Abstract

Objectives: Vaccination has prevented millions of deaths and cases of disease in low- and middle-income countries (LMICs). During the Decade of Vaccines (2011-2020), international organizations, including the World Health Organization and Gavi, the Vaccine Alliance, focused on new vaccine introduction and expanded coverage of existing vaccines. As Gavi, other organizations, and country governments look to the future, we aimed to estimate the economic benefits of immunization programs made from 2011 to 2020 and potential gains in the future decade.

Methods: We used estimates of cases and deaths averted by vaccines against 10 pathogens in 94 LMICs to estimate the economic value of immunization. We applied 3 approaches—cost of illness averted (COI), value of statistical life (VSL), and value of statistical life-year (VSLY)—to estimate observable and unobservable economic benefits between 2011 and 2030.

Results: From 2011 to 2030, immunization would avert $1510.4 billion ($674.3-$2643.2 billion) (2018 USD) in costs of illness in the 94 modeled countries, compared with the counterfactual of no vaccination. Using the VSL approach, immunization would generate $3436.7 billion ($1615.8-$5657.2 billion) in benefits. Applying the VSLY approach, $5662.7 billion ($2547.2-$9719.4) in benefits would be generated.

Conclusion: Vaccination has generated significant economic benefits in LMICs in the past decade. To reach predicted levels of economic benefits, countries and international donor organizations need to meet coverage projections outlined in the Gavi Operational Forecast. Estimates generated using the COI, VSL, or VSLY approach may be strategically used by donor agencies, decision makers, and advocates to inform investment cases and advocacy campaigns.

Keywords: cost of illness, immunization, productivity loss, value-of-statistical-life.
Introduction

The years 2011 to 2020 were designated as the Decade of Vaccines, a period when international organizations, such as the World Health Organization (WHO), Gavi, the Vaccine Alliance, and the scientific community came together to advocate for vaccines by accelerating, expanding, and improving access for every child. Significant progress has been made during the decade—global coverage of the second dose of measles-containing vaccines increased from 48% in 2010 to 69% in 2018, and 116 low- and middle-income countries (LMICs) introduced at least one new vaccine between 2010 and 2017. Despite these gains, sustained progress is fragile, as evidenced by frequent measles outbreaks and backslides in coverage, particularly in conflict zones. Recent research has continued to show that vaccines are a cost-effective intervention for preventing disease, deaths, and their associated costs in LMIC settings, but sustaining immunization programs requires continued commitment and funding. As the decade comes to a close, economic benefits, along with cases and deaths prevented, serve as goal-setting indicators for donors focused on further reducing the burden of vaccine-preventable diseases (VPDs). Past studies, including Ozawa et al (2011, 2017) and Stack et al (2011), that focused on the impact of vaccines in Gavi-eligible countries during the decade estimated significant economic gains attributable to vaccines. In 73 countries between 2011 and 2020, Ozawa et al estimated that vaccines against 10 pathogens would avert $250 billion ($190-$330) in costs and generate $600 billion ($420-$870) in broader economic benefits (2010 USD). New research estimates that immunization programs against 10 pathogens in 94 LMICs will require $71 billion ($57-$93) in investment from 2011 through 2030. A recent analysis of the return-on-investment (ROI) from immunization programs (using the estimates presented here) project the ROI to be $22 ($9-$42) for every dollar invested in immunization programs when considering direct and indirect costs of illness averted and $52 ($23-$90) when considering the broader economic benefits in 94 LMICs between 2011 and 2030. This study aims to refocus attention on economic benefits of vaccine programs by applying updated methodology and extending the analysis through the year 2030. By presenting alternative approaches for estimating economic benefits, the study will also inform goal setting for donor organizations.

We examine the economic impact of vaccination in 94 countries, including 73 current and former Gavi-supported countries (Appendix A in Supplemental Materials found at https://doi.org/10.1016/j.jval.2020.07.009), from 2011 to 2030. We assessed economic benefits of vaccination using 3 approaches: (1) cost of illness (COI) averted, which estimates observable economic benefits generated by
preventing VPDs, including direct medical costs, nonmedical costs, and productivity loss; (2) value of statistical life (VSL), which examines the broader economic benefits of averted deaths encompassed by individuals’ willingness to pay to reduce the risk of death, which may encompass noneconomic aspects of life, such as leisure or family bonds; and (3) value of statistical life-year (VSLY), which adjusts for the age at death of the affected individual. As decision makers face competing needs in health systems, examining economic benefits using multiple approaches is increasingly important and allows for comparability between investments in health and non-health interventions.

**Methods**

*Model Scope*

We modeled the economic benefits of Gavi-supported vaccines against 10 pathogens from 2011 to 2030 in 94 countries. The pathogens modeled, which are selected to monitor existing programs and inform future investment priorities, include Haemophilus influenzae type B, hepatitis B, human papillomavirus, Japanese encephalitis (JE), measles, Neisseria meningitidis serogroup A (Men A), rotavirus, rubella, Streptococcus pneumoniae, and yellow fever (YF) (Table 1). Our study builds on estimates of the cases and deaths averted by vaccines from the Vaccine Impact Modeling Consortium (VIMC). The VIMC coordinates modeling teams for each pathogen (Table 1, additional model specifications in Appendix B) and provides estimates to Gavi for program evaluation and goal setting. Historic coverage estimates are based on WHO/UNICEF Estimates of National Immunization Coverage (WUENIC), and projected coverage is outlined in Gavi’s Operational Forecast version 16. The Forecast projects coverage of new vaccines will reach the diphtheria-tetanus-pertussis coverage level within 3 years of introduction, followed by a 1% increase each year up to 90% or 95%, depending on historical vaccine coverage for that country. Population projections for each country are standardized across all models and are based on the United Nations World Population Prospects 2017 Revision. Health impact was modeled at the country level and not assumed to be correlated with rural or urban setting for most pathogens, with the exception of JE and YF. Cases and deaths averted were summed over the life course of the vaccinated population and reported in the year of vaccination, allowing economic benefits to be estimated for the specific year of vaccination. Impact projections are compared to deaths and cases caused by VPDs in a counterfactual scenario with no vaccination. All estimates were discounted to the year of vaccination at 3% and reported in 2018 USD and 2018 international dollars.
**COI Approach**

COI consists of treatment costs (facility fees, medications, and diagnostic costs), nonmedical costs (transportation), and productivity loss (caregiver absenteeism and reduced labor force participation due to disability and death). In the base case scenario for COI, we conservatively assumed all costs to be constant over the time horizon. Further sensitivity analysis was performed to explore the impact of these assumptions on the productivity loss estimates. Key model assumptions are outlined in Appendix C.

Treatment costs averted were calculated based on how many cases would have sought care at health facilities. Care-seeking rates from Demographic and Health Surveys (DHS) and Multi-Indicator Cluster Surveys (MICS) were used to estimate the proportion of care-seeking cases for each syndrome modeled, with the number of visits and hospital admittance rates extracted from literature reviews. Facility costs formed the basis for estimating treatment costs averted. Country- and level-specific facility costs were modeled using the WHO-CHOICE regression framework, using gross domestic product (GDP) per capita and exchange rates from 2017, the most recent year available. Costs were inflated to 2018 local currency units and converted to USD. Treatment costs were adjusted to rural or urban location by applying the proportion of urban population for each country to the number of care-seeking cases averted. The resulting facility costs were multiplied by the number of care-seeking cases. For inpatient cases, the per diem facility cost was multiplied by the average length of stay. Additional costs of medications and diagnostics were estimated as a proportion (25%-50%) of total facility fees for all pathogens excluding JE, for which treatment costs were extrapolated from four studies. Based on a recent systematic review, proportions used to estimate medication and diagnostic costs yielded a conservative estimate of these costs.

Transportation costs of patients traveling to and from a health facility were estimated by multiplying the country-specific average cost per trip by the number of visits per care-seeking case averted. Transportation costs were assumed to be the same for inpatient and outpatient cases.

Productivity loss includes short-term costs, such as absenteeism from caregivers and long-term costs associated with a reduced workforce due to death and disability. For short-term productivity loss, caregiver wages lost were estimated for syndromes impacting children under 15 years. We assumed caregivers would lose a half-day’s wages per outpatient visit and a full day’s wages per day spent in inpatient
care. Country-specific minimum wage\textsuperscript{32,33} was used as a conservative proxy for the value of a lost workday, because many caregivers in LMICs may work in the home or in a low-wage occupation.

Productivity loss averted reflects the economic value that vaccinated individuals contribute to society because of the absence of vaccine-preventable disability and death. We used a human capital approach\textsuperscript{34} in which the value of lost productive years was multiplied by the life-years lost as a result of disability or death. Data on average wage is limited in LMICs, so 2018 GDP per capita\textsuperscript{35} was used as a proxy for 1 year of productivity.

To estimate productive years lost, we restricted our calculation to life-years lost between ages 15 and 64 years, inclusive, based on the OECD definition of the working age population.\textsuperscript{36} Productive years lost due to death were calculated based on the difference between the average age of death for the modeled syndrome and the retirement age of 64. For countries and syndromes where the life expectancy at the age of disease onset was less than 64, the life expectancy was used for the maximum working age. For childhood diseases, cases and deaths were multiplied by the country-specific probability of survival to age 15 before estimating lost productivity to account for other possible causes of death prior to reaching the working age.\textsuperscript{16}

Years lived with disability were estimated based on the age of onset and duration of disability. For permanent disabilities, the number of affected years was estimated similarly to life-years lost as a result of death. The impact of long-term disability with onset prior to age 15 was multiplied by the probability of survival to age 15.\textsuperscript{16} Disability caused by acute illness was included if it occurred between the ages of 15 and 64. Discounted years lived with disability for each syndrome were multiplied by the relevant disability weight from the 2016 Global Burden of Disease study (Appendix C in Supplemental Material found at https://doi.org/10.1016/j.jval.2020.07.009) and GDP per capita.\textsuperscript{37}

In the baseline productivity loss calculation, all costs were held constant over the time horizon owing to the lack of data on projected wage growth in LMICs. One hundred percent labor force participation was applied to account for unpaid productive contributions and the large informal workforce, which comprises approximately 70\% of workers in LMICs and is not included in official labor-force participation rates.\textsuperscript{38}
Because productivity loss comprises the majority of COI, we explored different assumptions through 1-way sensitivity analysis. Four alternative assumptions were considered: 2 assessing for the value of productivity and 2 examining years of productivity. The 4 variations explored are listed below.

1. The value of productivity was assumed to grow at the rate of real GDP per capita\textsuperscript{39} to reflect the increasing value of productivity over time.

2. Productivity loss was valued using annual minimum wage\textsuperscript{32,33} instead of GDP per capita.

3. Productivity for individuals over age 64 was included by counting years from age 15 until the end of life\textsuperscript{16} to account for work after the retirement age.

4. Productive time was multiplied by the country-specific labor force participation rate\textsuperscript{32} instead of assuming 100\% for labor force participation.

Probabilistic sensitivity analyses were conducted to assess uncertainty of key parameters: inpatient and outpatient facility costs, transportation costs, number of cases and deaths, and GDP per capita. Ten thousand model iterations were produced to generate 95\% confidence intervals around all point estimates.

\textit{VSL and VSLY Approaches}

VSL is commonly used in benefit–cost analyses and is derived from individuals’ willingness to pay for small reductions in mortality risk, which are averaged over a population to estimate the value of saving one life.\textsuperscript{40} When considering willingness to pay to reduce mortality risk, individuals likely include the value of intangible aspects of life, such as leisure time, happiness, and passing knowledge to the next generation, thus providing a broader perspective of the value of averted mortality than the COI approach.\textsuperscript{40}

Owing to the limited availability of direct VSL estimates in LMICs, we applied the value-transfer method outlined in the Reference Case Guidelines for Benefit-Cost Analysis in Global Health and Development.\textsuperscript{40} The value-transfer method adjusts VSL from a high-income setting to a low-income setting based on the income ratio between the target and reference countries. The ratio is raised to the income elasticity for the value of reducing mortality risk, which is conservatively estimated at 1.5.\textsuperscript{41} We used a U.S. VSL of 160 times GDP per capita or $10,002,805 in 2018 as the reference.\textsuperscript{40}
For 31 very low-income countries, the value-transfer approach yielded values below 20 times GDP per capita, approximately the value of future earnings for a person of average age in a population. This is unrealistic because VSL is intended to capture monetary and nonmonetary aspects of life. As a result, we imputed 20 times GDP per capita as a minimum VSL. 40

VSLs were estimated for the expected year of death averted, rather than the year of vaccination, by applying a real growth rate39 to GDP per capita values (for both the target and reference countries) used in the value-transfer approach. The VSL for the year of impact was multiplied by the number of deaths averted and discounted to the year of vaccination.

The standard VSL approach applies the same value to all lives saved within a country regardless of age, which may underestimate the value of saving children’s lives and overestimate the value societies place on saving adult lives. Because the pathogens modeled in this analysis disproportionately impact children, we also estimated economic benefits using VSLY. VSLY approximates the marginal rate of substitution between one additional life-year and other goods and services.40 VSLY is derived from VSL by dividing the country-specific value by the undiscounted remaining life-years for an individual of average age in the population. VSLY is then multiplied by remaining life-years at the age of death. For child deaths, this results in a larger VSL than under the standard VSL approach because a greater number of life-years are lost. Likewise, for deaths occurring at older ages, the adjusted VSL is lower than under the standard approach.

Probabilistic sensitivity analysis was performed by varying the two primary inputs to the VSL and VSLY approaches: cases and deaths averted and GDP per capita. Ninety-five percent confidence intervals were generated based on 10 000 model iterations.

All primary results were generated using both USD and PPP-adjusted42 international dollars. International dollars represent the value of a prespecified basket of goods and services in the target country if comparable goods and services were purchased in the United States. Results for VSL and VSLY
estimated in inter-national dollars reflect the tradeoffs individuals are willing to make to reduce mortality risk accounting for purchasing power differences between the countries modeled.

**Results**

Using the COI approach, we estimated that immunization programs would avert $681.9 billion USD (95% CI $300.1-$1202.5 billion) in costs associated with VPDs between 2011 and 2020 in 94 LMICs and $828.5 billion from 2021 to 2030 (Table 2). Most of the benefits would accrue in the 73 current and former Gavi countries included in the model, with estimated benefits reaching $639.1 billion ($208.3-$1127.9 billion) from 2011 to 2020 and $781.6 billion ($351.8-$1356.3 billion) from 2021 to 2030.

Total short-term costs averted comprise just over 1% of COI averted, with treatment costs totaling $12.3 billion, or 0.8% of COI averted over 2 decades (Table 3). Productivity loss averted was the largest component of economic benefits from immunization programs, accounting for 98.9% of costs averted over the same time horizon. From 2011 to 2030, we estimated that 2758.8 million (1896.0-4403.0 million) and 250.1 million (193.3-355.7 million) undiscounted life-years between ages 15 and 64 were saved by death and disability averted, respectively (Appendix D in Supplemental Material found at https://doi.org/10.1016/j.jval.2020.07.009). Under baseline assumptions, productivity loss averted was valued at $1,494.1 billion ($652.8-$2636.7 billion) (Appendix D in Supplemental Material found at https://doi.org/10.1016/j.jval.2020.07.009).

Sensitivity analysis for productivity loss showed that estimates are highly sensitive to assumptions. Applying a growth rate to GDP per capita (variation 1) yielded productivity loss estimates of $3416.6 billion ($1537.5-$5936.6 billion) from 2011 to 2030, or 128.9% higher than the baseline results. Variation 2, using minimum wage to value productivity yielded the lowest estimate of all approaches, totaling $799.1 billion ($355.9-$1396.8 billion) for the same time period. Including productivity for all remaining life-years (variation 3) generated estimates 6.3% higher than the baseline estimates, amounting to $1587.6 billion ($681.6-$2700.8 billion). Applying the country-specific labor force participation rate (variation 4) restricted the productive years included in the estimate. This approach yielded productivity loss estimates of $867.8 billion ($383.9-$1523.8 billion). Figure 1 shows each variation relative to the primary estimates for productivity loss. Owing to large uncertainty ranges for cases and deaths averted and GDP per capita, confidence intervals for variations 3 and 4 overlap the baseline estimate.
As expected, the VSL approach, which reflects the value society places on saving lives, generated higher estimates of economic benefits than the COI approach. Using 2018 USD, we estimated that $1311.6 billion (607.0-$2203.4 billion) in benefits would accrue from 2011 to 2020 in 94 LMICs and $2125.1 billion ($1007.3-$3462.4 billion) from 2021 to 2030 owing to immunization (Table 2).

Because most vaccines included in the analysis impact children, the VSLY approach generated the highest estimates of benefits owing to immunization programs. Between 2011 and 2020, an estimated $2219.2 billion ($981.6-$3857.6 billion) in benefits were generated from immunization. From 2021 to 2030, $3443.4 billion ($1565.6-$5861.8 billion) in economic benefits are attributable to immunization (Table 2). Appendix E (in Supplemental Material found at https://doi.org/10.1016/j.jval.2020.07.009) contains a graphical comparison of results.

**Discussion**

These results demonstrate the large positive impact of vaccine use in LMICs over 2 decades. Framed in the context of overall economic activity in these countries, which was approximately $75.2 trillion from 2011 to 2020, economic benefits from vaccines equate to 0.9% of GDP for these countries during this decade using the COI method, and 1.7% and 3.0% using the VSL and VSLY approaches, respectively.

All methods modeled show total economic benefits increasing over time due to increases in deaths and cases averted by immunization (Fig. 2). Increases in cases and deaths averted by vaccination are attributable to improvements in vaccine coverage, introduction of new vaccines, and population growth.

Using the COI approach, estimated treatment costs averted account for less than 1% of total economic benefits but represent a critical component of economic benefits because they are directly observed in the health system. Treatment costs averted from preventing VPDs reflect freed-up resources for addressing other health needs or improving the quality of care. Lost caregiver wages and transportation costs averted also comprise a minor part of total economic benefits (0.14% and 0.13% from 2011 to 2030, respectively), but they represent financial risk protection for the poorest families, who are disproportionately impacted by VPDs.

Productivity loss comprises the largest component of economic benefits in the COI approach (98.9%), reflecting the gross impact on the labor force. The value of productivity suggests that death and
disability caused by VPDs would have a lasting and significant effect on macroeconomic productivity. As shown in Figure 1, productivity loss estimates are sensitive to these assumptions. The large variation in estimated productivity loss shows that exploring assumptions and methodological choices is important when using economic assessments to inform priorities. Despite the range of estimates shown, each alternative assumption introduces limitations to the estimate. Variation 1 may overestimate productivity loss because the growth of labor productivity may fall short of real GDP per capita growth. Using minimum wage to value productivity likely underestimates the average wage of those affected by vaccines. Including productivity beyond age 64 expands the scope of impact beyond the working age population, which may be less relevant to decision makers. Applying the labor force participation rate excludes workers in the informal sector, which comprise a significant component of the workforce in many LMICs. Although the difference in magnitude between each variation is large, all estimates comprise at least 98.0% of COI averted (Appendix F in Supplemental Material found at https://doi.org/10.1016/j.jval.2020.07.009).

COI is a conservative method of estimating vaccine impact because it only includes the observable costs and does not account for the value individuals place on reducing mortality risk. VSL is a distinct method for estimating economic benefits that does not attempt to directly measure the costs averted; rather, it reflects the value individuals place on averted illness and, as such, is a measure of benefits reflecting purely the demand side of the economy. VSL can be used to compare mortality risk-reducing interventions across sectors. Benefits estimated using the VSL approach are greater than the COI approach, suggesting that the value individuals place on averting mortality from VPDs far exceeds economic gains strictly derived from cost savings.

The primary method for estimating VSL benefits places equal value on lives saved, regardless of age. This differs from both COI and VSLY approaches, which are functions of life-years lost. Age at death averted further impacts results using the COI approach because productivity loss is excluded for individuals over 64 years. These methodological differences significantly affect the estimated value HepB and HPV averted, which primarily impact individuals over age 50. Although the number of deaths averted from HPV and HepB are significant, these pathogens contribute less to overall life-years lost than other modeled pathogens. Using the VSL approach, HepB and HPV comprise 26.7% of economic benefits over the time horizon, compared to 11.6% using the VSLY approach and 4.9% using the COI approach (Fig. 3).

Our analysis has several limitations. The primary limitation stems from uncertainty surrounding the potential double counting of averted deaths and cases of long-term disability. Because pathogens are modeled independently with common demographic inputs, there is some risk that vaccines may save one
individual’s life from 2 or more pathogens. The VIMC does not adjust for this effect because the absolute proportion of the population whose death is caused by these VPDs is small, and the overall impact may be limited. Further research to assess the degree of double counting on the health impact estimates is ongoing. In this analysis, estimates for productivity loss are adjusted for all-cause mortality before reaching age 15, which may correct for some of this effect.

There is high uncertainty in the estimates of cases and deaths averted by vaccines compared to the counterfactual with no vaccination. Disease burden in the counterfactual scenario is based largely on epidemiologic studies before vaccine introduction, and impacts of mortality reductions as a result of improvements in treatment are conservatively modeled. Additionally, most epidemiologic parameters and vaccine coverage estimates are estimated at the country level, but subnational variation may have a significant impact on cases and deaths averted.

As is common in LMICs, we encountered data limitations for facility and treatment costs. Data from empirical studies may not have been generalizable at the country level, so we used modeled data and inflated facility costs to estimate treatment costs, following the method used in previous analyses of vaccine-derived economic benefits. This approach has a small impact on the results but introduces uncertainty in short-term costs averted. Additionally, our analysis does not account for temporal changes in costs or care-seeking.

Modeling attempts to bridge the gap between complete knowledge and a lack of empirical data but renders our estimates sensitive to assumptions. Although our primary method for estimating productivity builds on those used in past studies, our estimates are sensitive to assumptions surrounding labor force participation, wage, and age restrictions. We attempted to address some of these uncertainties through 1-way sensitivity analysis, but other factors such as potential labor surpluses in LMICs and the impact on per-person productivity after population growth were not accounted for.

VSL and VSLY estimates rely on the value-transfer approach for adapting VSLs in high-income settings to LMICs. Empirical evidence on the income elasticity for health is limited, but emerging evidence suggests the elasticity may be closer to 1.0 than 1.5, which would conservatively bias our results. Furthermore, VSL and VSLY approaches may underestimate true economic benefits because they exclude the value of disability averted.
Lastly, our models are unable to estimate the incremental impact of scaling up vaccinations. These estimates can only be used to infer the total value of vaccine programs compared to no vaccination. Despite these limitations, this analysis offers insight into the significant economic benefits made possible by immunization.

This analysis builds on vaccine impact estimates that are currently available from VIMC. Future research should include generating evidence for other existing vaccines (e.g., DTP and polio) and new vaccines (e.g., typhoid and cholera). We applied updated data and methodology to estimate the economic benefits of immunization programs. These results have been used for goal setting by international NGOs, and the application of VSL and VSLY approaches allows for comparing the benefits of immunization to other interventions that impact mortality.

Conclusion

Our study shows that immunization programs in LMICs generate significant economic gains at the global level. Estimates generated using the COI, VSL, or VSLY approach may be strategically used for different purposes. The COI estimates are consistent with Gavi projections and can be used by the global immunization community. Each method adds insight when comparing the value of vaccines to other interventions. The economic benefits projected here will be achieved only provided there is adequate government and donor investment in vaccines to meet the projected coverage levels in the next decade. Investment in immunization programs will have a lasting and significant impact on the economies in LMICs.

Supplemental Material:
Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.jval.2020.07.009.

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Authors’ Contributions:
EW collected data, built the models, generated, and analyzed results and drafted the manuscript. SSY provided feedback on methodology, validated model results, and contributed to writing the manuscript. DC oversaw the initial phase of the analysis and provided feedback on methodology and data inputs. SS standardized data inputs, assisted in performing sensitivity analysis, and compiled results for tables and figures. LB conceptualized the project and contributed feedback on the methodology and data inputs. BP oversaw the analysis. All authors provided critical feedback to the manuscript.

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REFERENCES


### Table 1. Vaccine preventable pathogens and vaccine delivery strategies.

<table>
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<tr>
<th>Vaccine</th>
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<th>Delivery Strategy</th>
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<tr>
<td>Hepatitis B (Hep B)†</td>
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DTP indicates xxx; HepB, hepatitis B; Hib, *Haemophilus influenzae* type b; JHU, Johns Hopkins University; SIA, supplementary immunization activities.

*Economic benefits based on estimates from Vaccine Impact Modeling Consortium focal models only.

†Hepatitis B and *Haemophilus influenzae* type b estimates based on coverage of pentavalent (DTP-HepB-Hib) vaccine; Hep B estimates exclude birth dose.

‡Rubella estimates based on coverage of measles-rubella vaccine.
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<td>($1131.6-4355.1)</td>
<td>($5711.2-3195.4)</td>
<td>($8701.7-32253.4)</td>
</tr>
<tr>
<td></td>
<td>2011-30</td>
<td>$1510.4</td>
<td>$3436.7</td>
<td>$5662.7</td>
<td>$4586.6</td>
<td>$19,267.4</td>
<td>$31,059.9</td>
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<td></td>
<td></td>
<td>($674.3-2643.2)</td>
<td>($1615.8-5657.2)</td>
<td>($2547.2-9719.4)</td>
<td>($2048.1-8035.5)</td>
<td>($9075.3-31550.7)</td>
<td>($14,037.3-53079.1)</td>
</tr>
<tr>
<td>73 Current and former Gavi countries</td>
<td>2011-20</td>
<td>$639.1</td>
<td>$1203.9</td>
<td>$2056.4</td>
<td>$1947.4</td>
<td>$6636.8</td>
<td>$11,065.8</td>
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<td></td>
<td></td>
<td>($279.9-1137.0)</td>
<td>($356.1-2027.0)</td>
<td>($906.5-3982.0)</td>
<td>($855.3-3439.3)</td>
<td>($3071.9-11108.5)</td>
<td>($4898.1-19204.3)</td>
</tr>
<tr>
<td></td>
<td>2021-30</td>
<td>$781.6</td>
<td>$1977.8</td>
<td>$3219.5</td>
<td>$2352.9</td>
<td>$11,179.4</td>
<td>$17,753.1</td>
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<td>($351.5-1363.7)</td>
<td>($937.0-3230.4)</td>
<td>($1462.6-5489.8)</td>
<td>($1061.9-4090.4)</td>
<td>($5315.3-18100.6)</td>
<td>($8113.3-30086.4)</td>
</tr>
<tr>
<td></td>
<td>2011-30</td>
<td>$1421.8</td>
<td>$3181.8</td>
<td>$5275.8</td>
<td>$4300.3</td>
<td>$17,816.2</td>
<td>$28,818.9</td>
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<tr>
<td></td>
<td></td>
<td>($631.9-2485.6)</td>
<td>($1493.6-2535.9)</td>
<td>($2369.1-9072.3)</td>
<td>($1917.2-7529.7)</td>
<td>($8387.2-29209.1)</td>
<td>($13,011.3-7290.7)</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; COI, cost of illness; VSL, value of statistical life; VSLY, value of statistical life-year.

*Expressed in billions, using 2018 currency.

†Probabilistic sensitivity analysis was conducted by simultaneously varying five parameters for economic benefits and sampling 10,000 times to generate 95% confidence intervals.
Table 3. COI economic benefits by cost category in billions (2018 USD).

<table>
<thead>
<tr>
<th>Cost of illness averted</th>
<th>2011-2020</th>
<th>2021-2030</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total 94 (95% CI)</td>
<td>Gavi 73 (95% CI)</td>
</tr>
<tr>
<td></td>
<td>Proportion of total</td>
<td>Proportion of total</td>
</tr>
<tr>
<td>Treatment costs</td>
<td>$5.7 ($0.9-$17.1)</td>
<td>0.83%</td>
</tr>
<tr>
<td>Transportation costs</td>
<td>$1.0 ($0.1-$3.5)</td>
<td>0.15%</td>
</tr>
<tr>
<td>Caregiver wages lost</td>
<td>$0.9 ($0.8-$2.9)</td>
<td>0.13%</td>
</tr>
<tr>
<td>Productivity loss due to disability</td>
<td>$39.8 ($17.9-$71.3)</td>
<td>5.84%</td>
</tr>
<tr>
<td>Productivity loss due to death</td>
<td>$634.5 ($275.6-$1135.4)</td>
<td>93.05%</td>
</tr>
<tr>
<td>Total</td>
<td>$681.9 ($300.4-$1212.0)</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Results of sensitivity analysis compared with the baseline estimates for productivity loss, 2011 to 2030.
Figure 2. Estimated economic benefits and deaths averted by immunization using cost of illness, value of statistical life, and value of statistical life-year approaches, 2011 to 2030.
Figure 3. Proportion of benefits attributable to human papillomavirus and hepatitis B vaccinations by estimation strategy. *Other pathogens include: haemophilus influenzae type B, Japanese encephalitis, measles, meningococcal conjugate serotype A, rotavirus, rubella, streptococcus pneumoniae, and yellow fever.