Minimize attrition that could lead to bias.

Most existing studies on deworming randomize at the individual level; they fail to consider the potential for treatment externalities (Bundy and others 2009) and likely underestimate the impact of treatment. We review evidence from three deworming campaigns in different times and contexts—one in the United States in the early twentieth century and two in East Africa at the turn of the twenty-first century.[10]

The first program was launched by the Rockefeller Sanitary Commission (RSC) in 1910 to eradicate hookworm infections in the U.S. South. With baseline hookworm infection rates at 40 percent among school-age children, traveling dispensaries administered treatment to infected individuals in endemic areas and educated local physicians and the public about prevention. The RSC reported a 30 percentage point decrease in infection rates across affected areas 10 or more years after launch of the program (Bleakley 2007).[11]

The second program was a school-based treatment program sponsored by a nongovernmental organization that was phased into 75 schools in a rural district of western Kenya from 1998 through 2001. Baseline helminth infection rates were greater than 90 percent among school children in this area. The nongovernmental organization provided deworming drugs to treat STHs twice per year and schistosomiasis once per year, as well as educational materials on worm prevention. Schools were phased into the program in three groups over four years; each school was assigned to a group through list-randomization, resulting in a cluster randomized stepped-wedge research design.

The third program was delivered by community-based organizations during 2000–03 across 48 parishes in five districts of eastern Uganda.[12] Baseline infection rates were greater than 60 percent in children ages 5–10 years (Kabatereine and others 2001). Treatment was provided during child health days, in which parents were offered multiple health and nutrition interventions for children ages one to seven years. Using a cluster randomization approach, parishes were randomly assigned to receive either the standard intervention of vitamin A supplementation, vaccines, growth monitoring, and feeding demonstrations, or to deworming treatment in addition to the standard package (Alderman and others 2006; Croke 2014).

School Participation

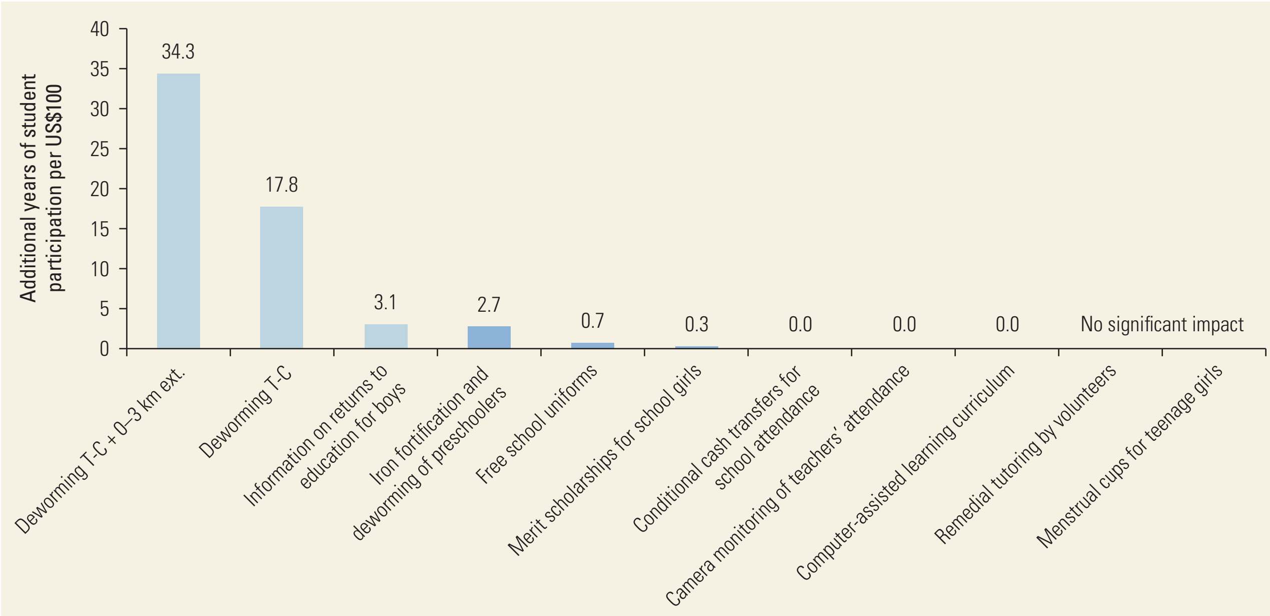
Using a difference-in-difference methodology in his study of the RSC program, Bleakley (2007) compared changes in counties with high baseline worm prevalence to changes in low baseline prevalence counties over the same period. Findings indicate that from 1910 through 1920, counties with higher worm prevalence before the deworming campaign saw substantial increases in school enrollment, both in absolute terms and relative to areas with lower infection rates. A child infected with hookworm was an estimated 20 percentage points less likely to be enrolled in school than a noninfected child and 13 percentage points less likely to be literate. Bleakley's estimates suggest that because of the deworming campaign, a county with a 1910 infection rate of 50 percent would experience an increase in school enrollment of 3 to 5 percentage points and an increase in attendance of 6 to 8 percentage points, relative to a county with no infection problem. This finding remains significant when controlling for a number of potentially confounding factors, such as state-level policy changes and the demographic composition of high- and low-worm load areas. In addition, the author found no significant effects on adult outcomes, which, given the significantly lower infection rates of adults, bolsters the case that deworming was driving these findings.

Miguel and Kremer (2004) provide evidence on the impact of deworming on school participation through their cluster randomized evaluation of the Kenyan school-based deworming program. The authors found substantially greater school participation in schools assigned to receive deworming than in those that had not yet been phased in to the program. Participation increased not only among treated children but also among untreated children in treatment schools and among pupils in schools located near treatment schools. The total increase in school participation, including these externality benefits, was 8.5 percentage points.[13] These results imply that deworming is one of the most cost-effective ways of increasing school participation (Dhaliwal and others 2012). Figure 29.2 shows the cost-effectiveness of deworming in increasing school attendance across a range of development interventions.[14]

Academic Test Scores

In their study of the Kenyan deworming program, Miguel and Kremer (2004) did not find short-term effects on academic test scores.[15] However, the long-term follow-up evaluation of the same intervention (Baird and others 2016) found that among girls, deworming increased the rate of passing the national primary school exit exam by almost 25 percent (9.6 percentage points on

Figure 29.2 Cost-Effectiveness of Development Interventions in Increasing School Attendance



Sources: Hicks, Kremer, and Miguel 2015 based on data from Abdul Latif Jameel Poverty Action Lab.
Note: T–C = the difference between outcomes for those allocated to the deworming treatment group and those allocated to the deworming comparison group; km = kilometers; ext. = externality benefits. Some values are adjusted for inflation but the deworming costs are not. Deworming is costed at US$0.49 per child in Kenya. Some of these programs create benefits beyond school attendance. For example, conditional cash transfers provide income to poor households. The Jameel Poverty Action Lab cost-effectiveness calculations for school participation include conditional cash transfers as program costs.

a base of 41 percent). Ozier (2014) found test-score gains for children younger than age two years at the time of the program.

In the long-term follow-up of the cluster randomized Uganda deworming program, Croke (2014) analyzed English literacy, numeracy, and combined test scores, comparing treatment and control. The study found that children in treatment villages have significantly higher numeracy and combined test scores compared with those in control villages; effect sizes across all three outcomes range from 0.16 to 0.36 standard deviations. The effects were significantly larger for children who were exposed to the program for multiple years.[16]

Labor Market Effects

Bleakley (2007) used data from the 1940 U.S. census to compare adult outcomes among birth cohorts who entered the labor force before and after the deworming campaign in the U.S. South. Adults who had more exposure to deworming as children were significantly more likely to be literate and had higher earnings as adults. The author found a 43 percent increase in adult wages among those exposed to the campaign as children. Given initial infection rates of 30 percent to 40 percent, hookworm eradication would imply a long-term income gain of 17 percent (Bleakley 2010).[17]

Children who were treated for worms in Kenya also had better labor market outcomes later in life. Baird and others (2016) considered women and men separately, given the different set of family and labor market choices they face. They found that Kenyan women who received more deworming treatment are more likely to grow cash crops and reallocate labor time from agriculture to nonagricultural self-employment. Treated men work 17 percent more hours per week, spend more time in entrepreneurial activities, and are more likely to work in higher-wage manufacturing jobs.

Baird and others (2016) estimated the net present value of the long-term educational and economic benefits to be more than 100 times the cost, implying that even policy makers who assume a small subjective probability of realizing these benefits would conclude that the expected benefits of MDA exceed their cost.

Based on these increased earnings, the authors computed an annualized internal rate of return to deworming of 32 percent to 51 percent, depending on whether health spillovers are included. This finding is high relative to other investments, implying that deworming is cost-effective on economic grounds, even without considering health, nutritional, and educational benefits.

Furthermore, because deworming increases the labor supply, it creates a fiscal externality though its impact on tax revenue. Baird and others (2016) estimated that the net present value of increases in tax revenues likely exceeds the cost of the program. The fiscal externalities are sufficiently strong that a government could potentially reduce tax rates by instituting free mass deworming.

EVIDENCE AND POLICY DECISION RULES

This section argues that available evidence is sufficient to support deworming subsidies in endemic regions, even if the magnitude and likelihood of program impacts realized in a given context are uncertain.

When assessing evidence, there will always be some uncertainty about whether an intervention will have benefits in a given context. First, any body of research risks two types of errors: identifying an impact that does not exist (type 1 error), and missing an impact that does exist (type 2). The risk of making a type 1 error is captured by the confidence level (*P*-value) on estimates of impact. The risk of making a type 2 error is captured by the power of the study. Second, questions about the extent to which a body of research applies to the specific context of interest to policy makers will always arise.

Some (for example, Taylor-Robinson and others 2015) contend that the evidence does not support investments in mass deworming. One area of disagreement is the decision rule used. The decision rule the *Cochrane Review* seems to implicitly apply is that programs should not be implemented unless a meta-analysis (with all its associated assumptions) of randomized controlled trials shows benefits and indicates that the risk of a type 1 error is less than 5 percent. This approach is inconsistent with policy making from both a cost-effectiveness and a public finance perspective.

This decision rule puts no weight on the risk of making a type 2 error, which may be quite important for policy makers who do not want to deny a potentially highly beneficial program to their constituents. Given the statistical tradeoff between type 1 and type 2 errors, the desire to avoid withholding treatment with potentially very high benefits will necessitate being comfortable with less-than-definitive proof about program impact. Note that Taylor-Robinson and others (2015) did not report power, but that Croke and others (2016) found that Taylor-Robinson and others (2015) did not have adequate power to rule out effects that would make deworming cost-effective.

A more reasonable policy rule under uncertainty would be to compare expected costs with expected benefits. Suppose that the costs of the program are known to be *C*. Suppose policy makers are uncertain about the benefits of the program (relative to not implementing the program) in their circumstances. For simplicity, consider an example in which they believe that the total benefits may be B_1 with probability P_1, B_2 with probability P_2, or B_3 with probability P_3. This framework encompasses the case in which policy makers believe that there is some chance of zero impact because B_3 could equal zero. A risk-neutral policy maker will undertake the program if[18]

$$P_1 \times B_1 + P_2 \times B_2 + P_3 \times B_3 - C > 0.$$

With this framework in mind, from a cost-effectiveness perspective, deworming would still be warranted in many settings on educational and economic grounds alone, even if its benefits were only a fraction of those estimated in the studies discussed. Policy makers would be warranted in moving ahead with deworming, even if they thought benefits were likely to be smaller in their own context or had some uncertainty about whether benefits would be realized at all. In particular, even if the policy maker believes the impact of deworming on school participation is only 10 percent of that estimated in Miguel and Kremer (2004), or equivalently, if the policy maker believes there is a 10 percent chance of an impact of the magnitude estimated by Miguel and Kremer (2004), and a 90 percent chance of zero impact, it would still be among the most highly cost-effective ways of boosting school participation (Ahuja and others 2015). If the impact on weight is even 3 percent of that estimated by Croke and others (2016), then deworming is cost-effective relative to school feeding in increasing weight. If the labor market impact were even 1 percent of that found by Baird and others (2016), then the financial benefits of deworming would exceed the cost. Of course, to the extent that deworming may affect multiple outcomes, deworming will be even more cost-effective.

An analogous expected-value approach would be natural in a welfare economics framework. Labor market effects half as large as those estimated in Baird and others (2016) would be sufficient for deworming to generate enough tax revenue to fully cover its costs.[19] Standard welfare economics criteria for programs being welfare improving are much weaker than for the tax revenue fully covering costs.

From either a cost-benefit or a welfare economics perspective, a sophisticated analysis would be explicitly Bayesian, taking into account policy makers' previous assumptions and their best current assessment of their specific context. Under a Bayesian analysis that places even modest weight on evidence discussed here, mass school-based deworming would be justified in areas with worm prevalence greater than the WHO thresholds.

It is worth noting that a Bayesian policy maker will make current policy decisions based on current information. However, the policy maker would also continue research if the expected benefits outweigh its costs; as new evidence becomes available, it would be systematically combined with the existing best information when making decisions about continuing or modifying the program.

COST OF MASS TREATMENT PROGRAMS VERSUS SCREENED TREATMENT

The WHO recommends mass treatment once or twice a year in regions where worm prevalence is greater than certain thresholds (WHO 2015). Screening, followed by treatment of those testing positive for worms, is far less practical and more costly than mass treatment without diagnostic testing.

School-based mass treatment costs approximately US$0.30 per child per treatment, including delivery costs (GiveWell 2016).[20] Diagnosis of worm infections, in contrast, is far more expensive and complicated. Speich and others (2010) estimate that the cost per child of the Kato-Katz test, the most widely used field test for worm infections, is US$1.88 in 2013 dollars. If the test works perfectly, costs would be more than seven times higher with treatment following screening, compared with mass treatment without screening. Even proponents of the test-and-treat approach acknowledge this huge differential; Taylor-Robinson and others (2015) stated that screening is not recommended by the WHO because screening costs 4–10 times the cost of treatment. Mass treatment is clearly preferred on cost-effectiveness and public finance grounds.

These figures ultimately underestimate the cost of screening, however.[21] First, tests for worms do not identify all infections. Estimates of the specificity for the Kato-Katz method range from approximately 52 percent to 91 percent (Assefa and others 2014; Barda and others 2013). With a specificity of 52 percent, the cost per infection treated would be much higher for screened treatment compared with mass treatment. Second, a large number of infections would remain untreated. With low specificity, many existing infections would be missed; additionally, screened treatment programs need to reach infected children a second time to treat them, and it is unlikely they can reach each child who was tested—making screening even less cost-effective.

In sum, the majority of the 870 million children at risk of worm infections (Uniting to Combat Neglected Tropical Diseases 2014) could be treated each year via mass deworming programs at a cost of less than US$300 million dollars a year, which is feasible given current health budgets. The cost of treating them via screened programs would likely be US$2 billion annually, if not higher, and fewer infections would be treated.

This chapter considers the cost of school-based mass deworming programs, which are particularly inexpensive per person reached. We do not consider the cost-effectiveness of more expensive community-based programs that would include extensive outreach efforts beyond schools. One reasonable hypothesis might be that these more intensive efforts may be most warranted in areas with either high prevalence, and thus likely high intensity, of STHs, or where multiple diseases, such as lymphatic filariasis, onchocerciasis, trachoma, and schistosomiasis, that can be addressed by MDA are endemic (Hotez and others 2007).

CONCLUSIONS

Recent estimates suggest that nearly one-third of children in low- and middle-income countries are treated for worms, many via school- or community-based programs (Uniting to Combat Neglected Tropical Diseases 2014). The most commonly used deworming drugs—albendazole, mebendazole, and praziquantel—have been approved for use by the appropriate regulatory bodies in multiple countries, have been shown to be efficacious against a variety of worm infections, and have minimal side effects (Bundy, Appleby, and others 2017).

The impact of deworming will vary with the local context—including circumstances such as type of worm, worm prevalence and intensity, comorbidity, the extent of school participation in the community, and labor market factors. The decision to expend resources on deworming should be based on a comparison of expected benefits and costs, given the available evidence. Our analysis of evidence from several contexts on the nutritional, educational, and economic impact suggests that the WHO recommendations for mass treatment are justified on both welfare economics and cost-effectiveness grounds. Additional studies will generate further evidence to inform future decisions.

DISCLAIMERS

USAID and the Douglas B. Marshall, Jr. Family Foundation support deworming. Michael Kremer is a former board member of Deworm the World and is currently Scientific Director of Development Innovation Ventures at USAID. Also, Amrita Ahuja is a board member of Evidence Action, a nonprofit organization that supports governments in scaling mass school-based deworming programs; this is a voluntary position with no associated remuneration. None of these organizations had any influence on this chapter.

NOTES

This chapter draws significantly on Ahuja and others (2015).

World Bank Income Classifications as of July 2014 are as follows, based on estimates of gross national income (GNI) per capita for 2014:

- Low-income countries (LICs) = US$1,045 or less
- Middle-income countries (MICs) are subdivided:
  a) lower-middle-income = US$1,046 to US$4,125
  b) upper-middle-income (UMICs) = US$4,126 to US$12,745
- High-income countries (HICs) = US$12,746 or more.

1. For further discussion of biological differences across worms, as well as a broader discussion of deworming, please refer to Bundy, Appleby, and others (2017).
2. See, for example, Hall and Horton (2008), GiveWell (2013), and Abdul Latif Jameel Poverty Action Lab (2012).
3. Bundy, Appleby, and others (2017) provide a discussion of Taylor-Robinson and others (2015).
4. Epidemiological externalities are benefits that accrue to individuals who did not necessarily receive the treatment, for instance, a drug that cures treated individuals, thereby reducing transmission of the disease to others.
5. We do not address the optimality of the WHO prevalence thresholds for MDA.
6. Miguel and Kremer (2014) provide an updated analysis of the data in Miguel and Kremer (2004), correcting some errors in the original paper. Throughout this chapter, we cite Miguel and Kremer (2004) but use the updated numbers, where appropriate.
7. Although they do not explicitly explore externality impacts, several medical studies also show decreases in infection rates among untreated individuals (Miguel and Kremer 2004).
8. See Dupas (2014), Kremer and Glennerster (2011), Kremer and Holla (2009), and Abdul Latif Jameel Poverty Action Lab (2011) for reviews of the literature on the impact of prices on adoption of health interventions.
9. As discussed in more detail in Bundy, Appleby, and others (2017), Croke and others (2016) argued that an influential earlier study (Taylor-Robinson and others 2015) was underpowered to reject the hypothesis that MDA is cost-effective in increasing weight. Croke and others (2016) doubled the sample of 11 estimates of the effect of multiple-dose MDA for worms on weight and updated some of the estimates in Taylor-Robinson and others (2015), for example, by using micro-data provided by the original trial authors.
10. Hall and others (2006) conducted a cluster randomized study of the impact of deworming on health and test score outcomes in Vietnam. Because there is no publicly available version of this paper, we do not discuss this study in detail.
11. This measure includes the direct impact on the treated, as well as indirect impacts accruing to the untreated, population.
12. A parish is an administrative division in Uganda comprising several villages.
13. A two-part reanalysis (Aiken and others 2015; Davey and others 2015) questioned some aspects of this study. However, several independent analysts have cast doubt on the methods and conclusions of the reanalyses, and concluded that the studies leave the case for deworming fundamentally unchanged (see, for instance, Berger 2015; Clemens and Sandefur 2015; Healthcare Triage 2015; and Ozler 2015).
14. Several early studies assessed the impacts of deworming on school attendance, using individually randomized evaluations. For example, Simeon and others (1995) studied treatment among Jamaican children ages 6–12 years; Watkins, Cruz, and Pollitt (1996) studied treatment of children ages 7–12 years in rural Guatemala; and Kruger and others (1996) studied treatment of children ages 6–8 years in South Africa. None of these studies found an impact on school attendance. However, any gains are likely to be underestimated since these are individually randomized studies that do not consider treatment externalities. In addition, attendance in the Watkins, Cruz, and Pollitt (1996) study was measured through the use of school register data, which is unreliable in many low-income countries and which excluded any students who dropped out during the study. Since dropping out is very likely correlated with treatment status, there is a high risk that this gives a biased picture of school participation over time. There is also the potential for school officials to overstate attendance because of their awareness of the program and the data collection.
15. Hall and others (2006) similarly found no impact on test scores of deworming in Vietnam. As noted previously, there is no publicly available version of this paper, so we do not discuss this study further.
16. The original deworming trial was conducted in 48 communities in five districts in Eastern Uganda. Croke (2014) used educational data collected by the Uwezo project. The Uwezo survey randomly sampled communities and households from all five of these districts, creating in effect a random subsample of communities from the original trial. Croke (2014) provided evidence that the sampling of communities by Uwezo was effectively a random sample of the original trial clusters by showing that the communities have no statistically significant differences across a wide range of variables related to adult outcomes. To further support his econometric identification strategy, Croke (2014) explored the pattern of test scores of all children tested in these parishes. The youngest children would have been too young to receive more than two rounds of deworming, while the oldest children, at age 16 years, would have never received the program. One would expect that if effects are truly from the deworming intervention, the impacts would be lower at the two extremes and higher for children in the middle age group, which is what the study found.

17. Two earlier studies looked at the relationship between deworming and labor market outcomes using nonrandomized methods. Using a first-difference research design, Schapiro (1919) found wage gains of 15 percent to 27 percent on Costa Rican plantations after deworming. Weisbrod and others (1973) observed little contemporaneous correlation in the cross-section between worm infections and labor productivity in St. Lucia.
18. This abstracts from curvature of the utility function. Because deworming is inexpensive, and there is no evidence that deworming has serious side effects; because there is evidence for large effects in some cases; and because those with the highest-intensity infections are likely to be poorer than average, risk-averse policy makers or those concerned with equity would be more willing to institute mass deworming than this equation implies.
19. This estimate is conservative, only taking into account direct deworming benefits and ignoring positive externality benefits.
20. GiveWell (2016) calculates the cost of deworming for STHs in India to be US$0.30 per child per treatment, which includes both drug and delivery costs, including the value of staff time.
21. Another screening approach could be to simply ask individuals if they have experienced any of the common side effects of worm infections. Although this screening method is cheaper and potentially useful in environments where stool testing is not practical, it is likely to be very imprecise.

REFERENCES

Abdul Latif Jameel Poverty Action Lab. 2011. "The Price Is Wrong." J-PAL Policy Bulletin, Abdul Latif Jameel Poverty Action Lab, Cambridge, MA.

———. 2012. "Deworming: A Best Buy for Development." J-PAL Policy Bulletin, Abdul Latif Jameel Poverty Action Lab, Cambridge, MA.

Ahuja, A., S. Baird, J. Hamory Hicks, M. Kremer, E. Miguel, and others. 2015. "When Should Governments Subsidize Health? The Case of Mass Deworming." *World Bank Economic Review* 29 (Suppl 1): S9–24.

Aiken, A. M., C. Davey, J. R. Hargreaves, and R. J. Hayes. 2015. "Re-Analysis of Health and Educational Impacts of a School-Based Deworming Programme in Western Kenya: A Pure Replication." *International Journal of Epidemiology* 44 (5): 1572–80. doi:10.1093/ije/dyv127.

Alderman, H., J. Konde-Lule, I. Sebuliba, D. A. P. Bundy, and A. Hall. 2006. "Increased Weight Gain in Preschool Children Due to Mass Albendazole Treatment Given during 'Child Health Days' in Uganda: A Cluster Randomized Controlled Trial." *BMJ* 333: 122–26.

Assefa, L. M., T. Crellen, S. Kepha, J. H. Kihara, S. M. Njenga, and others. 2014. "Diagnostic Accuracy and Cost-Effectiveness of Alternative Methods for Detection of Soil-Transmitted Helminths in a Post-Treatment Setting in Western Kenya." *PLoS Neglected Tropical Diseases* 8 (5): e2843.

Baird, S., J. Hamory Hicks, M. Kremer, and E. Miguel. 2016. "Worms at Work: Long-Run Impacts of a Child Health Investment." *Quarterly Journal of Economics*. doi: 10.1093/qje/qjw022. Working Paper No. 21428, National Bureau of Economic Research, Cambridge, MA. http://qje.oxfordjournals.org/content/early/2016/07/14/qje.qjw022.abstract.

Barda, B., H. Zepherine, L. Rinaldi, G. Cringoli, R. Burioni, and others. 2013. "Mini-FLOTAC and Kato-Katz: Helminth Eggs Watching on the Shore of Lake Victoria." *Parasites and Vectors* 6: 220.

Berger, A. 2015. "New Deworming Reanalyses and Cochrane Review." *The GiveWell Blog*, July 24.

Bleakley, H. 2007. "Disease and Development: Evidence from Hookworm Eradication in the American South." *Quarterly Journal of Economics* 122 (1): 73–117.

———. 2010. "Health, Human Capital, and Development." *Annual Review of Economics* 2 (1): 283–310.

Bobonis, G. J., E. Miguel, and C. Puri-Sharma. 2006. "Anemia and School Participation." *Journal of Human Resources* 41 (4): 692–721.

Bundy, D. A. P., N. de Silva, S. Horton, G. C. Patton, L. Schultz, and D. T. Jamison. 2017. "Child and Adolescent Health and Development: Realizing Neglected Potential." In *Disease Control Priorities* (third edition): Volume 8, *Child and Adolescent Health and Development*, edited by D. A. P. Bundy, N. de Silva, S. Horton, D. T. Jamison, and G. C. Patton. Washington, DC: World Bank.

Bundy, D. A. P., L. Appleby, M. Bradley, K. Croke, T. D. Hollingsworth, and others. 2017. "Mass Deworming Programs in Middle Childhood and Adolescence." In *Disease Control Priorities* (third edition): Volume 8, *Child and Adolescent Health and Development*, edited by D. A. P. Bundy, N. de Silva, S. Horton, D. T. Jamison, and G. C. Patton. Washington, DC: World Bank.

Bundy, D. A. P., M. Kremer, H. Bleakley, M. C. Jukes, and E. Miguel. 2009. "Deworming and Development: Asking the Right Questions, Asking the Questions Right." *PLoS Neglected Tropical Diseases* 3 (1): e362.

Bundy, D. A. P., M. S. Wong, L. L. Lewis, and J. Jorton. 1990. "Control of Geohelminths by Delivery of Targeted Chemotherapy through Schools." *Transactions of the Royal Society of Tropical Medicine and Hygiene* 84 (1): 115–20.

Clemens, M., and J. Sandefur. 2015. "Mapping the Worm Wars: What the Public Should Take Away from the Scientific Debate about Mass Deworming." *The Center for Global Development Blog*, July 30.

Croke, K. 2014. "The Long Run Effects of Early Childhood Deworming on Literacy and Numeracy: Evidence from Uganda." Unpublished.

Croke, K., J. H. Hicks, E. Hsu, M. Kremer, and E. Miguel. 2016. "Does Mass Deworming Affect Child Nutrition? Meta-Analysis, Cost-Effectiveness, and Statistical Power." Working Paper 22382, National Bureau of Economic Research, Cambridge, MA.

Davey, C., A. M. Aiken, R. J. Hayes, and J. R. Hargreaves. 2015. "Re-Analysis of Health and Educational Impacts of a School-Based Deworming Programme in Western Kenya: A Statistical Replication of a Cluster Quasi-Randomized

Stepped-Wedge Trial." *International Journal of Epidemiology* 44 (5): 1581–92. doi:10.1093/ije/dyv128.

Dhaliwal, I., E. Duflo, R. Glennerster, and C. Tulloch. 2012. "Comparative Cost-Effectiveness Analysis to Inform Policy in Developing Countries: A General Framework with Applications for Education." Abdul Latif Jameel Poverty Action Lab, Cambridge, MA.

Dupas, P. 2014. "Getting Essential Health Products to Their End Users: Subsidize, but How Much?" *Science* 345: 1279–81.

Galloway, R., E. Kristjansson, A. Gelli, U. Meir, F. Espejo, and others. 2009. "School Feeding: Outcomes and Costs." *Food and Nutrition Bulletin* 30 (2): 171–82.

GiveWell. 2013. "Top Charities." http://www.givewell.org/charities/top-charities.

———. 2016. "Deworm the World Initiative, led by Evidence Action." http://www.givewell.org/international/top-charities/deworm-world-initiative#sources1155.

Hall, A., and S. Horton. 2008. "Best Practice Paper: Deworming." Copenhagen Consensus Center, Denmark.

Hall, A., L. Nguyen Bao Khanh, D. A. P. Bundy, N. Quan Dung, T. Son Hong, and others. 2006. "A Randomized Trial of Six Monthly Deworming on the Growth and Educational Achievements of Vietnamese School Children." Unpublished.

Healthcare Triage. 2015. "Replication, Re-Analysis, and Worm Wars." https://www.youtube.com/watch?v=9SCFlYlNlLQ.

Hicks, J. H., M. Kremer, and E. Miguel. 2015. "Commentary: Deworming Externalities and Schooling Impacts in Kenya: A Comment on Aiken et al. (2015) and Davey et al. (2015)." *International Journal of Epidemiology* 44 (5): 1593–6. doi:10.1093/ije/dyv129.

Hotez, P. J., D. H. Molyneux, A. Fenwick, J. Kumaresan, S. Ehrlich Sachs, and others. 2007. "Control of Neglected Tropical Diseases." *New England Journal of Medicine* 357: 1018–27.

Kabatereine, N., E. Tukahebwa, S. Brooker, H. Alderman, and A. Hall. 2001. "Epidemiology of Intestinal Helminth Infections among Schoolchildren in Southern Uganda." *East African Medical Journal* 78: 283–86.

Kremer, M., and R. Glennerster. 2011. "Improving Health in Developing Countries: Evidence from Randomized Evaluations." In *Handbook of Health Economics*, Volume 2, edited by M. V. Pauly, T. G. McGuire, and P. P. Barros. Oxford, U.K.: Elsevier Press.

Kremer, M., and A. Holla. 2009. "Pricing and Access: Lessons from Randomized Evaluations in Education and Health." In *What Works in Development: Thinking Big and Thinking Small*, edited by W. Easterly and J. Cohen. Washington, DC: Brookings Institution Press.

Kremer, M., and E. Miguel. 2007. "The Illusion of Sustainability." *Quarterly Journal of Economics* 112 (3): 1007–65.

Kruger, M., C. J. Badenhorst, E.P.G. Mansvelt, J.A. Laubscher, and A.J.S. Benade. 1996. "The Effect of Iron Fortification in a School Feeding Scheme and Anthelminthic Therapy on the Iron Status and Growth of 6–8-Year-Old School Children." *Food and Nutrition Bulletin* 17 (1).

Miguel, E., and M. Kremer. 2004. "Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities." *Econometrica* 72 (1): 159–217.

———. 2014. "Guide to Replication of Miguel and Kremer 2004." http://emiguel.econ.berkeley.edu/research/worms-identifying-impacts-on-education-and-health-in-the-presence-of-treatment-externalities.

Ozier, O. 2014. "Exploiting Externalities to Estimate the Long-Term Effects of Early Childhood Deworming." Policy Research Working Paper 7052, World Bank, Washington, DC.

Ozler, B. 2015. "Worm Wars: A Review of the Reanalysis of Miguel and Kremer's Deworming Study." *Development Impact Blog*, July 24.

Schapiro, L. 1919. "The Physical and Economic Benefits of Treatment for Hookworm Disease." *Journal of the American Medical Association* 73: 1507–09.

Simeon, D. T., S. M. Grantham-McGregor, J. E. Callender, and M. S. Wong. 1995. "Treatment of *Trichuris trichiura* Infections Improves Growth, Spelling Scores and School Attendance in Some Children." *Journal of Nutrition* 125 (7): 1875–83.

Speich, B., S. Knopp, K. A. Mohammed, I. S. Khamis, L. Rinaldi, and others. 2010. "Comparative Cost Assessment of the Kato-Katz and FLOTAC Techniques for Soil-Transmitted Helminth Diagnosis in Epidemiological Surveys." *Parasites and Vectors* 3 (71): 1–11.

Taylor-Robinson, D. C., N. Maayan, K. Soares-Weiser, S. Donegan, and P. Garner. 2015. "Deworming Drugs for Soil-Transmitted Intestinal Worms in Children: Effects on Nutritional Indicators, Haemoglobin, and School Performance." *Cochrane Database of Systematic Reviews* 7: CD000371. doi:10.1002/14651858.CD000371.pub6.

Uniting to Combat Neglected Tropical Diseases. 2014. "Delivering on Promises and Driving Progress." http://unitingtocombatntds.org/sites/default/files/document/NTD_report_04102014_v4_singles.pdf.

Watkins, W. E., J. R. Cruz, and E. Pollitt. 1996. "The Effects of Deworming on Indicators of School Performance in Guatemala." *Transactions of the Royal Society of Tropical Medicine and Hygiene* 90 (2): 156–61.

Weisbrod, B. A., R. L. Andreano, R. E. Baldwin, and A. C. Kelley. 1973. *Disease and Economic Development: The Impact of Parasitic Diseases in St. Lucia*. Madison: University of Wisconsin Press.

WHO (World Health Organization). 2015. "Deworming to Combat the Health and Nutritional Impact of Helminth Infections." e-Library of Evidence for Nutrition Actions (eLENA), WHO, Geneva. http://www.who.int/elena/titles/deworming/en.