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An Updated Economic Analysis of the Global Polio Eradication Initiative

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Abstract

Despite a strong global commitment, polio eradication efforts continue now more than 30 years after the 1988 World Health Assembly resolution that established the Global Polio Eradication Initiative (GPEI), and 20 years after the original target of the year 2000. Prior health economic analyses estimated incremental net benefits of the GPEI of 40–50 billion in 2008 US dollars (US $2008, equivalent to 48–59 billion US$2019), assuming the achievement of polio eradication by 2012. Given the delays in achieving polio eradication and increased costs, we performed an updated economic analysis of the GPEI using an updated integrated global model, and considering the GPEI trajectory as of the beginning of 2020. Applying similar methods and assuming eradication achievement in 2023, we estimate incremental net benefits of the GPEI of 28 billion US$2019, which falls below the prior estimate. Delays in achieving polio eradication combined with the widescale introduction of relatively expensive inactivated poliovirus vaccine (IPV) significantly increased the costs of the GPEI and make it less cost-effective, although the GPEI continues to yield expected incremental net benefits at the global level when considered over the time horizon of 1988–2029. The overall health and financial benefits of the GPEI will depend on whether and when the GPEI can achieve its goals, when eradication occurs, the valuation method applied, and the path dependence of the actions taken. Reduced expected incremental net benefits of the GPEI and the substantial economic impacts of the COVID-19 pandemic pose large financial risks for the GPEI.

Keywords

polio; eradication; cost

1. INTRODUCTION

Launched in 1988, the Global Polio Eradication Initiative (GPEI) stands out one of the largest, internationally-coordinated global public health major projects conducted to date, with cumulative spending of over $16.5 billion (US, nominal) for 1988–2018 (World Health Organization Global Polio Eradication Initiative, 2019a). The GPEI seeks to end all transmission of wild polioviruses (WPVs) and permanently prevent cases of poliomyelitis (or paralytic polio, henceforth, cases). Updated global modeling (Kalkowska, Wassilak,

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Cochi, Pallansch, & Thompson, 2020) published prior to the Coronavirus Disease 2019 (COVID-19) pandemic suggests that the GPEI is not currently on track for completion before the end of its current Strategic Plan for 2019–2023 (World Health Organization Global Polio Eradication Initiative, 2019b). Thus, global polio eradication remains an elusive goal, but one with continued widespread support.

Prior economic analyses characterized the potential health and financial outcomes of investments in polio control and eradication. Multiple prospective studies explored the economic benefits of polio elimination in the Americas (Musgrove, 1988), and the expected benefits of polio eradication modeled to occur in 2000 (Bart, Foulds, & Patriarca, 1996), in 2005 (Khan & Ehreth, 2003), and at an unspecified time (Aylward, Acharya, England, Agocs, & Linkins, 2003). Two studies that included retrospective analyses characterized the (i) substantial net benefits associated with US polio vaccination efforts over time (Thompson & Duintjer Tebbens, 2006) and (ii) estimated expected incremental net benefits of $40–50 billion in 2008 US dollars (i.e., US$2008) for the GPEI assuming completion of polio eradication by 2012 (with sensitivity analysis extending to 2015) (Duintjer Tebbens et al., 2011). Economic analyses of polio eradication compared to control appeared in the mid-2000s (Thompson & Duintjer Tebbens, 2007) and in 2019 (Zimmermann, Hagedorn, & Lyons, 2020). However, these studies made substantially different assumptions about the baseline strategy: (1) assuming continued use of oral poliovirus vaccine (OPV) without inactivated poliovirus vaccine (IPV) by OPV-using countries as the comparator (Thompson & Duintjer Tebbens, 2007) versus (2) assuming permanent high control with 3 or more doses of OPV plus to a minimum of 2 doses of IPV in OPV-using countries in perpetuity (i.e., vaccine use consistent with 2019 GPEI policy, coverage at 2019 levels, but epidemiological experience consistent with 2005–2017 cases) (Zimmermann et al., 2020). These analyses also varied substantially in scope: (1) considering health outcomes and financial costs (Thompson & Duintjer Tebbens, 2007) versus (2) focusing on costs only (Zimmermann et al., 2020).

The delay in achieving global polio eradication and increased costs of the GPEI associated with changes in policies that occurred through 2019 necessitate an updated analysis of the expected health and economic outcomes of the GPEI. A prior health economic analysis of the GPEI identified 104 countries that directly received support from the GPEI and characterized the incremental cost-effectiveness ratios (ICERs) and incremental net benefits (INBs) of the GPEI compared to assuming no GPEI (Duintjer Tebbens et al., 2011). As of 2019, all 105 GPEI countries (i.e., the original 104 (Duintjer Tebbens et al., 2011) plus South Sudan, which split off from Sudan) continue to use OPV and now also use at least one dose of IPV in their routine immunization (RI) schedules. Many countries also continue to use supplementary immunization activities (SIAs) with OPV to achieve and maintain high population immunity to transmission: either preventively (pSIAs) or reactively to respond to outbreaks (oSIAs). An updated integrated dynamic model shows expected transmission of serotype 1 WPV (WPV1) through 2023 (Kalkowska, Wassilak, et al., 2020) associated with the 2019–2023 GPEI Strategic Plan (World Health Organization Global Polio Eradication Initiative, 2019b). A separate analysis identified strategies that could stop the remaining transmission of WPV1 in the remaining reservoirs by 2023 (Kalkowska & Thompson, 2020c), which confirms that the goal of achieving polio eradication remained possible as of early 2020 with sufficient attention to achieving high OPV coverage with pSIAs in the remaining WPV1 endemic areas. Specifically, like a 2007 analysis that focused on the importance of intensifying immunization activities to stop poliovirus transmission in India (Thompson & Duintjer Tebbens, 2007), stopping WPV1 transmission in Pakistan and Afghanistan remains possible so long as the countries and the GPEI commit to OPV immunization activities that achieve high coverage in under-vaccinated communities (i.e., intensified and better quality OPV immunization) (Duintjer Tebbens & Thompson, 2019; Kalkowska & Thompson, 2020c).

Although OPV offers substantial benefits and serves as the vaccine tool that enabled WPV elimination in most countries, as a live poliovirus (LPV) its use also comes with some risks, including vaccine-associated paralytic polio (VAPP) and paralysis cases caused by vaccine-derived polioviruses (VDPVs) (Duintjer Tebbens et al., 2006; Kalkowska, Wassilak, et al., 2020). After the certification of serotype 2 WPV (WPV2) eradication (Global Polio Eradication Initiative, 2015), in April-May 2016 the GPEI globally-coordinated the cessation of serotype 2-containing OPV (OPV2) with the hope of ending all cases caused by serotype 2 LPVs (LPV2s) (Hampton et al., 2016). Unfortunately, OPV2 cessation did not go as smoothly as hoped, and the GPEI and countries continue to use monovalent OPV2 (mOPV2) for oSIAs to respond to serotype 2 VDPVs (VDPV2s) as of early 2020 (Kalkowska, Wassilak, et al., 2020). Another recent analysis characterizes the risks of needing to restart the use of OPV2 in RI (Kalkowska, Pallansch, Cochi, et al., 2020). Although the GPEI certified WPV3 eradication in 2019 (World Health Organization, 2019a), to date the GPEI has not committed to globally-coordinating OPV3 cessation (Kalkowska & Thompson, 2020a).

As of the end of 2019, the GPEI reported cumulative external financial contributions exceeding $17.3 billion (nominal) (World Health Organization Global Polio Eradication Initiative, 2020a) (see Fig. 1 in (Thompson & Kalkowska, 2020b)), which translates to a net present value in US$2019 of approximately $20.7 billion. Notably, substantial increases in annual costs occurred for vaccination and programmatic activities since the prior analysis (Duintjer Tebbens et al., 2011), which increased the external contributions required for the GPEI to approximately $1 billion (US$2019) per year (until eradication). As the costs for the GPEI continue to accumulate, questions remain about the benefits of the investments, particularly with the 2015 GPEI shift in its focus to adopt IPV in anticipation of entering the last phases of the polio endgame before 2020 (World Health Organization Global Polio Eradication Initiative, 2013). Including IPV in national immunization schedules while still using OPV adds substantially to the GPEI costs. IPV use in the endemic areas also masks some of the transmission by preventing some cases, but it does not prevent or substantially reduce transmission (Kalkowska & Thompson, 2020c). Now, 10 years after the last health economic analysis of the GPEI, this study revisits the expected health and economic impacts of the GPEI based on its status as of early 2020 but prior to the COVID-19 pandemic. We emphasize that future analyses will need to provide another update of the GPEI economics upon its completion.

2. METHODS

We adopt the framing and assumptions from a prior analysis of the economics of the GPEI (Duintjer Tebbens et al., 2011) that stratifies GPEI countries by World Bank Income Level (WBIL) (World Bank, 2019b): low-income (LI), lower middle-income (LMI), and upper middle-income (UMI). The analysis excludes all high-income, many UMI, and all western hemisphere countries that committed to polio eradication prior to the GPEI (Duintjer Tebbens et al., 2011). For this analysis, we characterize the disease burden over time for the GPEI retrospectively using an updated global differential equation-based (DEB) poliovirus transmission and OPV evolution model that stratifies the population into 72 blocks (Kalkowska, Wassilak, et al., 2020) and categorizes the blocks by WBIL (World Bank, 2019b). We consider two prospective reference case (RC) scenarios, relevant in early 2020 (prior to the COVID-19 pandemic). The first (i.e., RC2) represents our characterization of the path of the GPEI as of the end of 2019, which assumes immunization coverage maintained at levels consistent with epidemiology and the GPEI strategy as of the end of 2019 (which a prior analysis characterized as high control for WPV1 due to insufficient pSIAs with bOPV in the remaining endemic areas of Pakistan and Afghanistan) (Kalkowska, Pallansch, Cochi, et al., 2020; Kalkowska & Thompson, 2020b; Kalkowska, Wassilak, et al., 2020). The second, an alternative reference case (RC2*), assumes improvements in the quality and coverage achieved for OPV pSIAs in Pakistan and Afghanistan such that global eradication of WPV1 occurs by 2023 (Kalkowska, Pallansch, Cochi, et al., 2020; Kalkowska & Thompson, 2020c; Kalkowska, Wassilak, et al., 2020). Both RC prospective scenarios assume immunization use consistent with actual vaccine schedules and coverage (Kalkowska, Wassilak, et al., 2020), but they differ on the outcome of eradication of WPV1. The model assumes IPV introduction into RI occurred in all countries prior to 2019, and uses fractional IPV doses in the immunization schedules in blocks with properties that represent countries like Bangladesh, India, and Sri Lanka. Since RC2 does not achieve WPV1 eradication, globally-coordinated cessation of bOPV does not occur. For RC2*, we assume that WPV1 eradication occurs followed by globally-coordinated cessation of bOPV use on January 1, 2025, and that at the time of bOPV cessation, LI and LMI countries adopt a 2-dose IPV-only RI schedule, and UMI countries adopt a 3-dose IPV-only RI schedule.

Taking 2019 as the reference year, we emphasize that this analysis considers both the retrospective (i.e., 1988–2018) and prospective (i.e., 2019–2029) health and economic benefits of the GPEI applied only to GPEI countries (i.e., excluding countries that did not receive any direct financial support from the GPEI (Duintjer Tebbens et al., 2011)). For the comparator scenario (i.e, no GPEI), we assume that the GPEI countries would have continued using trivalent OPV (tOPV) with coverage that increased like their historical 3-dose diphtheria-tetanus-pertussis (DTP3) immunization coverage (Kalkowska, Wassilak, et al., 2020). For the no GPEI scenario, we assume only tOPV use in RI (i.e., no monovalent OPV (mOPV) or bivalent OPV (bOPV)) and no pSIAs. We also assume that importations of WPV would regularly occur throughout the time horizon into subpopulations that achieved local WPV elimination from exporting countries that do not. Due to the WPV importation threat, we assume the blocks using IPV-only in the global model (Kalkowska, Wassilak, et al., 2020) would use an IPV/OPV sequential schedule for RI (instead of IPV-only) to minimize VAPP, while continuing to benefit from high population immunity.

For the GPEI countries (Duintjer Tebbens et al., 2011), we characterized the countries by demographic data (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2019) and both historical (World Bank, 2020) and 2019 WBILs (World Bank, 2019a). The 105 GPEI countries represented approximately 3.7 billion people in 1988 (72% of the global population) (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2019), which collectively reported approximately 35,000 paralytic poliomyelitis cases (i.e., nearly all of the 1988 reported global burden) (Kalkowska, Wassilak, et al., 2020). Table 1(a) shows the number of people in GPEI countries in each WBIL in 1988 and 2019. Fig. 1 shows the changes over time that reflect the shifts in WBILs for large countries (e.g., shifts for China in 1998 from LI to LMI and in 2010 from LMI to UMI, and for Indonesia in 2003 and India in 2007 from LI to LMI, see appendix). Using the historical and 2019 WBILs (World Bank, 2019a) leads to categorizing the GPEI countries as: 50 LI, 46 LMI, and 9 UMI countries in 1988, and 30 LI, 42 LMI, and 33 UMI countries in 2019 as shown in Table 1(a). We abstractly correspond the list of countries to the global model blocks, which yielded 50 full and 7 partial blocks that represent conditions similar to GPEI countries (see Table 1(b)). We assume countries and blocks remain in their 2019 WBIL for 2019–2029.

To estimate financial costs, treatment costs, and productivity losses related to cases, ICERs, and INBs for each WBIL, we use a combination of information for individual countries and income level-specific model inputs (Kalkowska, Pallansch, Cochi, et al., 2020; Kalkowska, Wassilak, et al., 2020). We use updated retrospective and prospective WBIL-specific estimates for costs and valuation inputs that reflect current costs and methods for economic analyses (e.g., vaccine, treatment) (Thompson & Kalkowska, 2020a). We apply these to the appropriate blocks using the appropriate WBIL (i.e., the historical WBIL for each country for 1988–2018 (World Bank, 2020) or the 2019 WBIL (World Bank, 2019a) for 2019–2029). We use the historical (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2019) demographic data and WBIL for each county to estimate the 1988–2018 population-weighted life expectancy by year by WBIL and the resulting disability-adjusted life-years (DALYs) per case by year by WBIL (see appendix for details). We also estimate global programmatic costs for surveillance, coordination, technical support, stockpile procurement and management, social mobilization, containment, etc. by year by WBIL and convert these to US$2019 (see appendix for details). Unlike the GPEI, which from 2013 on focused on the financial resource requirements (FRRs) to support the implementation of activities performed by the WHO and UNICEF, we focus our cost estimates on total costs required to support polio eradication, which includes the non-FRR spending by some GPEI partners and costs paid by countries. Despite our best efforts to estimate costs, our global programmatic cost estimates do not fully capture the investments made by some GPEI partners (e.g., time donated by individuals for social and resource mobilization, support from the Bill & Melinda Gates Foundation for its staff and their related activities, etc.) and this analysis does not consider these costs. This analysis also does not consider the external benefits of the GPEI, for which a prior analysis quantified substantial benefits associated with the delivery of vitamin A as part of GPEI pSIAs (Duintjer Tebbens et al., 2011). Overall, the external benefits associated with the GPEI remain poorly documented and difficult to quantify, and consequently for this analysis we qualitatively highlight the limitation in framing of this analysis and emphasize our focus on polio-specific health and economic outcomes.

We generally frame this analysis to facilitate comparison to a prior analysis including a discount rate of 3% (Duintjer Tebbens et al., 2011). Given the passage of time, we report economic outcomes expressed in 2019 US dollars (US$2019) converted using the US Consumer Price Index (CPI) (Bureau of Labor Statistics, 2020) for years before 2019. We use a 3% rate both to inflate future unit cost input estimates and to discount prospective costs back to a 2019 net present value for the prospective years in the time horizon (i.e., 2019–2029). We report ICERs in US$2019 per case prevented and US$2019 per DALY saved by WBIL, and INBs as net present value US$2019 by WBIL and summed over all WBILs to estimate the overall expected INB for the GPEI. The prior analysis (Duintjer Tebbens et al., 2011) followed the World Health Organization (WHO) 2008 guidelines and practice for the standardization of health economic analyses, which suggests valuation of a dollar per DALY on the order of a unit of the gross national income (GNI) or gross domestic product (GDP) per capita and discounting prospective financial and health outcomes (World Health Organization, 2008). More recent WHO guidance suggests a preference for the utilization of national health opportunity costs for valuation (i.e., for dollar per DALY comparisons), when available, and performing cost-effectiveness analysis with discounting of financial outcomes and both with and without discounting of health outcomes (World Health Organization, 2019b). In the context of threshold analyses for the consideration of ICERs, the WHO maintains the option to use the GNI per capita as a surrogate value of a dollar per DALY (World Health Organization, 2019b). Similar to a prior analysis (Duintjer Tebbens et al., 2011), we present ICERs assuming discounting of both health and economic outcomes by WBIL and provide thresholds for comparison based on 1 GNI per capita. Building on a recent analysis of implied WBIL-adjusted estimates of health opportunity costs by WBIL as a function of population-weighted GNI per capita (Ochalek, Claxton, Lomas, & Thompson, 2020), we assume multipliers of 0.2, 0.2, and 0.6 for LI, LMI, and UMI, respectively, to characterize approximate health opportunity cost thresholds by WBIL. With our economic analysis framed according to WBIL, for INB estimation we use the same methods as a prior analysis (Duintjer Tebbens et al., 2011) and assume a societal willingness to pay equal to the population-weighted GNI per capita (by WBIL) per DALY saved (see appendix for details).

We code the global model using the general-purpose programming language JAVA™ and the integrated development environment Eclipse™, and we run stochastic simulations on the Amazon Elastic Compute Cloud (Amazon EC2). We performed one deterministic run up for the counterfactual scenario (i.e., no GPEI) for the full time horizon, and for the GPEI for the time horizon of 1988–2018 (Kalkowska, Wassilak, et al., 2020), which we then followed by 100 stochastic simulations for each of the RCs (i.e., RC2, RC2* (Kalkowska, Pallansch, Cochi, et al., 2020)) for the time horizon of 2019–2029. We control the stochastic introductions to facilitate comparison of RC2 and RC2* (Kalkowska, Pallansch, Cochi, et al., 2020).

3. RESULTS

For the 105 GPEI countries, Fig. 2 presents the model estimates of cases for 1988–2029 for the GPEI retrospectively followed by RC2 and RC2* (black lines) prospectively (i.e., GPEI +RC2 and GPEI+RC2*), and compared to the counterfactual of no GPEI (red dashed lines) for (a) LI, (b) LMI, (c) UMI and (d) all GPEI countries. As in the prior analysis (Duintjer Tebbens et al., 2011), Fig. 2 shows substantial declines in global polio incidence due to RI alone, but with the GPEI the cases drop dramatically in the early 1990s. Overall, the GPEI prevents an estimated approximately 3 million total (undiscounted) cases over the time horizon. With most of the population in GPEI countries in LI and LMI, most of the cases occur in these WBILs. Direct comparison of Fig. 2 to Fig. 1 of a prior analysis (Duintjer Tebbens et al., 2011) shows the impact of using the appropriately time varying WBILs for the current analysis with respect to the overall distribution of cases.

Fig. 3 presents the estimated costs from 1988–2029 for the GPEI+RC2 and GPEI+RC2* (black lines) compared to the counterfactual of no GPEI (red dashed lines) for (a) LI, (b) LMI, (c) UMI and (d) all GPEI countries. The reduction in cases due to the GPEI shown in Fig. 2 came at substantial cost, which increased notably over time prior to 2019 and which we expect will continue to increase with time. The inclusion of IPV in RI, which started in UMI countries in the 2000s and in LI and LMI countries in 2015, leads to notable increases in the costs. For RC2, the model does not include WPV1 eradication, while for RC2*, WPV1 eradication occurs in 2023 and the continuing expected cases over time largely reflect the impact of model iterations that lead to OPV1 and/or OPV2 restart in RI. For LI and LMI countries, the costs of RC2 exceed the costs of RC2*, because for RC2, the model assumes these countries will continue to use both OPV and IPV and maintain very high control throughout the time horizon. For UMI countries, the cost of RC2* exceeds the cost of RC2 because we assume that with WPV1 eradication, globally-coordinated cessation of bOPV use would occur on January 1, 2025, and the addition of a third IPV RI dose in these countries would substantially increase their costs. Fig. 4 shows the estimated health-related costs (including treatment and productivity costs) used for the INB estimates for 1988–2029 for the GPEI+RC2 and GPEI+RC2* (black lines) compared to the counterfactual of no GPEI (red dashed lines) for: (a) LI, (b) LMI, (c) UMI and (d) all GPEI countries. Fig. 3 shows higher costs for the GPEI compared to no GPEI (black lines vs. red line), while Fig. 4 shows lower costs for the GPEI compared to no GPEI (black lines vs. red line).

Restarts of OPV2 in RI can occur in the model for all of the prospective iterations with the GPEI (i.e., RC2 or RC2*), while restarts of OPV1 or OPV3 can only occur in the model for RC2*, because bOPV cessation only occurs for RC2* (Kalkowska, Pallansch, Cochi, et al., 2020). For all income levels, the RI costs related to OPV restarts for RC2 exceed those for RC2* due to the higher probability of restarts for RC2. However, while OPV restarts lead to increases in immunization costs, the immunization leads to off-setting decreases in health costs due to cases prevented (Kalkowska & Thompson, 2020b). The model assumes higher SIA costs for 2020–2021 for RC2* compared to RC2, due to the improvement in quality required to eradicate WPV1 (Kalkowska, Pallansch, Cochi, et al., 2020), for which we assume a premium (Ozawa, Yemeke, & Thompson, 2018) by including a cost of $50 million in 2020 in the LMI as part of the global programmatic costs. However, after 2022 the SIA costs for RC2 exceed those for RC2* because of more cases, more OPV restarts, and more oSIAs using IPV in IPV-only countries once mOPV2 use for oSIAs stops (assumed to stop in 2024). Consistent with the higher number of cases, RC2 leads to higher surveillance costs compared to RC2*. The net result of combining these costs leads to a higher cost of RC2 in LI and LMI countries (i.e., higher than originally planned RI costs of RC2* becoming offset by new RI, SIA, and surveillance costs related to OPV restarts, which makes RC2 relatively more expensive), but lower costs in UMI countries (i.e., the majority of costs come from the RI schedule becoming 3 IPV doses once cessation of all OPV use happens in RC2*).

Table 2 summarizes the cases and costs for the different scenarios for the GPEI with RC2 or RC2* compared to no GPEI retrospectively (i.e., 1988–2018), prospectively (i.e., 2019–2029), and overall (i.e., 1988–2029). As shown in Table 2, we estimate incremental financial costs of the GPEI on the order of $34 billion for 1988–2018. This estimate includes costs for vaccination and surveillance (in addition to programmatic costs allocated to each WBIL) and includes implied estimates of "in kind" costs for vaccination and surveillance from countries. This implies a factor of approximately 1.7 (i.e., $34 billion vs. $20 billion) to extrapolate external GPEI financing to total financial costs for 1988–2018, or "in kind" financing on the order of 60% of external GPEI financing for that time period). Table 2 also shows the substantial monetized health-related savings (i.e., negative costs) associated with the GPEI and prospective RC2 or RC2* preventing cases and thus avoiding the need to pay to treat paralyzed individuals and incur losses in productivity.

Table 3 summarizes the ICERs, relevant ICER thresholds, and INBs for the two different valuation approaches. Assuming 1 GNI per DALY, for the period of 1988–2018, we estimate INBs of the GPEI of approximately 27 billion US$2019. For 2019–2029, we estimate an incremental loss of 4.1 billion US$2019 for RC2 or an incremental gain of 1.3 billion US $2019 for RC2*. For GPEI+RC2, Table 3 suggests an overall INB of 23 billion US$2019 for the GPEI for 2019–2029, and we would expect ongoing high control with the GPEI+RC2 vaccination strategy (e.g., permanent high control using both OPV and IPV in OPV-using countries) would continue to reduce the expected INBs as the time horizon extends. Separate modeling suggests that alternative prospective vaccination strategies may lead to improved overall health and economic outcomes than considered here (Kalkowska & Thompson, 2020b). In contrast, if the GPEI can achieve WPV1 eradication by 2023 (e.g., GPEI+RC2*), then the GPEI could lead to overall INBs for 1988–2029 of approximately 28 billion US $2019. The estimate of 28 billion US$2019 represents a decrease of approximately 40% compared to a prior study, which suggested INBs on the order of 48–59 billion US$2019 (Duintjer Tebbens et al., 2011). Table 3 also shows the ICER results, which we find difficult to interpret but include for consistency with a prior analysis (Duintjer Tebbens et al., 2011). Compared to the 1 GNI per capita threshold, the ICERs in Table 3 (in $/DALY) for the GPEI compared to no GPEI appear cost effective for all WBILs for 1988–2018, but not when compared to the health opportunity cost thresholds. The ICERs show more mixed results for GPEI+RC2 and for GPEI+RC2* prospectively (i.e., for 2019–2029) compared to the 1 GNI per capita threshold, although neither appears cost-effective for any WBIL compared to the health opportunity cost thresholds. For the UMI countries, the relatively high ICERs result from relatively high incremental costs and low incremental cases prevented, which make the ICERs for GPEI+RC2 and GPEI+RC2* not cost-effective relative to the threshold for 2019–

2029. The jump to 3 doses of IPV after 2023 dominates the ICER for UMI countries and makes the GPEI+RC2* relatively less cost effective than GPEI+RC2, because both scenarios yield the same number of incremental cases prevented relative to no GPEI (i.e., 12,869 shown in Table 2). For LI and LMI countries, GPEI+RC2* prevents more cases than GPEI +RC2, but the trade-offs for paying extra costs for immunization compared to the savings associated with achieving this incremental prevention of cases drive the results and make the ICERs cost-effective for LMI and not cost-effective for LI compared to the 1 GNI per capital thresholds. Overall, the results of this health economic analysis suggest that delays in achieving eradication and continuing on the 2019–2023 expected GPEI trajectory as of the end of 2019 (Kalkowska, Wassilak, et al., 2020) have reduced and will continue to reduce the expected overall health and economic benefits of the GPEI.

4. DISCUSSION

Delays in achieving polio eradication, which requires high coverage with OPV in most countries, combined with the widescale introduction of relatively expensive IPV, significantly increases the expected costs of the GPEI, and make it less cost-effective. The GPEI continues to yield expected incremental net benefits at the global level when considered over the time horizon of 1988–2029, although the GPEI now appears on track to yield substantially lower expected INBs compared to a prior analysis (Duintjer Tebbens et al., 2011). Considered together with a prior analysis (Duintjer Tebbens et al., 2011), this study demonstrates that the overall health and financial benefits of the GPEI will depend ultimately on whether and when the GPEI achieves its goals and the path dependence of the actions taken. While prospective modeling can provide glimpses of potential futures, the actual future remains uncertain and will depend on the decisions and actions taken (Thompson & Kalkowska, 2020b).

As with any economic analysis, the results depend on the framing. Notably, this analysis contrasts with a recent 2019 prospective cost analysis that applied the benefits of polio eradication for all countries and assumed only the GPEI projected budget for 2020–2030 as the incremental costs associated with the GPEI, compared to an assumed comparator of high control with both IPV and continued OPV use in perpetuity (Zimmermann et al., 2020). Further analyses will need to consider the full set of prospective vaccine and other policy options and the impacts of immunization policy decisions on expected future polio endgame health and economic costs.

The results of this analysis also come with the limitations associated with the model structure, assumptions, and available information (see detailed model limitations in the technical appendix of a prior publication that describes the poliovirus transmission model (Kalkowska, Wassilak, et al., 2020)). Specifically, as a stochastic model, the results depend on the number of stochastic iterations. The trade-offs between running a large, complex dynamic global model and the observation of different types of events depend on the number of iterations to observe rare events. For this analysis, the events that drive the results (e.g., OPV restarts) occur with sufficient frequency that we do not anticipate substantial changes in the overall expected results as a function of different numbers of iterations. In addition, the prospective analyses depend on our knowledge and understanding of potential future policies and therefore our estimates of future inputs.

Most importantly, we anticipate that the global COVID-19 pandemic will affect the polio endgame. In 2020, the COVID-19 pandemic reduced national and GPEI polio immunization activities and the extent and nature of human contacts. This analysis does not consider the COVID-19 pandemic effects on cases and costs, which we leave to future studies. However, we emphasize that while the COVID-19 pandemic led to disruptions of RI and SIAs that decreased immunization coverage, it also led to physical distancing efforts that partially reduced transmission. Overall, these two impacts offset each other to some degree while they occur contemporaneously. If the impacts of the COVID-19 pandemic only lead to temporary and short-term disruptions, then the effects of COVID-19 on expected incidence may be relatively small and transient. More significantly, the economic disruptions caused by COVID-19 will likely substantially decrease productivity for most if not all countries and impact the willingness of donors to continue to prioritize polio eradication while they make substantial contributions to efforts aimed at fighting the COVID-19 pandemic. This analysis also does not consider any external benefits (or unquantified costs) of the GPEI, which we highlight as a limitation in framing of this analysis. We did not find justification to assume any benefits of OPV non-specific protection associated with COVID-19 (Thompson, Kalkowsa, & Badizadegan, 2020). Recognizing that the risks of OPV restarts present a substantial threat to a successful polio end game, future analyses will need to consider the impacts of any new vaccine options (e.g., new OPV strains (Kalkowska, Pallansch, Wilkinson, et al., 2020) and/or GPEI strategies (World Health Organization Global Polio Eradication Initiative, 2020b)).

Since the goal of the GPEI remains unfinished, future economic analyses will need to characterize the ultimate health and financial impacts of the GPEI for the actual path taken. We hope that this analysis provides a useful update of the expected health and economic impacts of its current status that will help the GPEI partners and countries appreciate the benefits of the GPEI to date and the consequences of delays in achieving eradication and shifting to high cost immunization policies (i.e., IPV and OPV simultaneously and multiple doses of IPV). Overall, the GPEI continues to represent an intervention with substantial expected INBs compared to a world without the GPEI, although the valuation method changes the interpretation of the overall economic outcomes in Table 3. Using a health opportunity cost threshold instead of assuming 1 GNI per capita per DALY implies valuation that may better represent national preferences for spending domestic resources on societal health interventions. The results demonstrate how assuming a higher valuation can lead to investments that countries would not make on their own when spending domestic funds. An early economic analysis of polio (Khan & Ehreth, 2003) highlighted that “for developed regions of the world, not to adopt polio immunization is simply irrational but for developing countries polio immunization program competes with other medical interventions for funding.” Thus, with a health opportunity cost approach, polio eradication looks substantially worse as a national financial investment for GPEI countries, but in the context of external donor financing, the valuation preferred by the donors for their investments may drive policies.

Overall, continued delays in achieving WPV eradication, poor management of OPV cessation, and decisions that increase costs diminish the overall expected INBs of the GPEI. In addition, alternative prospective vaccination strategies may lead to better or worse overall health and economic outcomes than considered here (Kalkowska & Thompson, 2020b). In addition, the results of GPEI policies in place at the beginning of 2020 imply further delay and raise questions about the feasibility of achieving WPV1 eradication and successful OPV cessation in the polio endgame. Further studies should explore prospective strategies that may more cost-effectively achieve polio eradication and improve health and financial outcomes for the polio endgame.

Reduced expected INBs of the GPEI combined with the substantial economic impacts of the COVID-19 pandemic pose large financial risks for the GPEI. This updated analysis suggests that the GPEI could still lead to substantial expected INBs if it achieves its objectives within the next few years and can focus on more cost-effective polio endgame strategies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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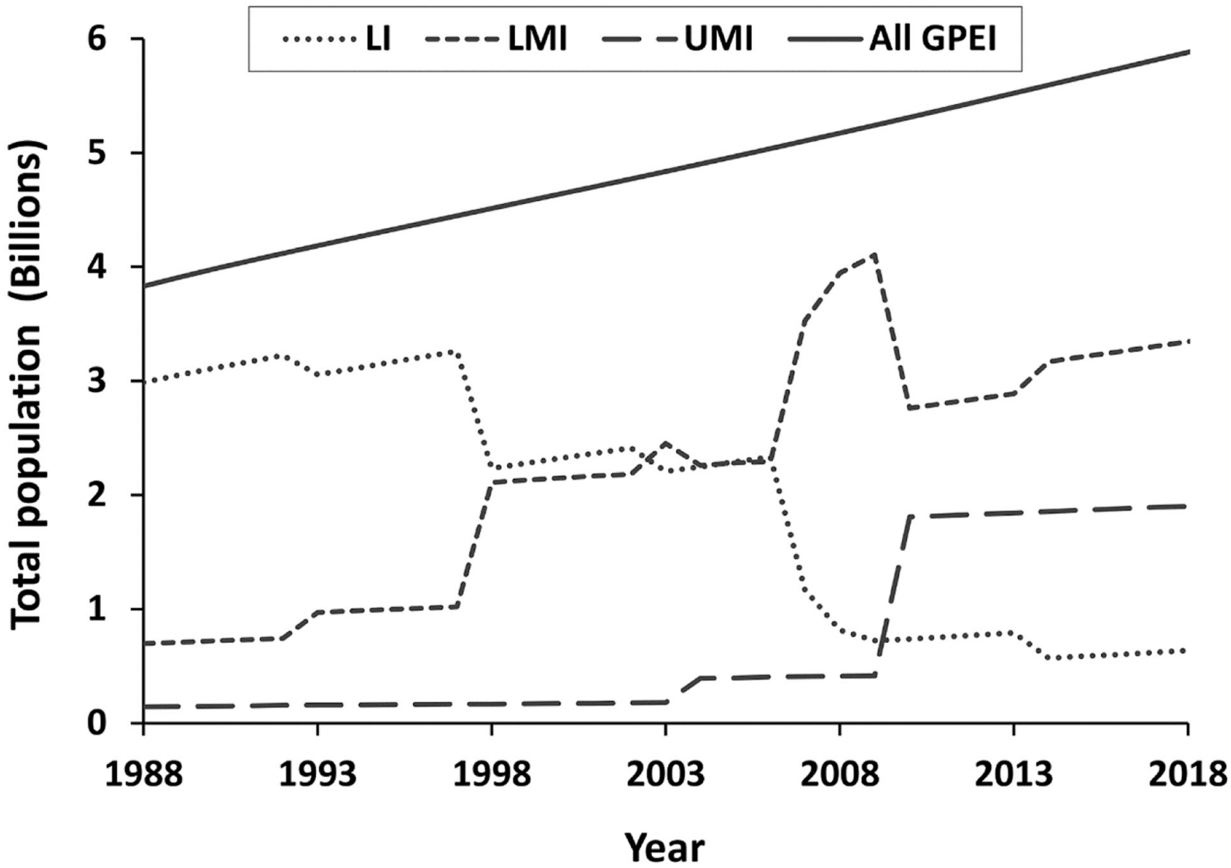

Fig. 1:
Population in GPEI countries by year and by World Bank Income Level
Abbreviations: GPEI, Global Polio Eradication Initiative; LI, low-income, LMI, lower middle-income; UMI, upper middle-income

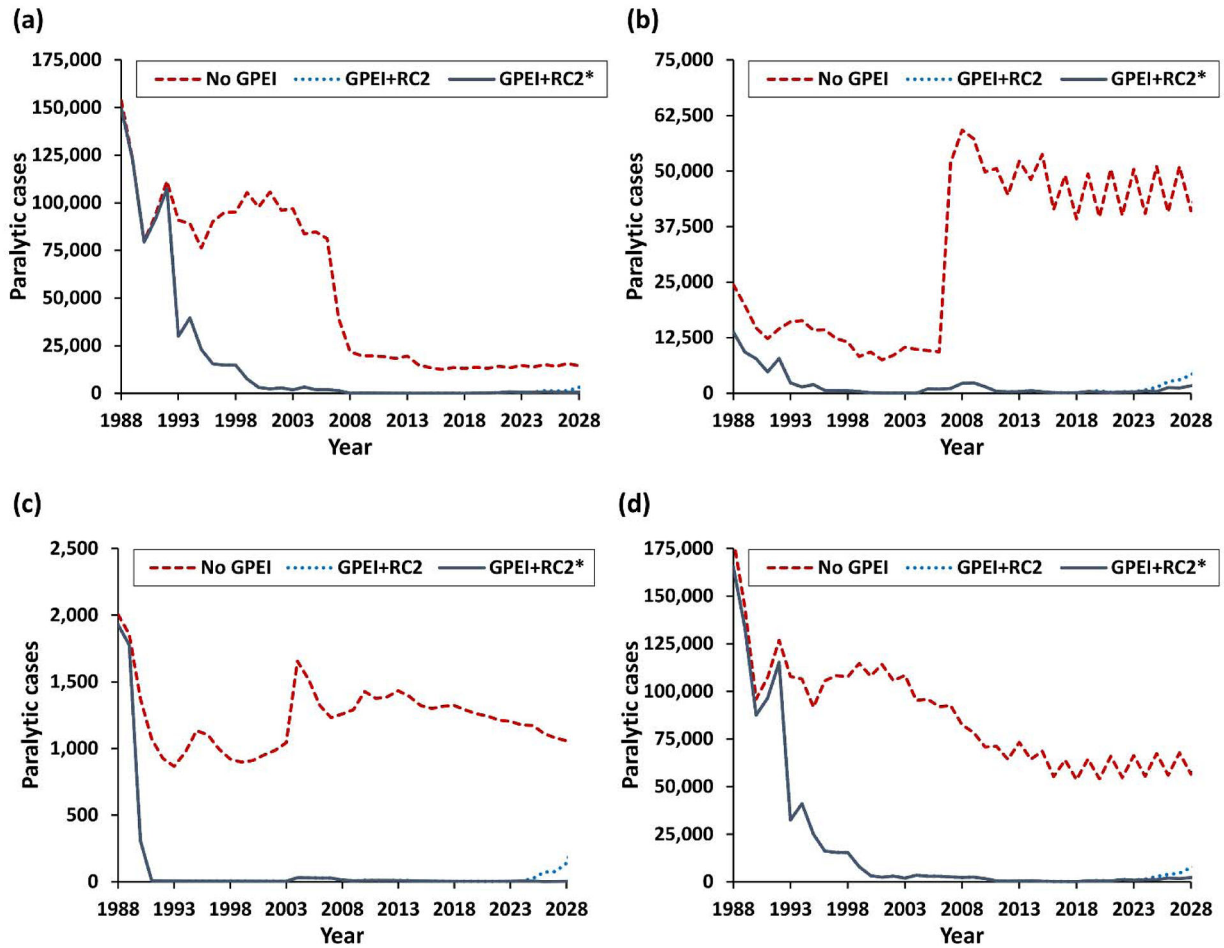

Fig. 2:

Estimated paralytic polio incidence for the different scenarios by year for (a) LI, (b) LMI, (c) UMI, and (d) All GPEI countries

Note: The scales on the y-axes differ across panels

Abbreviations: GPEI, Global Polio Eradication Initiative; LI, low-income, LMI, lower middle-income; RC2, reference case; RC2*, alternative reference case; UMI, upper middle-income

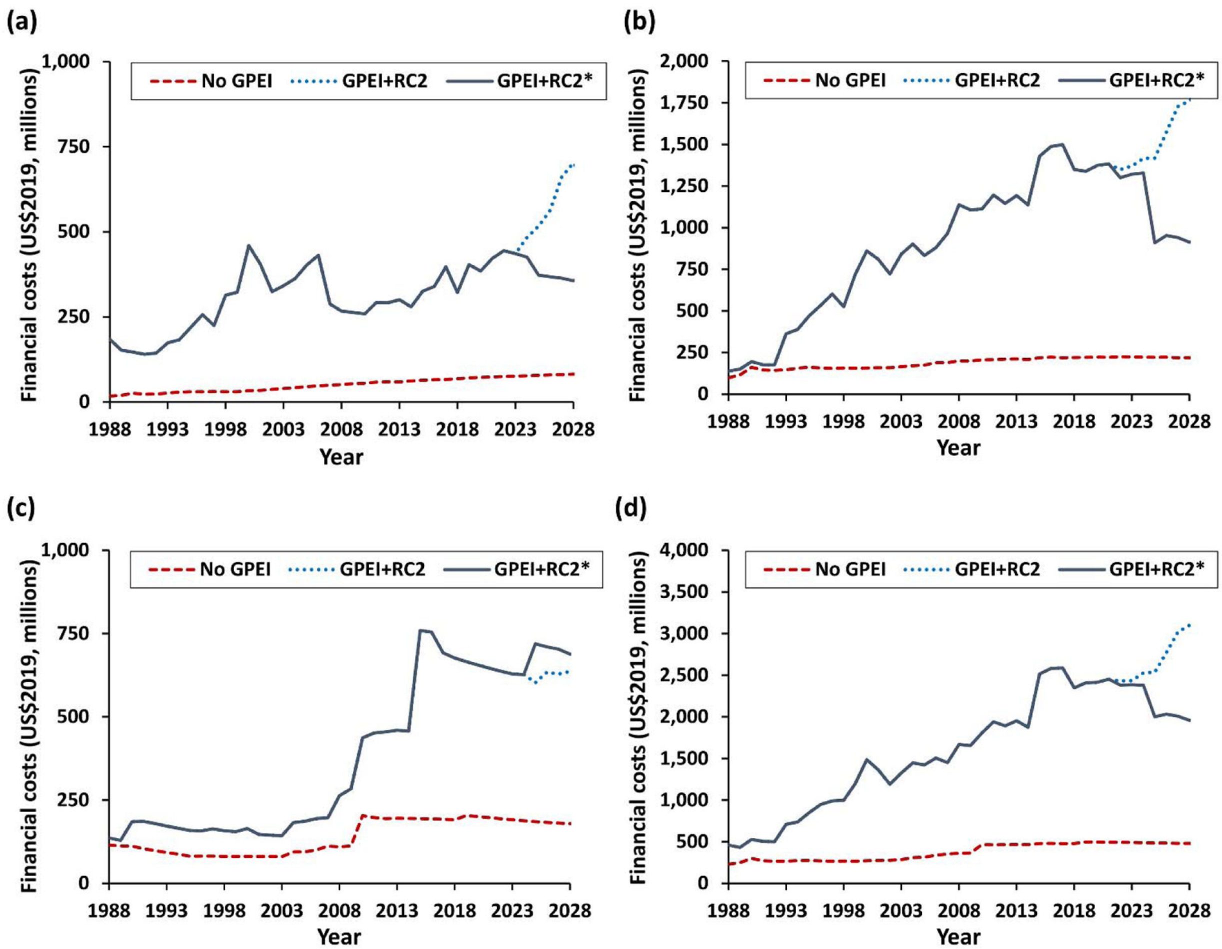

Fig. 3:

Financial cost estimates (2019$US) (excluding health-related and treatment costs) for the different scenarios by year for (a) LI, (b) LMI, (c) UMI, and (d) All GPEI countries

Note: The scales on the y-axes differ across panels

Abbreviations: GPEI, Global Polio Eradication Initiative; RC2, reference case; RC2*, alternative reference case

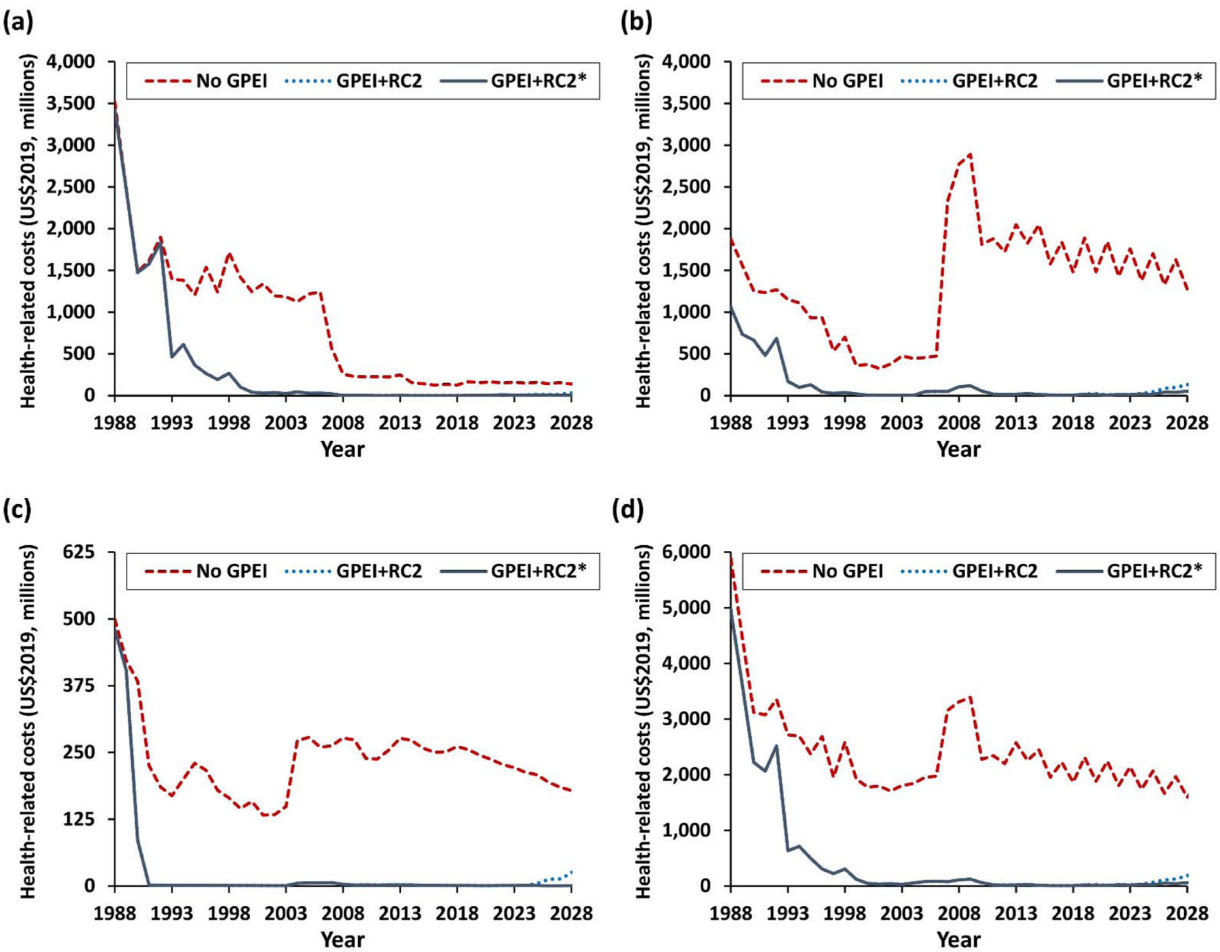

Fig. 4:

Monetized health-related cost estimates (including treatment costs) (US$2019) for the different scenarios by year for (a) LI, (b) LMI, (c) UMI, and (d) All GPEI countries

Note: The scales on the y-axes differ across panels

Abbreviations: GPEI, Global Polio Eradication Initiative; RC2, reference case; RC2*, alternative reference case

Table 1:

Model structure related to the population included and breakdown by World Bank Income Level (WBIL)

(a) Population distribution in T_{GPEI}=1988 and T_0=2019				
Category	**No. countries T_{GPEI}=1988**	**Total population T_{GPEI}=1988**	**No. countries T_0=2019**	**Total population T_0=2019**
GPEI	105	3,727 M	105	5,868 M
LI	50	2,909 M	30	713 M
LMI	46	644 M	42	3,025 M
UMI	9	174 M	33	2,101 M
(b) Distribution of countries by block and 2019 WBIL and by GPEI country status				
	Total blocks	**Blocks with no GPEI countries**	**Blocks with some GPEI countries**	**Blocks with only GPEI countries**
Blocks	72	15	7	50
LI	6	0	0	6
LMI	28	1	0	27
UMI	27	5	5	17
HI	11	9	2*	0

Notes:

*2 blocks counted overall as HI for 2019 prospective analyses (Kalkowska, Wassilak, et al., 2020) include UMI countries, which for purposes of this analysis we count as UMI blocks and only consider a fraction of the block for the GPEI countries

Abbreviations: GPEI, Global Polio Eradication Initiative; HI, high-income; LI, low-income; LMI, lower middle-income; UMI, upper middle-income

Table 2:

Expected vaccine costs and cases (US$2019)

Vaccine policies compared (time period)	Cumulative vaccination costs (US$2019 billions)		Expected cumulative paralytic polio cases		Incremental paralytic polio cases prevented	Incremental financial costs (US$2019 billions)	Incremental health-related savings (US $2019 billions)
	RC	**No GPEI**	**RC**	**No GPEI**			
GPEI vs. no GPEI (1988 – 2018)							
LI	3.3	1.3	715,914	2,074,813	1,358,898	8.0	18.8
LMI	17.7	5.4	63,815	840,874	777,059	20.5	35.4
UMI	7.5	3.8	4,308	38,556	34,248	5.2	6.5
Total	**28.5**	**10.6**	**784,037**	**2,954,243**	**2,170,206**	**33.8**	**60.6**
RC2 vs. no GPEI (2019 – 2029)							
LI	4.1	0.8	12,826	158,283	145,457	5.0	1.6
LMI	12.0	2.4	19,894	505,598	485,704	14.6	16.6
UMI	6.4	2.1	743	12,869	12,125	5.0	2.2
Total	**22.5**	**5.4**	**33,463**	**676,750**	**643,286**	**24.5**	**20.4**
RC2* vs. no GPEI (2019 – 2029)							
LI	2.8	0.8	6,238	158,283	152,044	3.7	1.6
LMI	8.3	2.4	8,719	505,598	496,879	10.7	17.0
UMI	6.8	2.1	54	12,869	12,815	5.3	2.3
Total	**17.8**	**5.4**	**15,011**	**676,750**	**661,738**	**19.7**	**20.9**
GPEI + RC2 vs. no GPEI (1988 – 2029)							
LI	7.4	2.2	728,740	2,233,096	1,504,355	13.0	20.3
LMI	29.8	7.9	83,709	1,346,472	1,262,763	35.1	52.0
UMI	13.8	5.9	5,051	51,425	46,374	10.2	8.7
Total	**51.0**	**15.9**	**817,501**	**3,630,993**	**2,813,492**	**58.3**	**81.1**
GPEI + RC2* vs. no GPEI (1988 – 2029)							
LI	6.1	2.2	722,153	2,233,096	1,510,943	11.7	20.4
LMI	26.0	7.9	72,534	1,346,472	1,273,938	31.2	52.4
UMI	14.2	5.9	4,362	51,425	47,063	10.6	8.8
Total	**46.3**	**15.9**	**799,049**	**3,630,993**	**2,831,944**	**53.5**	**81.6**

Abbreviations: DALY, disability-adjusted life year; GPEI, Global Polio Eradication Initiative; ICER, Incremental cost-effectiveness ratio; INB, Incremental net benefits; LI, low income; LMI, lower middle-income; NA, not analyzed; RC2, reference case; RC2*, alternative reference case; UMI, upper middle-income

Table 3:

Economic analysis results (US$2019)

Vaccine policies compared (time period)	Incremental cost-effectiveness ratio (ICER)		ICER comparator threshold ($/DALY)		Incremental net benefits (INBs) (US$2019 billions)
	Per paralytic polio case (US$2019/case)	Per DALY (US$2019/ DALY)	Health opportunity cost approximation	Assuming 1 GNI per capita per DALY	
GPEI vs. no GPEI (1988 – 2018)					
LI	5,194	278	143	713	10.8
LMI	19,296	1,150	466	2332	14.9
UMI	81,936	4,488	3876	6461	1.3
Total	NA	NA	NA	NA	**26.9**
RC2 vs. no GPEI (2019 – 2029)					
LI	33,521	2,907	173	866	−3.4
LMI	22,887	1,947	462	2,310	2.1
UMI	338,764	27,748	5,484	9,140	−2.8
Total	NA	NA	NA	NA	**−4.1**
RC2* vs. no GPEI (2019 – 2029)					
LI	23,342	2,034	173	866	−2.0
LMI	14,418	1,229	462	2,310	6.3
UMI	344,195	28,389	5,484	9,140	−3.0
Total	NA	NA	NA	NA	**1.3**
GPEI + RC2 vs. no GPEI (1988 – 2029)					
LI	7,933	441	151	753	7.3
LMI	20,677	1,393	465	2326	16.9
UMI	149,089	8,940	4297	7162	−1.5
Total	NA	NA	NA	NA	**22,8**
GPEI + RC2* vs. no GPEI (1988 – 2029)					
LI	7,020	391	151	753	8.7
LMI	17,393	1,174	465	2326	21.1
UMI	153,347	9,244	4297	7162	−1.7
Total	NA	NA	NA	NA	**28.1**

Abbreviations: DALY, disability-adjusted life year; GPEI, Global Polio Eradication Initiative; ICER, Incremental cost-effectiveness ratio; INB, Incremental net benefits; LI, low income; LMI, lower middle-income; NA, not applicable; RC2, reference case; RC2*, alternative reference case; UMI, upper middle-income