Appendix A. List of countries included in the economic benefits models.

Table A1. List of countries included in the economic benefits models.

Country	WHO Region	World Bank Income Group	Gavi Transition classification
		2018	2018
Afghanistan	EMRO	Low-income	Initial self-financing
Angola	AFRO	Lower-middle income	Fully self-financing
Armenia	EURO	Upper-middle income	Fully self-financing
Azerbaijan	EURO	Upper-middle income	Fully self-financing
Bangladesh	SEARO	Lower-middle income	Preparatory transition phase
Belize	AMRO	Upper-middle income	Not eligible
Benin	AFRO	Low-income	Initial self-financing
Bhutan	SEARO	Lower-middle income	Fully self-financing
Bolivia	AMRO	Lower-middle income	Fully self-financing
Burkina Faso	AFRO	Low-income	Initial self-financing
Burundi	AFRO	Low-income	Initial self-financing
Cambodia	WPRO	Lower-middle income	Preparatory transition phase
Cameroon	AFRO	Lower-middle income	Preparatory transition phase
Cape Verde	AFRO	Lower-middle income	Not eligible
Central African Republic	AFRO	Low-income	Initial self-financing
Chad	AFRO	Low-income	Initial self-financing
Comoros	AFRO	Low-income	Initial self-financing
Congo, Dem. Rep.	AFRO	Low-income	Initial self-financing
Congo	AFRO	Lower-middle income	Fully self-financing
Cote d'Ivoire	AFRO	Lower-middle income	Preparatory transition phase
Cuba	AMRO	Upper-middle income	Fully self-financing
Djibouti	EMRO	Lower-middle income	Preparatory transition phase
Egypt	EMRO	Lower-middle income	Not eligible
El Salvador	AMRO	Lower-middle income	Not eligible
Eritrea	AFRO	Low-income	Initial self-financing
Ethiopia	AFRO	Low-income	Initial self-financing
Fiji	WPRO	Upper-middle income	Not eligible
Gambia	AFRO	Low-income	Initial self-financing
Georgia	EURO	Lower-middle income	Fully self-financing
Ghana	AFRO	Lower-middle income	Preparatory transition phase
Guatemala	AMRO	Upper-middle income	Not eligible
Guinea	AFRO	Low-income	Initial self-financing
Guinea-Bissau	AFRO	Low-income	Initial self-financing
Guyana	AMRO	Upper-middle income	Fully self-financing
Haiti	AMRO	Low-income	Initial self-financing
Honduras	AMRO	Lower-middle income	Fully self-financing
India	SEARO	Lower-middle income	Accelerated transition phase
Indonesia	SEARO	Lower-middle income	Fully self-financing
Iraq	EMRO	Upper-middle income	Not eligible
Kenya	AFRO	Lower-middle income	Preparatory transition phase
Kiribati	WPRO	Lower-middle income	Fully self-financing
Korea, DPR	SEARO	Low-income	Initial self-financing
Kosovo	EURO	Lower-middle income	Not eligible
Kyrgyzstan	EURO	Lower-middle income	Preparatory transition phase
Lao PDR	WPRO	Lower-middle income	Accelerated transition phase
Lesotho	AFRO	Lower-middle income	Preparatory transition phase
Liberia	AFRO	Low-income	Initial self-financing
Madagascar	AFRO	Low-income	Initial self-financing

Malawi	AFRO	Low-income	Initial self-financing
Mali	AFRO	Low-income	Initial self-financing
Marshall Islands	WPRO	Upper-middle income	Not eligible
Mauritania	AFRO	Lower-middle income	Preparatory transition phase
Micronesia	WPRO	Lower-middle income	Not eligible
Moldova	EURO	Lower-middle income	Fully self-financing
Mongolia	WPRO	Lower-middle income	Fully self-financing
Morocco	EMRO	Lower-middle income	Not eligible
Mozambique	AFRO	Low-income	Initial self-financing
Myanmar	SEARO	Lower-middle income	Preparatory transition phase
Nepal	SEARO	Low-income	Initial self-financing
Nicaragua	AMRO	Lower-middle income	Accelerated transition phase
Niger	AFRO	Low-income	Initial self-financing
Nigeria	AFRO	Lower-middle income	Accelerated transition phase
Pakistan	EMRO	Lower-middle income	Preparatory transition phase
Papua New Guinea	WPRO	Lower-middle income	Accelerated transition phase
Paraguay	AMRO	Upper-middle income	Not eligible
Philippines	WPRO	Lower-middle income	Not eligible
Rwanda	AFRO	Low-income	Initial self-financing
Samoa	WPRO	Upper-middle income	Not eligible
Sao Tome and Principe	AFRO	Lower-middle income	Accelerated transition phase
Senegal	AFRO	Low-income	Initial self-financing
Sierra Leone	AFRO	Low-income	Initial self-financing
Solomon Islands	WPRO	Lower-middle income	Accelerated transition phase
Somalia	EMRO	Low-income	Initial self-financing
Sri Lanka	SEARO	Lower-middle income	Fully self-financing
Sudan: North	EMRO	Lower-middle income	Preparatory transition phase
Sudan: South	AFRO	Low-income	Preparatory transition phase
Eswatini	AFRO	Lower-middle income	Not eligible
Syria	EMRO	Low-income	Not eligible
Tajikistan	EURO	Low-income	Preparatory transition phase
Tanzania	AFRO	Low-income	Initial self-financing
Timor-Leste	SEARO	Lower-middle income	Fully self-financing
Togo	AFRO	Low-income	Initial self-financing
Tonga	WPRO	Upper-middle income	Not eligible
Turkmenistan	EURO	Upper-middle income	Not eligible
Tuvalu	WPRO	Upper-middle income	Not eligible
Uganda	AFRO	Low-income	Initial self-financing
Ukraine	EURO	Lower-middle income	Fully self-financing
Uzbekistan	EURO	Lower-middle income	Accelerated transition phase
Vanuatu	WPRO	Lower-middle income	Not eligible
Viet Nam	WPRO	Lower-middle income	Accelerated transition phase
West Bank and Gaza	EMRO	Lower-middle income	Not eligible
Yemen	EMRO	Low-income	Preparatory transition phase
Zambia	AFRO	LMIC	Preparatory transition phase
Zimbabwe	AFRO	Low-income	Initial self-financing

Appendix B. List of health impact models and characteristics

Estimates of economic benefits used results from the 'focal' models in the Vaccine Impact Modeling Consortium (VIMC). Modelers and modeling teams that provided inputs for the analysis are listed in the table below. In mid-2019, VIMC began producing health impact estimates using averages of the 'focal' and 'non-focal' models., which will be available in a forthcoming publication. All models use data from the UN World Population Prospects, 2017 Revision to estimate the target population and demographic data. Coverage data is provided by the VIMC Secretariat, with historical coverage data based on WHO/UNICEF Estimates of National Immunization Coverage (WUENIC) and forecasted coverage estimated by Gavi.

Table B1. Overview of health impact models used in the economic benefits analysis (continued next page)

Pathogen	**HepB**	**Hib***	**HPV***	**JE**	**Measles**	**MenA***	**PCV***	**Rota***	**Rubella**	**YF***
Institution (Modelers/ Modeling team)	Independent (Xi Li)	Johns Hopkins University (Lives Saved Tool [LiST])	Harvard School of Public Health	Oxford University Clinical Research Unit (OUCRU) - Vietnam	Pennsylvania State University	Kaiser Permanente Washington Health Research Institute/Centers for Disease Control and Prevention	Johns Hopkins University (LiST)	Johns Hopkins University (LiST)	Public Health England	Imperial College London
Model character-istics	Static (no herd effects), deterministic	Static (no herd effects), deterministic, linear mathematical model	Static (no herd effects), cohort simulation	Dynamic (no herd effects), deterministic force of infection model	Dynamic, semi-mechanistic, discrete time-step annual SIR	Dynamic, stochastic, age-structured, compartmental transmission model	Static (no herd effects), deterministic, linear mathematical model	Static (no herd effects), deterministic, linear mathematical model	Dynamic, age and sex-structured, deterministic, compartmental model of transmission dynamics	Static force of infection model (no herd effects)
Syndromes included	Acute early hepatitis, acute late (>5 years) hepatitis, cirrhosis, hepatocellular carcinoma (HCC)	Pneumonia, meningitis	HPV-related cervical cancer	Symptomatic JE	Acute measles, encephalitis	Meningitis and sequelae	Pneumonia, meningitis	Severe diarrhea	Congenital rubella syndrome	Mild cases and severe hemorrhagic disease
Vaccine efficacy	95% for 3 doses; protection from partial immunization not modeled	93% for 3 doses; protection from partial immunization not modeled	100% with full dose schedule; lifelong immunity; protection from partial immunization not modeled	100% (single dose), lifelong immunity	First dose: 85% at age 9 months or 93% at age 12 months; second dose: 99%; campaign: 99%	First stage: 75% against colonization; 100% against invasive disease; second stage: 25% against colonization; 90% against disease	3 doses of PCV provides 58% efficacy against all serotypes of invasive pneumococcal disease;	Asia: 87.9%; North Africa: 87.9%; Southern Africa, West Africa, East Africa: 49.7%; Eastern Europe: 82%, Latin America: 81%	95% efficacy with lifelong protection	97.5% efficacy with lifelong protection
Age at vaccination	3 doses prior to age 1 year (economic benefits not modeled for birth dose)	3 doses prior to age 1 year	age 9 years	Routine: age 9 months; campaign: age 9 months-15 years	First dose: age 0; second dose: age 1; campaign dose age 9 months -15 years	Routine: 1 dose age 9 months; campaign: ages 1-29 years	3 doses prior to age 1 year	2 or 3 doses prior to age 1 year, depending on formulation	First dose: age 0 years; second dose: age 1 year; campaign dose age 9 months -15 years	Routine: 1 dose at 9 months; campaign dose age 9 months - 15 years

Pathogen	HepB	Hib*	HPV*	JE	Measles	MenA*	PCV*	Rota*	Rubella	YF*
Average age of infection	Early childhood: age 2.5 years; Late: age 17.5 years; Chronic disease asymptomatic until late adulthood	Prior to age 5 years (only childhood cases and deaths included in the model)	Disease onset at ages 50-56 years [varies by country]	Age 15-33 years [varies by country]	Susceptible at ages 2-25 years if not previously infected and never vaccinated [varies by country]	Routine: age 10-12 years [varies by country]; campaign age 30-31 years [varies by country]	Prior to age 5 years (only childhood cases and deaths included in the model)	Prior to age 5 years (only childhood cases and deaths included in the model)	Congenital rubella syndrome diagnosed in the perinatal period	Age 9-38 years [varies by country]
Case fatality ratio	70% for fulminant hepatitis, 100% for HCC	Applied using overall <5 mortality envelope	80%	20-30%	Varies by age and country	Varies by age (ranges from 8.6%-12.2%)	Applied using overall <5 mortality envelope	Applied using overall <5 mortality envelope	30%	10% of cases are severe and 20% of severe cases are fatal
Reference	Goldstein, S. T., Zhou, F., Hadler, S. C., Bell, B. P., Mast, E. E., & Margolis, H. S. (2005). A mathematical model to estimate global hepatitis B disease burden and vaccination impact. Int J Epidemiol, 34(6): 1329-1339.	Walker, N., Tam, Y., Friberg, I.K. (2013) Overview of the Lives Saved Tool (LiST). BMC Public Health, 13(S1).	Goldie, S.J., O'Shea, M., Campos, N.G., Diaz, M., Sweet, S., Kim, S.Y. (2008). Health and economic outcomes of HPV 16,18 vaccination in 72 GAVI-eligible countries. Vaccine, 26(32): 4080-4093	Tran, M.Q., Tran, T.N.T., Nguyen, M.D., Tran M.N., Clapham, H.E. (2019). Estimates of the global burden of Japanese Encephalitis and the impact of vaccination from 2000-2015 [Pre-print]. https://www.medrxiv.org/content/early/2019/09/25/19006940.full.pdf	Chen. S, Fricks J, Ferrari M.J. Tracking measles infection through non-linear state space models. J R Stat Soc, 61(1): 117-134.	Tartof, S., Cohn, A., Tarbangdo, F., Djingarey, M.H., Messonnier, N., Clark, T.A., Kambou, J.L., et. al. (2013). Identifying Optimal Vaccination Strategies for Serogroup A Neisseria meningitidis Conjugate Vaccine in the African Meningitis Belt. PLOS ONE, 8(5): e63605.	(see Hib)	(see Hib)	Vynnycky E, Papadopoulos T, Angelis K. The impact of Measles-Rubella vaccination on the morbidity and mortality from Congenital Rubella Syndrome in 92 countries. Hum Vaccin Immunother 2019; 15(2): 309-16.	Garske, T., Van Kerkhove, M.D., Yactayo, S., Ronveaux, O., Lewis, R.F., Staples, J.E., Comm, Y.F.E. (2014). Yellow Fever in Africa: Estimating the Burden of Disease and Impact of Mass Vaccination from Outbreak and Serological Data. PLoS Med, 11(5): e1001638

*Additional notes:

Hib/PCV: Only includes impact on children under 5 years. Model estimates deaths averted using residual deaths after accounting for existing interventions, thus reducing risk of double counting deaths averted from other (non-vaccine interventions); coverage of other interventions (sanitation, antibiotic treatment) held constant.

HPV: Vaccine provides protection against vaccine-type (HPV 16 and 18), no cross-protection.

MenA: Vaccination is assumed to be superior to natural immunity.

Rotavirus: Model accounts for regional variation in the proportion of severe diarrhea caused by rotavirus; Only includes protection from complete vaccination (either 2-dose or 3-dose rotavirus vaccine).

YF: Proportion of cases leading to severe disease and the case fatality ratio have been updated to 12% and 47%, respectively for model runs following 2015. This analysis applies the lower estimates for consistency with previous analyses, therefore generating a conservative estimate of the economic impact.

Appendix C. Key model assumptions for COI, VSL and VSLY approaches

Table C1. Assumptions for COI approach

<table>
<tr><th>Model Component</th><th>Key Model Assumptions</th></tr>
<tr><td rowspan="3">Overall</td><td>Discount rate: 3%</td></tr>
<tr><td>Time horizon:
• Short-term costs: 2011-2030
• Long-term costs: 2011-2094*
*Congenital rubella syndrome productivity loss included through 2110</td></tr>
<tr><td>Costs:
• Constant costs assumed over time horizon for both short- and long-term costs</td></tr>
<tr><td>Treatment costs</td><td>Cost of medications and diagnostics are estimated as a proportion of facility costs:
• 25% applied for Hib pneumonia, pneumococcal pneumonia, rotavirus severe diarrhea, measles, HepB (all syndromes), Men A, YF, HPV
• 50% applied for congenital rubella syndrome</td></tr>
<tr><td>Caregiver productivity</td><td>• Caregiver productivity loss included for individuals under age 15 only
• Caregiver assumed to be 1 wage earner at minimum wage rate
• One outpatient visit equivalent to ½ day
• One inpatient day equivalent to 1 day</td></tr>
<tr><td>Productivity loss (baseline assumptions)</td><td>• 100% labor force participation rate
• One year of productivity loss valued at the country’s GDP per capita
• Productivity only included for OECD working age population (ages 15-64)
• Productivity during years of disability assumed to be proportional to GBD disability weight
• Disability weights and duration of disability are listed in the table below:
<table>
<tr><th>Pathogen [syndrome]</th><th>Sequelae (disability weight, duration)</th></tr>
<tr><td>HepB</td><td>Fulminant hepatitis (0.051, 2 weeks)
Cirrhosis (0.194, 9 years)
Hepatocellular carcinoma (0.451, 1.4 years)</td></tr>
<tr><td>Hib [meningitis]</td><td>Cognitive impairment (0.043, remaining life expectancy)
Deafness (0.27, remaining life expectancy)
Seizure disorder (0.552, remaining life expectancy)
Severe motor deficit (0.61, remaining life expectancy)</td></tr>
<tr><td>Hib [pneumonia]</td><td>Restrictive lung disease (0.019, remaining life expectancy)</td></tr>
<tr><td>HPV</td><td>Cervical cancer (0.294, 6 years)</td></tr>
<tr><td>JE</td><td>Motor deficit (0.542, remaining life expectancy)
Acute encephalitis (0.133, 3 weeks)</td></tr>
<tr><td>Measles</td><td>Permanent disability due to encephalitis (0.637, remaining life expectancy)</td></tr>
<tr><td>MenA</td><td>Composite weight for all meningitis sequelae (0.260, remaining life expectancy)</td></tr>
<tr><td>PCV [meningitis]</td><td>Cognitive impairment (0.043, remaining life expectancy)
Deafness (0.27, remaining life expectancy)
Seizure disorder (0.552, remaining life expectancy)
Severe motor deficit (0.61, remaining life expectancy)</td></tr>
<tr><td>PCV [pneumonia]</td><td>Restrictive lung disease (0.019, remaining life expectancy)</td></tr>
<tr><td>Rubella</td><td>Congenital rubella syndrome (0.471, remaining life expectancy)</td></tr>
<tr><td>YF</td><td>Convalescent hemorrhagic fever (0.219, 4 weeks)
Acute hemorrhagic fever (0.133, 3 weeks)</td></tr>
</table></td></tr>
</table>

Table C2. Assumptions for VSL and VSLY approaches

Model Component	Key Model Assumptions
Discount rate	3%
Time horizon	2011-2094* *Congenital rubella syndrome included through 2110
Income elasticity	1.5 (Reference Case Guidelines for Benefit Cost Analysis, 2019)
GDP growth	VSL in year of death estimated using projected real GDP per capita (Global Burden of Disease Health Financing Network, 2018)
Minimum VSL value	20x GDP per capita (Reference Case Guidelines for Benefit Cost Analysis, 2019)

Appendix D. Productive life-years lost estimated for COI approach

We estimated the number of productive life years lost, as defined by the OECD definition of the working age population, ages 15-64. Table D1 shows the undiscounted and discounted years of life lost for individuals aged 15-64, inclusive.

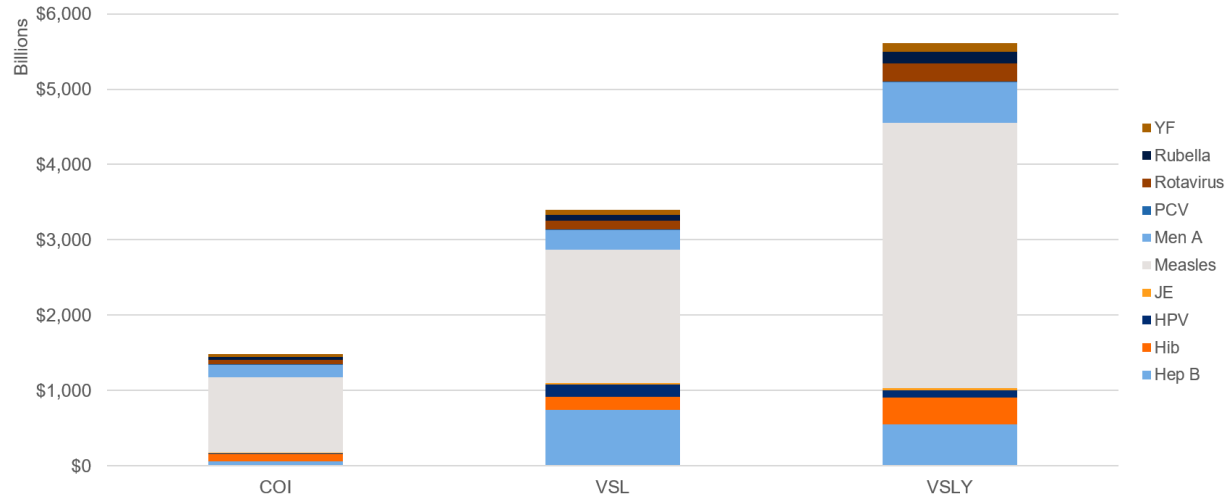
Table D1. Productive years of life lost and productivity loss in 2018 USD

	Decade	Productive years* lost due to death in millions *(undiscounted)*	Productive years lost due to death in millions *(discounted)*	Productivity loss due to death (billions of USD)	Productive years lost due to disability in millions *(undiscounted)*	Productive years lost due to disability in millions *(discounted)*	Productivity loss due to disability (billions of USD)
Total 94 countries	2011-20	1,231.3 (830.2-1,989.3)	422.7 (280.1-691.8)	$634.5 ($275.6-$1,135.4)	109.6 (83.4-156.6)	45.4 (34.0-65.0)	$39.8 ($17.9-$71.3)
	2021-30	1,527.5 (1,064.4-2,414.9)	515.2 (351.9-826.0)	$769.6 ($339.3-$1,348.8)	140.5 (109.7-200.0)	55.5 (42.5-79.2)	$50.2 ($23.2-$87.3)
	2011-30	2,758.8 (1,896.0-4,403.0)	937.9 (632.4-1,516.4)	$1,404.1 ($611.6-$2,477.5)	250.1 (193.3-355.7)	100.9 (76.6-144.2)	$90.0 ($41.2-$159.2)
73 Current and former Gavi countries	2011-20	1,199.2 (807.4-1,938.8)	412.0 (272.8-674.8)	$598.7 ($259.0-$1,072.3)	99.9 (75.9-142.3)	41.4 (31.1-59.2)	$33.9 ($15.3-$60.6)
	2021-30	1,492.7 (1,039.2-2,360.4)	503.7 (343.7-808.1)	$730.0 ($321.2-$1,280.0)	130.2 (101.8-184.9)	51.2 (39.4-72.9)	$44.0 ($20.6-$75.9)
	2011-30	2,691.9 (1,847.7-4,297.7)	915.7 (616.9-1,481.8)	$1,328.7 ($577.4-$2,344.2)	230.0 (178.1-326.1)	92.7 (70.4-132.2)	$77.9 ($35.9-$136.4)

Discounted years calculated based on 3% discount rate.

Appendix E. Comparison of methods for estimating economic benefits

Figure E1. Economic benefits using the COI, VSL, and VSLY approaches, 2011-2030, with breakdown by pathogen



Appendix F. Sensitivity analysis for productivity loss, 94 countries

As productivity loss estimates drive the overall estimates of COI averted, we explored the impact of assumptions for wage, labor force participation, and age restrictions on productivity loss estimates. Table F1 shows the assumptions used in the primary results and how they were varied in scenario analysis. Variations 1 and 2 focus on changing the value of productivity in the productivity loss assumption, whereas 3 and 4 explore other methods for calculating productive years of life lost.

Table F1. Assumptions used for estimating productivity loss and variations explored in scenario analysis

Baseline assumptions for primary results	**Variation in scenario analysis**
1. We assumed the value of productivity (GDP per capita) is constant over the model time horizon.	1. We applied a growth rate for GDP per capita to account for increasing value of labor over time based on education gains and increased worker productivity.
2. One year of productivity was valued using GDP per capita.	2. We explored using minimum wage to value productivity, as the wage distribution in the target countries is likely skewed toward minimum and low wages.
3. We assumed individuals were only productive between ages 15 and 64, based on the OECD definition of the working age population.	3. We estimated productivity for ages 15 until the end of life based on life expectancy at the age of disease onset.
4. We assumed labor force participation was 100% to estimate value of productivity in the informal sector and of unpaid labor.	4. We applied country-specific labor force participation rates.

Our results show that productivity loss calculations are highly sensitive to assumptions that change how lost productive years were counted and valued. Table F2 shows the estimates of productivity loss as a proportion of total COI averted.

Table F2.

Scenario	**Productivity loss averted**	**Proportion of COI**
Baseline	$1494.1 ($662.0-$1,425.9)	98.95%
(1) Apply GDP per capita growth forecast	$3,416.6 ($1,537.5-$5,936.6)	99.53%
(2) Value productivity using minimum wage	$799.1 ($355.9-$1,396.8)	98.00%
(3) Include productivity for ages over 64	$1,587.6 ($681.6-$2,700.8)	98.98%
(4) Apply labor force participation rate	$867.8 ($383.9-$1,523.8)	98.16%

We found that productivity loss is very sensitive to assumptions placed on the value of productivity and the number of years counted toward productivity. However, even when applying the most conservative assumption (2), productivity loss still comprised at least 98.00% of the total COI averted. Despite the sensitivity to these assumptions, each variation introduces new limitations in the estimates, and our baseline assumptions were most consistent with previous studies and generalizable to the countries included based on available data.

Preliminary results of this sensitivity analysis were presented as a poster at the 2019 International Health Economics Association Congress in Basel, Switzerland.