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Supplementary appendix 2

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Supplementary Appendix for

Health Impact and Economic Evaluation of Expanded Program on Immunization in China from 1974 to 2024: A Modelling Study

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1. Summary of modelling

We constructed an age-structured stochastic dynamic compartment model for each of the seven pathogens (measles, pertussis, hepatitis B, tuberculosis, hepatitis A, meningitis A, and poliomyelitis, apart from JE) to interpret the combined effects of the natural course of infection, demographic changes, and vaccination. Dynamic models of infectious diseases offer significant advantages in estimating the impact of vaccines. Primarily, these models can capture the dynamics of disease transmission, allowing for the simulation of various scenarios to assess the potential effectiveness of vaccines in controlling outbreaks[1]. Moreover, these models enable scenario analyses, aiding policymakers in predicting the long-term impact of different vaccination strategies, which is crucial for decision-making[2]. For JE, a vector-borne viral disease transmitted primarily by mosquitoes, a static model was utilized based on a pre-established catalytic model assuming a constant force of infection according to previous literature[3]. In this analysis, we considered salient features of pathogens, and a summary of these eight-pathogen model is listed in the **Table S1**. We utilized the R^2 (R-squared) statistic to assess the performance and goodness-of-fit of our predictive model. A higher R^2 value suggests that a larger portion of the variance is accounted for by the model, indicating a better fit.

Table S1: Summary of eight pathogen-specific models

Pathogen	Modelling period	Vaccine effectiveness	Features & assumption	R^2
Measles	1965 - 2060	• 69% for liquid measles vaccine • 87% for lyophilized measles vaccine • 95% for measles-containing vaccines (MCV)	Seasonality	0.918
Pertussis	1960 - 2060	• 88% for DTwP • 79% for DTaP	Waning immunity, shift in vaccine	0.908
Hep B	1990 - 2109	• 99% for hepatitis B immunoglobulin prophylaxis • 95% for Hep B vaccine	Horizontal transmission, vertical (mother-to-child) transmission, disease progression	0.940
TB	1960- 2109	18% for BCG vaccine	Acquiring drug resistance, latent infection	0.990
Hep A	1990 - 2060	95% for Hep A vaccine	Subclinical infection	0.837
JE	1960 - 2060	100% for JE vaccine	Constant force of infection	0.951
Men A	1980 - 2060	90% for Men A vaccine	Waning immunity	0.831
Polio	1960 - 2060	100% for Polio vaccine	Vaccine-associated paralytic polio, including non- paralytic infection	0.763

1.1 Force of infection

In this study, the model is age-structured with five age groups: below 1, 1-5, 6-20, 21-40, and 40+. Each age group interacts with other age groups through a Who Acquires Infection from Whom (WAIFW) matrix. Due to limited availability of time-varying social contact data in China, such as daily contact rates, we simplified the WAIFW matrix by incorporating contact information into force of infection based on the transmission intensity between different age groups. The final WAIFW matrix was constructed using five parameters, based on a fixed pattern derived from previous literature and the

nature of the infection. These parameters demonstrate the combined effect of infection rates and contact probabilities. We assumed that the final force of infection is closely related to age and that all models share the same pattern. The structure of the WAIFW matrix is detailed below.

Table S2: WAIFW matrix

	Infectious individual (j)					
Susceptible individual (i)	Age Group	Below 1	1-5	6-20	20-40	40+
	Below 1					
	1-5					
	6-20					
	21-40					
	40+					

The *i, j* entry represents the rate at which infectious individuals in age class *j* infect given susceptible individuals in age class *i*.

Once the WAIFW matrix is defined, the model's force of infection λ can be expressed as

$$\lambda = \left(\frac{I}{N}\right) \cdot \mathrm{WAIFW}(w)$$

Where:

I: infectious population (age structured)

N: population (age structured)

w: parameters of the WAIFW matrix

Unless otherwise specified, we used this formula to calculate the force of infection for all pathogens.

1.2 Model calibration

The model parameters were estimated using the Markov Chain Monte Carlo (MCMC) method within a Bayesian inferential framework, utilizing the R package *Bayesian tools*. The model-generated-outcomes were fitted against observed data, including reported annual incidence, estimated annual incidence, or prevalence. Specifically, for measles, pertussis, Hep A, JE, Men A, and polio, we utilized annual incidence data reported by the National Notifiable Infectious Disease Reporting System (NIDRS) of China[4]. In the NIDRS, suspected cases were included. For hepatitis B, we calibrated the model with annual HBsAg+ prevalence data in China from 1990 to 2020[5]. For tuberculosis (TB), we used annual incident cases in China sourced from the WHO[6].

Table S3: Definition of cases in this study

Cases	Definition	Standard
Measles	1. Fever, typically with a body temperature of ≥ 38°C. 2. Red maculopapular rashes typically appear on the 3rd to 4th day of illness, with normal skin between the rashes. The rashes usually begin behind the ears and on the face, spreading from top to bottom across the entire body, and can involve the mucous membranes. The rashes typically last for 3 to 5 days. 3. Symptoms of upper respiratory catarrh, such as cough, runny nose, and sneezing, along with photophobia, tearing, and conjunctivitis.	China CDC

Cases	Definition	Standard
	4. In the early stage of the illness (usually on the 2nd to 3rd day), Koplik's spots can be seen on the buccal mucosa inside the mouth.	
Pertussis	1. Paroxysmal, spasmodic cough lasting for ≥ 2 weeks. 2. Infants experience recurrent episodes of respiratory arrest, asphyxia, cyanosis, and bradycardia, or intermittent paroxysmal cough, often with a history of epidemiological exposure to pertussis or contact with confirmed cases. 3. Older children, adolescents, and adults experience a persistent cough lasting more than 2 weeks, without fever or other explanations, and with a history of epidemiological exposure to pertussis or contact with confirmed cases.	China CDC
Hep B	Hepatitis B Surface Antigen (HBsAg) positive	Clinical guidelines
Active TB	1. Presence of tuberculosis-related symptoms, such as low-grade fever, fatigue, night sweats, loss of appetite, weight loss, and others. 2. Accompanied by respiratory symptoms, such as cough and sputum production lasting more than 2 weeks, or hemoptysis and blood-streaked sputum. 3. Suspected pulmonary tuberculosis identified through a health examination, showing lung abnormalities or shadows.	Clinical guidelines
Hep A	1. Liver function tests: Alanine aminotransferase (ALT) is significantly elevated, serum bilirubin > 17 μmol/L, urine bilirubin positive, and jaundice of the sclera and skin present. 2. Hepatitis A virus (HAV) markers test: serum anti-HAV IgM positive, or a fourfold increase in anti-HAV IgG.	China CDC
JE	1. Acute onset with fever, headache, and projectile vomiting, followed by impaired consciousness after 2-3 days. Severe cases may present with convulsions and tonic spasms. 2. Cerebrospinal fluid shows increased pressure. 3. Positive for anti-Japanese encephalitis virus IgG.	Clinical guidelines
Men A	1. Petechiae or purpura, accompanied by Gram negative kidney-shaped diplococci in fluid samples. 2. Neisseria meningitidis cultured from fluid samples, positive nucleic acid or polysaccharide antigen test for Neisseria meningitidis, or a fourfold increase in serum IgG antibody titer from the acute to the convalescent phase.	Clinical guidelines
Polio	1. Any case of acute flaccid paralysis (AFP) of unknown etiology in individuals under 15 years of age, including those initially diagnosed as Guillain-Barré syndrome (GBS). 2. IgM antibodies are detected in cerebrospinal fluid or blood, or there is a sharp increase in IgG levels.	Clinical guidelines

A likelihood function was formed by assuming a Poisson distribution for the data:

$$L(\lambda(t); k(t, X)) = log\left(\prod_{t=1}^{n} \frac{\lambda^{k(t,\boldsymbol{X})} e^{-\lambda(t)}}{k(t, \boldsymbol{X})!}\right)$$

Where:

$\boldsymbol{X}$: model parameters

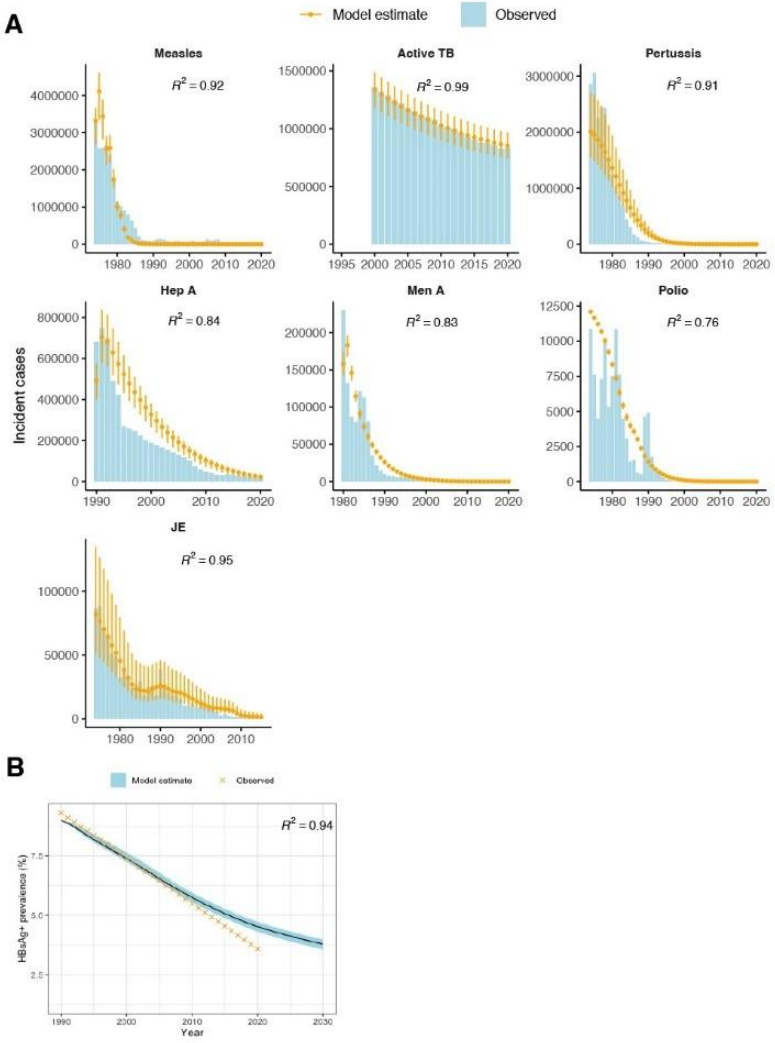
$\lambda(t)$: observed data in year t

$k(t; \boldsymbol{X})$: model-estimated data in year t

In the MCMC estimation, flat prior distributions were assumed for all model parameters. A differential-evolution-MCMC (DE-MCMC) algorithm was used to obtain the posterior distribution, which excels in sampling from posterior distributions by leveraging parallel chains to enhance exploration and convergence[7]. The evolutionary operations of this method, such as mutation and crossover, facilitate efficient navigation through complex, high-dimensional parameter spaces, reducing the risk of getting trapped in local optima. Additionally, DE-MCMC dynamically adjusts the jumping distribution, enhancing robustness and reducing the need for manual tuning, making it particularly effective for multimodal distributions and correlated parameters.

In this study, a total of at least 10,000 iterations were used as the burn-in period, followed by 40,000 iterations to draw the posterior estimates. The convergence of the MCMC chains was assessed with time-series trace plots and autocorrelation functions. The medians and 95% credible intervals (CIs) of the posterior distributions were used to summarize the estimates and their uncertainty. The results for trajectory matching are presented in **Figure S1.** All models demonstrate good performance in target fitting, with variability in credible intervals primarily attributable to the stochastic nature of the models, the parameters used in our dynamic modelling framework, and the Bayesian-based inference method.

Figure S1: Trajectory matching of incident cases between model predictions and observed data

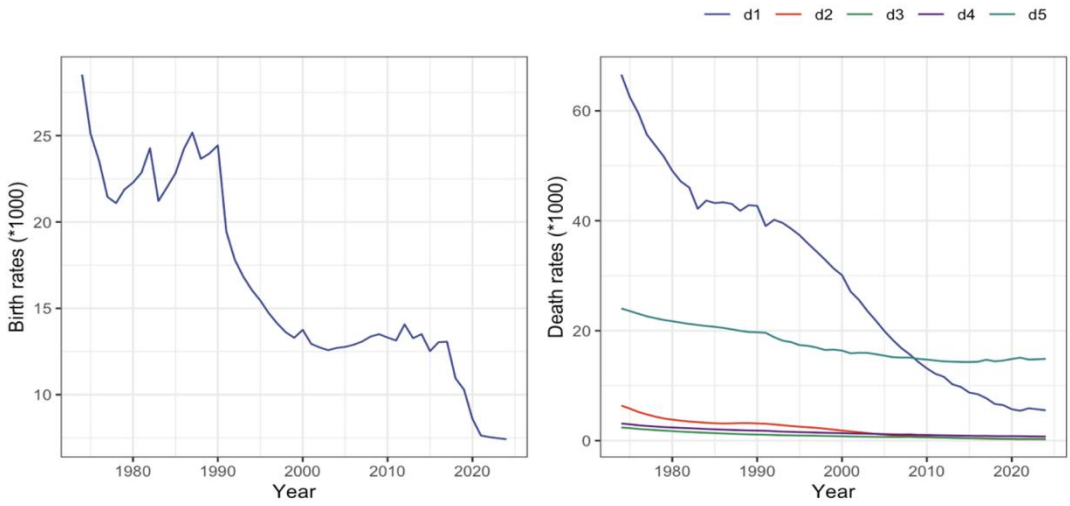


R^2 represents the coefficient of determination, with a higher value indicating better model performance.

1.3 Demographic parameters

We retrieved China's demographic parameters from the United Nations (UN) World Population Prospects[8]. Annual birth rates and death rates between 1974 and 2024 are presented in the figure below, with all models sharing these parameters.

Figure S2: Birth rates and death rates in China between 1974 and 2024



d1, d2, d3, d4, and d5 represent the death rates for the following age groups: below 1, 1-5, 6-20, 21-40, and 40+.

To account for the dynamics of the age structure, we also calculated age transition rates to simulate the aging process using the following formula:

For the age group below 1 year, $i = 1$:

$$\mathrm{Trans}(1, t) = 1 - \mathrm{birth\ rate}(t)$$

For age groups 1-5, 6-20, 21-40, and 40+, $i = 2$, 3, 4, and 5:

$$\mathrm{Trans}(i, t) = \frac{\mathrm{population}(i, t-1) \cdot (1 - \mathrm{death\ rate}(i, t)) + \mathrm{population}(i-1, t-1) \cdot \mathrm{Trans}(i-1, t-1)}{\mathrm{population}(i, t)}$$

Where:

$\mathrm{Trans}(i, t)$: transition rate from age group i to age group i+1 in year t

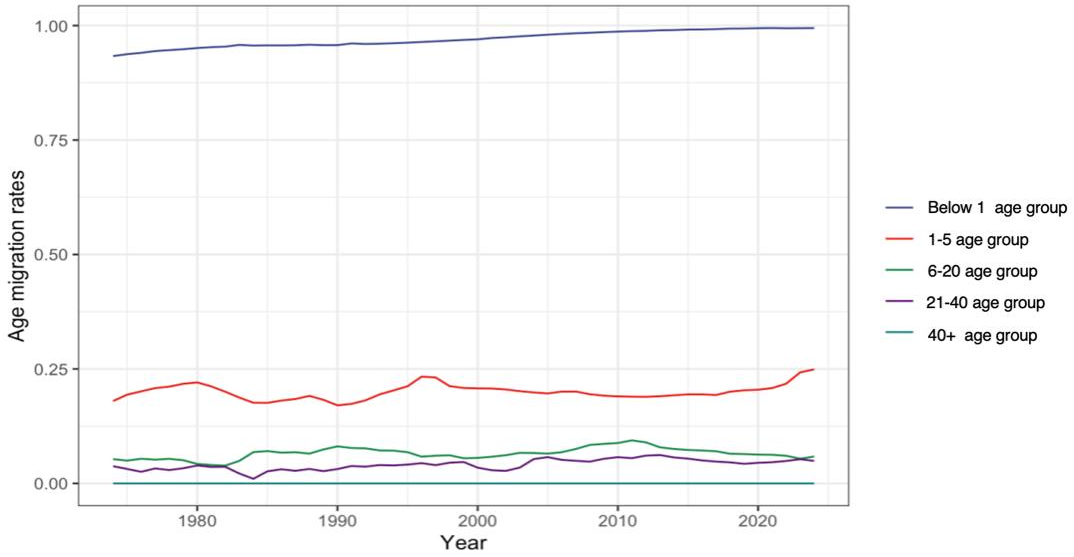
$\mathrm{population}(i, t)$: population of age group i in year t

$\mathrm{death\ rate}(i, t)$: death rate of age group i in year t

$\mathrm{birth\ rate}(t)$: birth rate in year t

The resulting age-transition rates from 1974 to 2024 is presented in the figure below.

Figure S3: Age transition rates from 1974 to 2024



1.4 Projecting vaccination coverage

Vaccination coverage data in China are compiled from various sources; however, data on the early Expanded Program on Immunization (EPI) coverage, particularly before 1983, are limited. Considering the historically low coverage rates prior to the EPI initiative and the well-established correlation between vaccination coverage and economic development in China, we used generalized additive models (GAM) to estimate vaccination coverage for the unrecorded years, with GDP per capita as a covariate. The use of GAM allows for flexible modeling of non-linear relationships and provides robust estimates even with limited data, making it well-suited to our analytical objectives. Below, we present the sources of vaccine coverage data alongside the outcomes derived from GAM estimation. As vaccination coverage for all eight vaccines reached 99% in 2019 and COVID-19 had minimal impact on vaccination coverage in China's EPI, we assumed that, after 2019 or 2022 (depending on data source), vaccination coverage of all various EPI vaccines in China remained at 99%. To mitigate potential bias in this assumption, we sampled the vaccination coverage from a triangular distribution with a 5% deviation.

Table S4: Vaccination coverage data sources

Vaccine	Period	Source	Type
Measles	Before 1983	GAM estimated	Estimated
	1983 - 2022	WUENIC (WHO-UNICEF Estimates National Immunization Coverage)	Official report[9]
	After 2022	99%	Assumed
DTP	Before 1983	GAM estimated	Estimated
	1983 - 2022	WUENIC (WHO-UNICEF Estimates National Immunization Coverage)	Official report[9]
	After 2022	99%	Assumed
Hep B	1990 - 2000	Impact of immunization programs on 11 childhood	Literature[10]

Vaccine	Period	Source	Type
		vaccine-preventable diseases in China	
	2000-2022	WUENIC (WHO-UNICEF Estimates National Immunization Coverage)	Official report[9]
	After 2022	99%	Assumed
BCG	Before 1983	GAM estimated	Estimated
	1983 – 2022	WUENIC (WHO-UNICEF Estimates National Immunization Coverage)	Official report[9]
	After 2022	99%	Assumed
Hep A	1990-2012	Changing epidemiology of Hepatitis A in China: evidence from three national serological surveys and the National Notifiable Disease Reporting System	Surveys[11]
	2012-2019	Impact of immunization programs on 11 childhood vaccine-preventable diseases in China	Literature[10]
	After 2019	99%	Assumed
JE	Before 1983	GAM estimated	Estimated
	2010 -2022	WUENIC (WHO-UNICEF Estimates National Immunization Coverage)	Official report[9]
	After 2022	99%	Assumed
Men A	Before 2009	GAM estimated	Estimated
	2009 - 2019	Impact of immunization programs on 11 childhood vaccine-preventable diseases in China	Literature
	After 2019	99%	Assumed
Polio	Before 1983	GAM estimated	Estimated
	1983 - 2022	WUENIC (WHO-UNICEF Estimates National Immunization Coverage)	Official report[9]
	After 2022	99%	Assumed

The model was constructed using the *mgcv* package in R, which employs thin plate regression splines for smooth terms. The GAM model can be expressed mathematically as follows:

$$\log(y) = \beta_0 + \sum_{j=1}^{k} \beta_j B_j(x) + \beta_{GDP} \log(\text{GDP}) + \epsilon$$

where:

$\log(y)$: the natural logarithm of the response variable y

β_0: the intercept term

$\sum_{j=1}^{k} \beta_j B_j(x)$: the smooth function of the predictor x

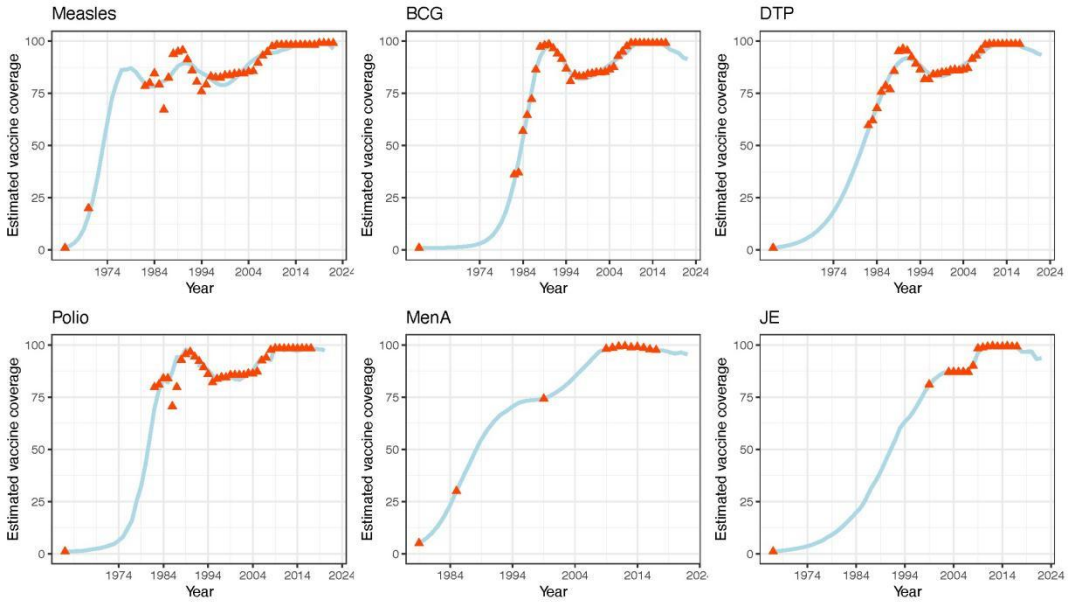
β_{GDP}: the coefficient for the natural logarithm of the GDP

ϵ: the error term

Here, $B_j(x)$ represents the basis functions generated by thin plate regression splines, and k is the number of basis functions, which is set to 10 in this model. $B_j(x)$ are radial basis functions, typically

of the form $\phi(r) = r^2 \log(r)$, where r is the Euclidean distance between x and the knots κ_j. The smoothing parameters were estimated using Restricted Maximum Likelihood (REML), a robust method that balances model fit and smoothness.

Figure S4: GAM estimation results



The red dots represent observed vaccination coverage, while the solid blue line shows the fitted coverage.

1.5 Vaccine impact assessment

In this study, vaccine impact assessment involves two approaches: the calendar year approach and the birth cohort approach, each defining how the impact is attributed based on established definitions from previous studies[12,13]. Specifically, for the calendar year approach, we assessed the disease burden with and without vaccination for the entire population in each calendar year (1974-2024), quantifying the difference in cases and deaths. Alternatively, for birth cohort approach (1974-2024), we compared lifetime disease burden with and without vaccination to determine the cumulative impact of vaccination over the cohort's lifespan.

For the calendar year approach, we calculated the total impact across all age groups in the population for each given year. This method is intuitive and widely used for assessing vaccination impact. Here, vaccine impact is defined as the difference in disease burden between scenarios with different vaccination coverage levels or no vaccination at all. When constructing the model, we inputted the population distribution at the beginning of the model's operational year, subsequently capturing age-specific case and death numbers in different years. Summing the impact across all modeled age groups in a given year provides a snapshot of the disease burden averted in that year for China. However, this method does not account for the future disease burden averted by current vaccination activities (i.e. beyond 2024).

For the birth cohort approach, we considered the long-term impact on disease burden accumulated over the lifetime of individuals born in a specific year. The duration of modelling should align with the

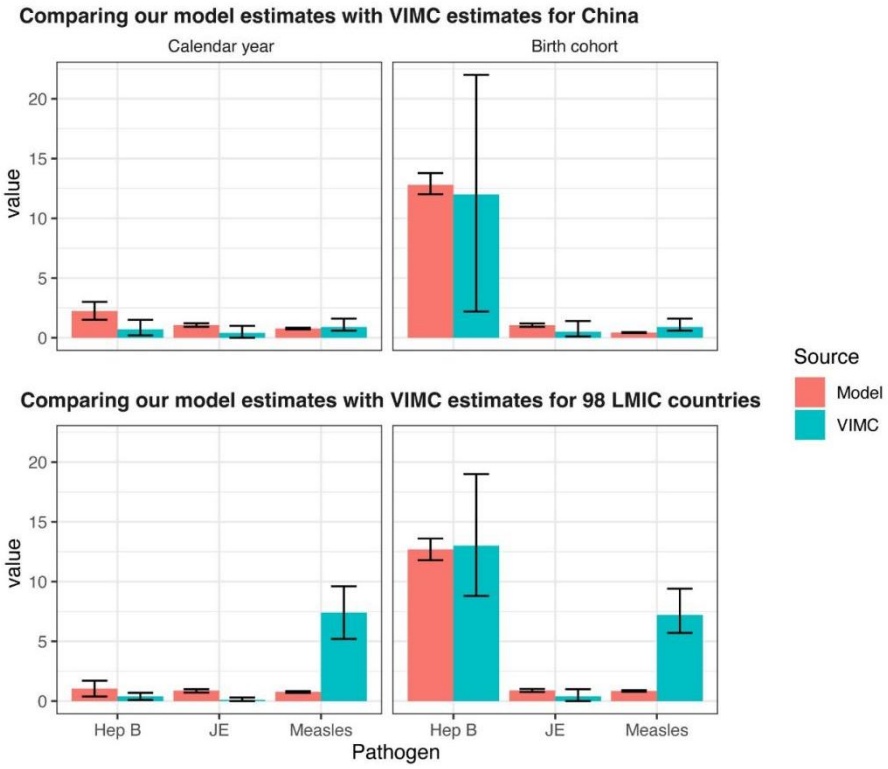
disease dynamics of the pathogen; for instance, diseases like Hepatitis B manifest later in life. In our study, we modeled vaccination impact for birth cohorts spanning from 1990 (the first year Hep B vaccine was introduced in China) to 2024 and projected Hepatitis B burden until 2109. Throughout all simulated years, the disease burden was allocated across different age groups, with the burden traced back to the birth cohorts to calculate the lifetime burden for each cohort.

1.6 Comparison with VIMC estimates

The Vaccine Impact Modeling Consortium (VIMC) previously used models to estimate the vaccine-preventable disease burden for different pathogens across various countries[13]. Among these pathogens, three were reported for China, namely Hep B, JE, and Measles. We directly compared the results obtained from models in this study with those from VIMC, focusing on the parameter of deaths averted per 1,000 individuals vaccinated. The results are depicted in **Figures S5**.

Deaths averted per 1,000 vaccinated individual represents the combined effect of vaccination coverage and vaccine effectiveness, providing a clearer reflection of the health impact of vaccination. Figure S5 shows that, whether using the calendar year or birth cohort approach, our estimates are generally consistent with those of the VIMC. For example, using the birth cohort approach, the VIMC reported 0.9, 12.0, and 0.5 deaths averted per 1,000 individuals vaccinated against measles, Hep B, and JE in China from 2000 to 2030. In comparison, our study estimated 0.44, 12.80, and 1.06 deaths averted per 1,000 vaccinated individuals against measles, Hep B, and JE over the same period. Some differences remain, which can be attributed to variations in calibration targets, age structure, and model parameters such as vaccination coverage.

Figure S5: Deaths averted per 1,000 individuals vaccinated calculated in this study and by VIMC



Another indication of the robustness of our results is the consistency in the relative impact on disease burden. Both the VIMC and our estimates suggest that more than 90% of deaths from measles can be averted. Overall, this comparison supports the reliability of the model results for three pathogens commonly examined in both studies.

1.7 Calculation of cost-effectiveness

1) Cost of vaccination

We calculated the cost of vaccination by summing vaccine procurement cost, administrative service cost, and other costs including transportation and lost productivity (e.g. missed work time for child guardians). All costs were adjusted for inflation, with 2022 as the base year in the study. Annual procurement prices for each vaccine were obtained from the official Chinese government procurement website (http://www.ccgp.gov.cn/), where cost data were compiled. We calculated weighted averages for each vaccine type annually, and for years with missing records on vaccine costs, we used the inflated values from the nearest available year. According to a survey conducted by China CDC, the administrative service cost per dose for EPI vaccines in China was set at CNY 23.19[14]. For other costs including transportation and lost productivity, sourced from the same data, the cost per visit was calculated to be CNY 41.77.

Since multiple dosages can be administered in a single visit, the per-visit cost of transportation and lost productivity can be distributed across the various dosages. Therefore, vaccine- and dose-specific costs for transportation and lost productivity were calculated based on the number of doses administered per visit in the EPI schedule to avoid overestimating costs. Specifically, we calculated the number of visits required to complete the EPI schedule for each vaccine and determined the average transportation and lost productivity costs per dose.

Table S5: EPI schedule for children in China

Vaccine	Immunization schedule															
	Birth	1 m	2 m	3 m	4 m	5 m	6 m	8 m	9 m	12 m	15 m	18 m	2 y	3 y	4 y	6 y
Measles								1				2				
DTP				1	2	3						4				
Hep B	1	2					3									
BCG	1															
Hep A												1	2			
JE								1、2					3			4
MPSV (Men AC)							1		2					3		4
Polio			1	2	3										4	

EPI schedule, updated on April 11, 2022, as assessed from China CDC at: https://www.chinacdc.cn/nip/kyjz/mycxbjsm/mycxb/202105/t20210513_230543.html.

Table S6: Average transportation and lost productivity costs per dose

Vaccine	Required doses	Required visits	Average transportation and lost productivity costs per dose (in 2022 CNY)
Measles	2	0.83	17.41
DTP	4	2.33	24.37
Hep B	3	1.50	20.89
BCG	1	0.00	0.00
Hep A	2	0.83	17.41
JE	4	2.50	26.11
MPSV (Men AC)	4	3.00	31.33
Polio	4	3.00	31.33

We then obtained the total vaccination costs for each vaccine using the following formula:

$$Cost\ of\ vaccination\ for\ each\ vaccine = \sum_{t=1}^{n} (\text{Procurement cost} + \text{Administrative service cost} + \text{Other cost}) * \text{Number of doses in schedule} * \text{Vaccination coverage} * \text{Size of birth cohort}$$

Where:

n: years of vaccination

2) Disease burden measures

Apart from cases and deaths, this study employed Disability-Adjusted Life Years (DALYs) to measure the burden associated with various pathogens. DALYs combine both the years of life lost due to premature mortality (YLL) and the years lived with disability (YLD) to provide a comprehensive measure of disease burden. The decision to utilize DALYs instead of Quality-Adjusted Life Years (QALYs) was based on three primary considerations. Firstly, QALYs rely heavily on survey data, which can vary significantly depending on the study population, research design, and contextual factors. This variability can introduce substantial differences in QALY measurements, complicating comparisons across studies. In contrast, DALYs provide a more standardized approach to measuring disease burden[15]. This is particularly crucial for our study, as we assess eight diseases along with their associated complications and sequelae, which may vary widely across different populations and settings. Secondly, many vaccine-preventable diseases primarily affect infants and children, but quality of life (QoL) estimates for short-term illnesses in young children are nearly non-existent, and the appropriate methodology for such assessments remains debated. Since DALYs are the only summary measure for which consistent estimates are available globally, the WHO guide recommends using DALYs when suitable QALY weights are not readily accessible[16]. Thirdly, the findings of our study should enable comparisons with established literature, where DALYs are commonly used as a primary metric for assessing disease burden[13,17,18].

The choice between DALYs and QALYs can impact health economic evaluation results. However, as suggested by the WHO[16], the use of either QALYs or DALYs in economic evaluations can support decisions regarding allocative efficiency within healthcare systems. In our case, the use of DALYs

provides a more accurate and relevant measure of the health burden associated with infectious diseases, particularly considering the specific disease profiles and available data in China.

3) Cost of disease

This study also calculated the costs associated with disease outcomes, including direct medical, direct non-medical, and indirect costs, all adjusted for inflation to the base year of 2022. For pathogen-related deaths, we incorporated age-specific income values to estimate the productivity losses resulting from premature death across different age groups. For survivors with sequelae, we incorporated DALY weights and age-specific productivity losses to estimate lifelong productivity impairment. Additionally, we measured DALY losses attributable to the disease by calculating corresponding losses in dynamic models for short-term disease states based on disease duration, while aggregating future DALY losses for long-term fatalities and sequelae.

$$Cost\ of\ disease = Direct\ medical\ cost + Direct\ non-medical\ cost + Indirect\ cost + Productivity\ loss$$

4) Benefit-cost ratio (BCR) and incremental cost effectiveness ratio (ICER)

The study captures cases and deaths either by calendar year or birth cohort, with both approaches accounting for lifetime costs from a societal perspective. Under the calendar year approach, cases and deaths are considered only for the specific year in which they occur, without accounting for infections or deaths in other years. However, once an individual is recorded as infected or deceased in that year, the associated costs are calculated over their lifetime and attributed to that year.

The BCR for a vaccine was computed by dividing the total benefits by the total vaccination costs for that vaccine. The total benefits were defined as vaccine-preventable pathogen-related costs. It can be expressed as:

$$BCR = \frac{Total\ Benefits}{Total\ costs\ of\ vaccination}$$

The aggregated BCR for China's EPI, including the eight vaccines, was calculated to reflect the overall cost-benefit of these vaccines using the following formula:

$$Aggraeted\ BCR = \frac{\sum_{i=1}^{n} \text{Pathogen-specific benift}}{\sum_{i=1}^{n} \text{Pathogen-specific } vaccination\ cost}$$

Where:

n: number of vaccines included in China's EPI

The ICER for one vaccine was calculated by dividing the difference in costs between two scenarios by the difference in their effectiveness for that vaccine, where effectiveness was quantified in DALYs. The ICER is expressed as:

$$ICER = \frac{\Delta Total\ cost}{\Delta Effectiveness}$$

Where:

$\Delta Total\ cost$ = Total cost with vaccination − Total cost without vaccination

$\Delta Effectiveness$ = Averted DALYs by vaccination

We obtain the aggregated ICER of China's EPI using the following formula:

$$Aggraeted\ ICER = \frac{\sum_{i=1}^{n} \Delta Pathogen-specific\ total\ cost}{\sum_{i=1}^{n} \Delta Pathogen-specific\ effectiveness}$$

Where:

n: number of vaccines included in China's EPI

1.8 Double counting

Given the separate estimation of deaths averted for various disease-vaccine-activities, we examined potential double counting using a Bernoulli process. Although the Bernoulli method for competing risks provides a conservative estimate, it is considered the most reliable approach for determining an approximate value[17].

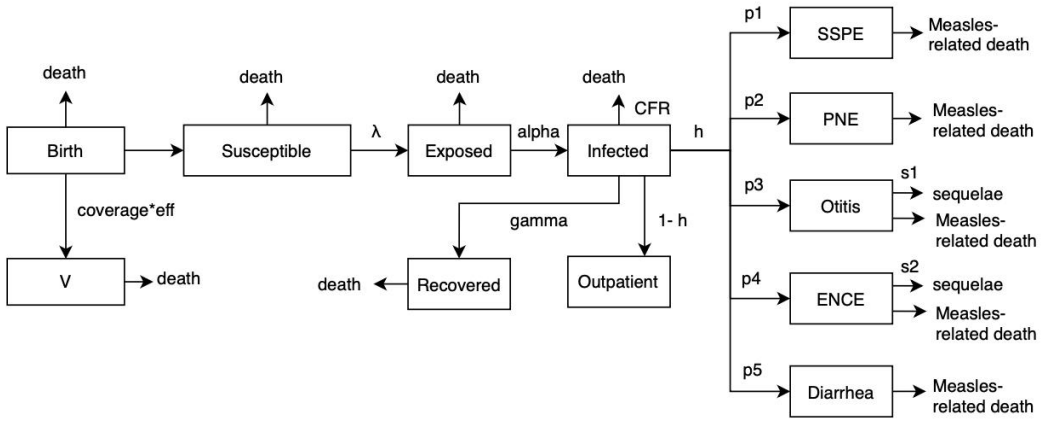
$$\text{mortality}_{\text{combined}} = 1 - \prod_{i=1}^{n} (1 - \text{mortality}_{\text{dva}_i})$$

After adjusting for potential double counting, we estimated that 292 deaths (0.012% of deaths averted by calendar year) may be counted twice, demonstrating a limited impact of double counting on deaths averted.

2. Detailed modelling descriptions

2.1 Measles

1) Model structure



Abbreviations

SSPE: Subacute sclerosing panencephalitis

PNE: Pneumonia

ENCE: Encephalitis

2) Natural history & assumptions

Measles is a highly contagious infectious disease that exhibits a pronounced cyclic pattern. We employed a hybrid model combining dynamic and decision tree models to assess the impact and cost-effectiveness of the measles vaccine. The simulations used a weekly time step, assuming lifelong immunity. Newborns entered the population through the birth compartment (B) and were classified as either susceptible (S) or vaccinated and immunized (V). Susceptible individuals can become exposed (E) to the measles virus, then progress to the infected (I) state, where they can transmit the disease. After infection, individuals can recover (R) and gain immunity. Throughout the process, there are risks of death at various stages.

The economic model further categorizes the infected individuals based on the severity of the disease, distinguishing outpatient and inpatient cases. Inpatients may experience complications such as subacute sclerosing panencephalitis (SSPE), pneumonia (PNE), otitis, encephalitis (ENCE), and diarrhea. In severe cases, inpatient measles can result in measles-related deaths. The measles vaccine has been administered in China since 1965, but over time, changes in the types of measles vaccines have led to variations in vaccine effectiveness. We accounted for changes in vaccine effectiveness due to the replacement of measles vaccines in our analysis. Additionally, the case fatality rate (CFR) for measles has significantly decreased due to societal advancements. In our model, the CFR was made time-varying over the study period to reflect these changes.

Considering the cyclic pattern of measles transmission, we adjusted the force of infection by incorporating a seasonal coefficient. The force of infection was modelled using the following formula, accounting for the higher contact rate during school term[19,20].

$$\lambda = \lambda\,(1 + b_{\text{season}} \cos\,(\frac{2\pi}{52t_{\text{season}}} \cdot (\text{week} - 4)))$$

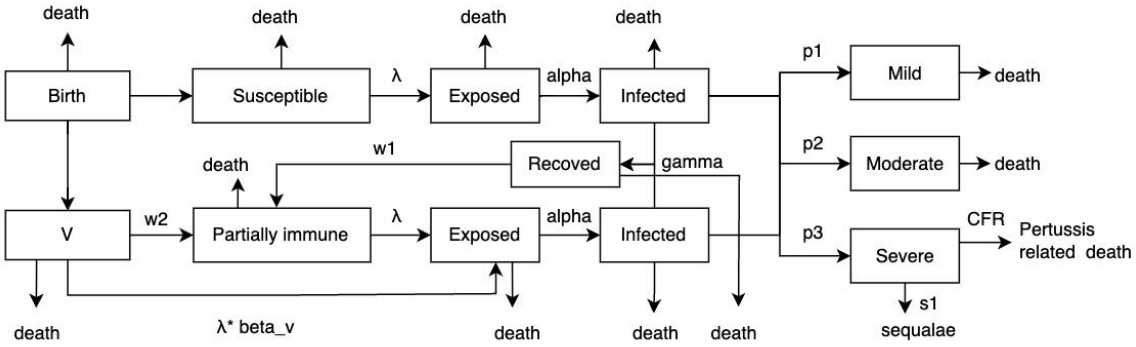
3) Important model parameters

Variable	Definition	Value	Source
Epidemiology			
Alpha	Incubation period	14 days	[21]
Gamma	Time to recovery	9 days	[22]
h	Hospitalization rate	0.20	[23]
λ	Force of infection	Fitted	
CFR	Case-fatality ratio	1974-1976: 0.0053 1977-1987: 0.0046 1988-2007: 0.0022 2008-2024: 0.0007	[24]
eff	Vaccine effectiveness	• 69% for liquid measles vaccine • 87% for lyophilized measles vaccine • 95% for measles-containing vaccines (MCV)	[25,26]
Risk of complications			
p1	Subacute sclerosing Panencephalitis	0.00001	[27]
p2	Pneumonia	Below 1: 0.0371 1-5: 0.0277 6-20: 0.0104 21-40: 0.0290 40+: 0.0290	[28]
p3	Otitis	Below 1: 0.1411 1-5: 0.0860 6-20: 0.0234 21-40: 0.0146 40+: 0.0146	[28]
p4	Encephalitis	Below 1: 0.0005 1-5: 0.0007 6-20: 0.0003 21-40: 0.0009 40+: 0.0009	[28]
p5	Diarrhea	0.08	[29]
Risk of sequelae			
s1	Otitis	0.0001	[28]
s2	Encephalitis	0.25	[30]

Variable	Definition	Value	Source
Cost (CNY)			
c1	Direct cost (medical and non-medical)	4056.47	[31]
c2	Indirect cost	0-20: 4047.91 20+: 5334.74	[31]
c3	Loss of productivity due to death	0-20: 1814403.87 21-40: 1305314.21 40+: 354141.67	[32]
DALY weight			
u1	Mild cases	0.00102	[33]
u2	Severe cases	0.00266	
u3	Death	Below 1: 65.00 1-5: 63.05 6-20: 53.32 21-40: 37.08 40+: 16.90	

2.2 Pertussis

1) Model structure



2) Natural history & assumptions

Pertussis, commonly known as whooping cough, is a highly contagious respiratory disease caused by the bacterium *Bordetella pertussis*. The disease progresses through several stages, beginning with an incubation period of 7 to 10 days, during which the infected individual is asymptomatic but still capable of transmitting the bacterium. The initial catarrhal stage lasts 1 to 2 weeks and presents with mild cold-like symptoms such as coughing, sneezing, rhinorrhea, and low-grade fever, making it highly contagious. This is followed by the paroxysmal stage, which lasts 1 to 6 weeks and is characterized by severe, spasmodic coughing fits, often accompanied by a characteristic "whooping" sound during inhalation. These coughing episodes can lead to vomiting, exhaustion, and severe complications such as rib fractures or pneumonia, especially in infants and young children. Additionally, immunity from natural infection or vaccination wanes over time.

The pertussis model in this study is age-structured, with individuals categorized into different compartments based on their susceptibility, vaccination status, and infection state[34]. Newborns enter the population through the birth compartment (B) and are allocated into susceptible (S), partially immune (S2), or vaccinated (V) compartments based on vaccination coverage and vaccine effectiveness. Susceptible individuals (S) are those who have not received the vaccine and were at risk of exposure (E) to the pertussis pathogen. If exposed, they progress to the infected (I) state, where they can transmit the disease to other susceptible individuals. Recovered individuals (R) are assumed to have gained immunity, which wanes overtime. Infected individuals can experience varying levels of disease severity (mild, moderate, or severe) as depicted in the model. Severe cases may lead to pertussis-related deaths.

Vaccinated individuals still face the risk of infection due to vaccine failure or waning immunity. Previously immune individuals, who acquired immunity from vaccination or natural infection, remain susceptible to pathogen exposure and subsequent infection if their immunity wanes. This reflects the real-world scenario where vaccines, while highly effective, do not provide absolute protection.

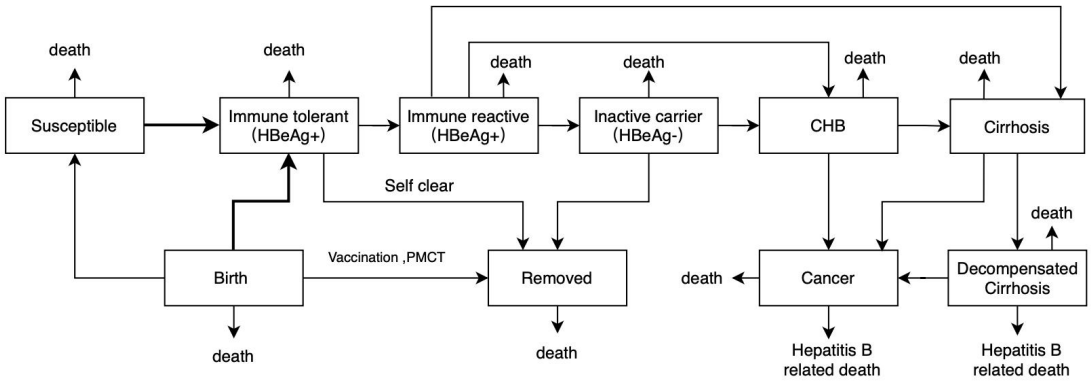
3) Important parameters

Variable	Definition	Value	Source
Epidemiology			
v	Vaccine effectiveness	79~88%	[35,36]
Alpha	Incubation period	7~10 days	[37]
Gamma	Time to recovery	5 weeks	[38]
Beta_v	Breakthrough infection rate	Fitted	
λ	Force of infection	Fitted	
CFR	Death rate for severe pertussis	Below 1: 0.0118 1-5: 0.0071 6-20: 0.0024 20+: 0.0086	[39]
w1	Annual immunity waning rate for natural infection-derived immunity	0.05~0.25	[39]
w2	Annual immunity waning rate for vaccine-derived immunity	0.05~0.1	[39]
Risk of complications			
p1	Mild pertussis	Below 1: 0.57 1-5: 0.21 6-20: 0.24 21-40: 0.11 40+: 0.14	[34,39]
p2	Moderate pertussis	Below 1: 0.27 1-5: 0.73 6-20: 0.73 21-40: 0.86 40+: 0.74	[34,39]
p3	Severe pertussis	Below 1: 0.15 1-5: 0.05 6-20: 0.02 21-40: 0.03 40+: 0.12	[34,39]
Risk of sequelae			
S1	Rate of developing sequelae after severe pertussis	Below 1: 0.0032 1-5: 0.0071 6-20: 0.0238 21-40: 0.0143 40+: 0.0143	[34,39]
Cost (CNY)			
c1	Direct cost (medical and non-medical)	6923.90	[31]
c2	Indirect cost	0-20: 5456.27 20+: 2464.57	[31]

Variable	Definition	Value	Source
c3	Loss of productivity due to death	0-20: 1814403.87	[32]
		21-40: 1305314.21	
		40+: 354141.67	
c4	Loss of productivity due to sequelae	0-20: 110678.64	[32,40]
		21-40: 79624.17	
		40+: 21602.64	
DALY weight			
u1	Mild and moderate cases	0.01	[33]
u2	Severe cases	Below 1: 1.12	
		1-5: 1.14	
		6-20: 1.08	
		21-40: 0.93	
		40+: 0.65	
u3	Death	Below 1: 65.00	
		1-5: 63.05	
		6-20: 53.32	
		21-40: 37.08	
		40+: 16.90	

2.3 Hepatitis B

1) Model structure



Abbreviations

HBeAg: Hepatitis B e antigen

CHB: Chronic hepatitis B

PMCT: Preventive mother-to-child transmission

2) Natural history & assumptions

Hepatitis B is a major public health concern in China, characterized by complex and widespread epidemiology and natural history. China has one of the highest rates of hepatitis B virus (HBV) infection globally, with an estimated 70 to 90 million people chronically infected. HBV is transmitted through vertical (mother-to-child), and horizontal (childhood and adult) routes, with mother-to-child

transmission being a significant contributor to chronic infections. The natural history of HBV infection includes an initial acute phase, which may be asymptomatic or present with mild to severe symptoms. While most adults clear the virus, a significant proportion of perinatal and childhood infections progress to chronic hepatitis B, marked by persistent HBV surface antigen (HBsAg) in the blood. Chronic infection can lead to serious liver diseases, including cirrhosis and hepatocellular carcinoma.

This model is built based on a previously established framework[41,42] and incorporates nine mutually exclusive health states to represent the internationally recognized natural history of chronic HBV infection: immune tolerant (IT), immune reactive (HBeAg positive chronic hepatitis, IR), inactive carrier (IC), reactivation (HBeAg negative chronic active hepatitis, CHB), compensated cirrhosis (CC), decompensated cirrhosis, and hepatocellular carcinoma (HCC). The IR and reactivation states capture chronic active hepatitis, characterized by high or fluctuating viral load, elevated transaminases, and evidence of fibrosis.

The model primarily focuses the dynamics of hepatitis B infection and disease progression. We assumed that acute hepatitis B is not simulated due to its relatively low disease burden in China. The stages of immune tolerant, immune reactive, inactive carrier, reactivation chronic hepatitis B, compensated cirrhosis, decompensated cirrhosis, and hepatocellular carcinoma collectively constitute the HBsAg+ prevalence in the model. Varying levels of infectiousness are assumed across stages, with all CHB patients receiving antiviral treatment.

We consider two types of transmission: horizontal transmission and vertical (mother-to-child) transmission.

For horizontal transmission:

$$\lambda(a,t) = \sigma \frac{WAIFW \cdot (m1 \cdot \boldsymbol{IT}(a,t) + m2 \cdot \boldsymbol{IA}(a,t) + m3 \cdot \boldsymbol{IC}(a,t) + m4 \cdot \boldsymbol{CHB}(a,t))}{\boldsymbol{N}(a,t)}$$

Where:

$WAIFW$: age stratified transmission rate

$N(a,t)$: population of age group a (5 age groups in the model) at time t (1990-2024)

σ: proportion of infected persons who develop chronic carriage from acute infection

m: multiplier on infectiousness

For vertical (mother-to-child) transmission:

$$\boldsymbol{IT}(1,t) = \beta \cdot Pa \cdot (\boldsymbol{IT}(a,t) + \boldsymbol{IA}(a,t) + \boldsymbol{IC}(a,t) + \boldsymbol{CHB}(a,t)) \cdot (1 - v1 \cdot e1)$$

$$\boldsymbol{S}(1,t) = \beta \cdot (\boldsymbol{N}(a,t) - Pa \cdot (\boldsymbol{IT}(a,t) + \boldsymbol{IA}(a,t) + \boldsymbol{IC}(a,t) + \boldsymbol{CHB}(a,t))) \cdot (1 - v2 \cdot e2)$$

$$\boldsymbol{R}(1,t) = \beta \cdot Pa \cdot (\boldsymbol{IT}(a,t) + \boldsymbol{IA}(a,t) + \boldsymbol{IC}(a,t) + \boldsymbol{CHB}(a,t)) \cdot (v1 \cdot e1) + \beta \cdot (\boldsymbol{N}(a,t) - Pa \cdot (\boldsymbol{IT}(a,t) + \boldsymbol{IA}(a,t) + \boldsymbol{IC}(a,t) + \boldsymbol{CHB}(a,t))) \cdot (v2 \cdot e2)$$

Where:

β: annual birth rate

Pa: 1 - coverage rate of antiviral treatment for mothers with Hep B infection

$v1$: coverage of hep B immunoglobulin prophylaxis

$e1$: effectiveness of hep B immunoglobulin prophylaxis

$v2$: coverage of Hep B three-dose vaccine

$e2$: effectiveness of Hep B three-dose vaccine

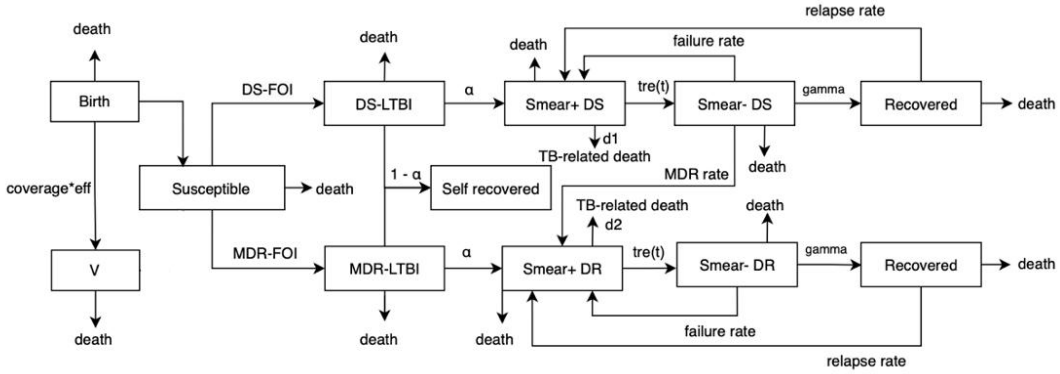
3) Important model parameters

Variable	Definition	Value	Source
Epidemiology			
λ	Force of infection	Fitted	
e1	Effectiveness of Hep B immunoglobulin prophylaxis	0.99	[43]
e2	Effectiveness of Hep B three-dose vaccine	0.95	[43]
k	Coverage rate of antiviral treatment for mothers with Hep B infection	0.72	[44]
Annual transition probabilities			
t1	Immune active to inactive carrier	0.005	[45,46]
t2	Inactive carrier to CHB	0.01	[46-48]
r1	Inactive carrier recover rate	0.01	[45,49,50]
r2	CHB recovery rate	0.0005	[51,52]
i1	Immune reactive to inactive carrier	Fitted	[42]
i2	Immune reactive to CHB	0.02	Assumed
i3	Immune reactive to Compensated cirrhosis	0.03	Assumed
p3	CHB to hepatocellular carcinoma	0-40: 0 40+: 0.003	[41]
p4	Compensated cirrhosis to decompensated cirrhosis	0.008	[41,53]
p5	Compensated cirrhosis to hepatocellular carcinoma	0-40: 0.009 40+: 0.021	[41]
p6	Decompensated cirrhosis to hepatocellular carcinoma	0.034	[54-56]
p7	Decompensated cirrhosis to death	0.160	[41,57]
p8	Hepatocellular carcinoma to death in first year	0.610	[41 58]
p9	Hepatocellular carcinoma to death in subsequent years	0.089	[41,58]
Direct medical cost (CNY)			
c1	CHB for inpatient cases	15812.29	[59]
c2	CHB for outpatient cases	2967.56	
c3	Compensated cirrhosis	25426.28	
c4	Decompensated cirrhosis	33219.17	
c5	Hepatocellular carcinoma	44856.43	
c6	Death	0-20:1814403.87 21-40:1305314.21 40+: 354141.67	[32]
Indirect cost (CNY)			
c7	CHB	4571.76	[59]

Variable	Definition	Value	Source
c8	Compensated cirrhosis	7340.98	[59]
c9	Decompensated cirrhosis	10496.31	
c10	Hepatocellular carcinoma	17373.83	
DALY weight			
u1	Decompensated cirrhosis	0.18	[33]
u2	Hepatocellular carcinoma	0.45	
u3	Death	Below 1: 65.00	
		1-5: 63.05	
		6-20: 53.32	
		21-40: 37.08	
		40+: 16.90	

2.4 Tuberculosis

1) Model structure



Abbreviations

DS-LTBI: Drug-sensitive latent tuberculosis infection

MDR-LTBI: Multi-drug-resistant latent tuberculosis infection

2) Natural history & assumptions

This model integrates the dynamics of drug-sensitive (DS) and multi-drug-resistant (MDR) tuberculosis (TB) infection, progression, and treatment outcomes. It is structured to capture key transitions between different health states, considering both natural progression and the impact of interventions such as vaccination and medical treatment. Individuals enter the model at birth and move into the susceptible population. A portion of these newborns receive vaccination, providing partial protection against TB. From the susceptible state, individuals can either remain uninfected or progress to latent TB infection, which is categorized as either drug-sensitive (DS-LTBI) or multi-drug-resistant (MDR-LTBI). The majority of individuals with latent TB may self-recover, while others progress to active TB. Active TB is further categorized into smear-positive (smear+) and smear-negative (smear-) states for both DS and MDR cases. We assumed that only smear-positive cases transmit the disease to others. Medical treatment can lead to recovery, although there is a risk of treatment failure. Following completion of medical treatment, individuals typically achieve recovery but may relapse into the smear+ state.

To reflect the effect of the Directly Observed Treatment, Short-course (DOTS) policy[60] recommended by the World Health Organization in the 1990s, which aimed to enhance TB cure rates and minimize transmission, we designed a sigmoid function to simulate the medical treatment coverage of active TB, as shown below.

$$tre(t,a) = 0.5 + \frac{0.45}{1 + \exp(-a(t - 1990))}$$

Where:

tre(t,a): treatment coverage of smear positive active TB

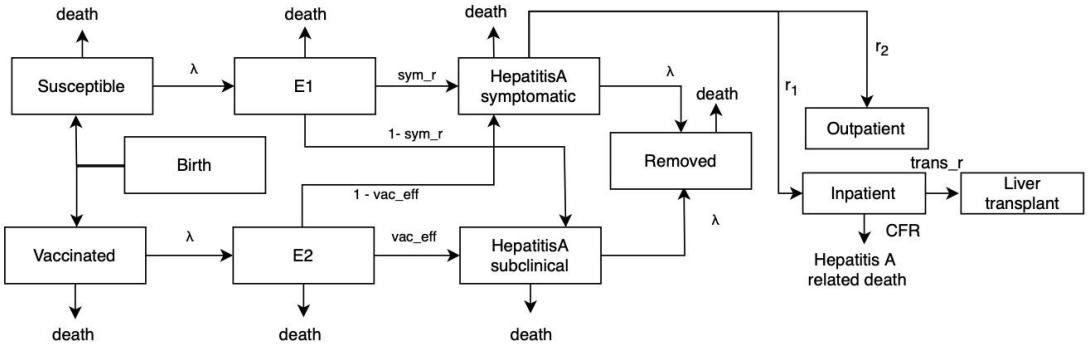
a: function parameter (fitted)

3) Important model parameters

Variable	Definition	Value	Source
Epidemiology			
v	Effectiveness for BCG vaccine	18%	[61]
Alpha	TB disease rate	5%~20%	[62]
Gamma1	Infectious period for DS	6 months	[63]
Gamma2	Infectious period for MDR	9 months	[64]
λ	Force of infection	Fitted	
f	Failure rate of medical treatment	DS-TB: 0.07	[65,66]
		MDR-TB: 0.43	
d1	CFR after treatment failure for DS-TB	0.067	[67,68]
e	CFR during treatment for MDR-TB	0.14	[69]
d2	CFR after treatment failure for MDR-TB	0.15	[69]
g	DS to MDR transition rate	0.014	[66]
r	Relapse rate	0.01	[70-72]
tre(t)	Medical treatment coverage rate	Fitted	
Direct medical cost (CNY)			
c1	DS-TB	7358.00	[73,74]
c2	MDR-TB	108761.00	
Indirect cost (CNY)			
c3	DS-TB/MDR-TB	18442.00	[73,74]
c4	Death	0-20: 1814403.87	[32]
		21-40: 1305314.21	
		40+: 354141.67	
DALY weight			
u1	TB cases	0.33	[33,75]
u2	Death	Below 1: 65.00	
		1-5: 63.05	
		6-20: 53.32	
		21-40: 37.08	
		40+: 16.90	

2.5 Hepatitis A

1) Model structure



2) Natural history & assumptions

The hepatitis A model begins with individuals classified as either susceptible or vaccinated. Both susceptible and vaccinated individuals can become exposed to the Hepatitis A, transitioning to the exposed states E1 or E2. Once exposed, individuals may remain asymptomatic (subclinical infection) or develop symptoms, with the probability of symptomatic infection determined by the parameter sym_r and vaccination status. Vaccinated individuals were protected against symptomatic infection through vaccine effectiveness. In our model, subclinical cases remain asymptomatic, but contribute to virus transmission with reduced infectiousness, whereas symptomatic cases exhibited typical signs of hepatitis A, such as fever, jaundice, and fatigue.

Symptomatic individuals follow a decision tree determining their treatment status. Based on severity, they may receive outpatient or inpatient care, with the most severe cases potentially requiring a liver transplant. Both symptomatic and subclinical cases ultimately transition to the removed state upon recovery, signifying the acquisition of lifelong immunity to the virus. Deaths can occur at various stages due to hepatitis A-related complications or other causes.

3) Important model parameters

Variable	Definition	Value	Source
Epidemiology			
Alpha	Incubation period	28 days	[76,77]
Gamma	Time to recovery	21 days	[76,77]
sym_r	Symptomatic rate	Below 1: 0.10	[78]
		1-5: 0.20	
		6-20: 0.30	
		21-40: 0.81	
		40+: 0.81	
vac_eff	Effectiveness of Hep A vaccine	95%	[79,80]
r_1	Inpatient rate	0-20: 0.08	[81]
		20+: 0.15	

Variable	Definition	Value	Source
r_2	Outpatient rate	0-20: 0.92	[81]
		20+: 0.85	
λ	Force of infection	Fitted	
CFR	Case-fatality ratio	0-40: 0.004	[82,83]
		40+: 0.057	
trans_r	Liver transplant rate	Below 1: 0	[82,83]
		1-5: 0	
		6-20: 0.0003	
		21-40: 0.0012	
		40+: 0.0036	
Cost (CNY)			
c1	Direct cost (medical and non-medical)	11681.27	[31]
c2	Indirect cost	0-20: 2286.40	[31]
		20+: 7219.16	
c3	Loss of productivity due to death	0-20: 1814403.87	[32]
		21-40: 1305314.21	
		40+: 354141.67	
DALY weight			
u1	Inpatient case	0.025	[33]
u2	Outpatient case	0.005	
u3	Death	Below 1: 65.00	
		1-5: 63.05	
		6-20: 53.32	
		21-40: 37.08	
		40+: 16.90	

2.6 Japanese encephalitis

1) Natural history & assumptions

Japanese encephalitis (JE) is a vector-borne viral disease transmitted primarily by Culex mosquitoes, with pigs and birds serving as amplifying hosts. Humans are incidental hosts and typically represent a dead-end in the transmission cycle, meaning they do not significantly contribute to further transmission of the virus. In endemic areas, the transmission of JE tends to be stable over time, with consistent exposure risks due to environmental and ecological factors that support mosquito breeding and virus amplification in animal hosts[84,85]. This stability allows for the application of a constant force of infection assumption, which is suitable for a catalytic model, simplifying the modeling process. The catalytic model leverages age-specific seroprevalence data to estimate the cumulative incidence of infection[86]. By analyzing the proportion of individuals who have antibodies against JE in different age cohorts, the average age of infection and the force of infection can be estimated.

In this study, we incorporate vaccination into the model as a removal of susceptible individuals (or a reduction in risk of infection in this vaccinated group, depending on vaccine effectiveness) and does not alter the force of infection. Therefore, in this model, individuals can become immune to infection through either natural infection (depending on the force of infection) or vaccination.

Denoting $s'(a,t)$ as the susceptible population of age group a in year t and $c(a,t)$ as the proportion of the vaccinated population in age group a in year t, we obtain:

$$s'(a,t) = pop(a,t) \cdot (1 - c(a,t))$$

Then, we use the following formula to estimate the incidence:

$$I(a,t) = (1 - e^{-\lambda}) \cdot e^{1-\lambda \cdot a} \cdot p \cdot s'(a,t)$$

where:

$I(a,t)$: incident cases of age group a in year t

λ: force of infection

p: symptomatic rate

$s'(a,t)$: susceptible population of age group a in year t

We fit the model-generated incident cases to the reported incident cases to estimate the force of infection for JE. Subsequently, we construct a counterfactual scenario without vaccination, where $s'(a,t) = pop(a,t)$.

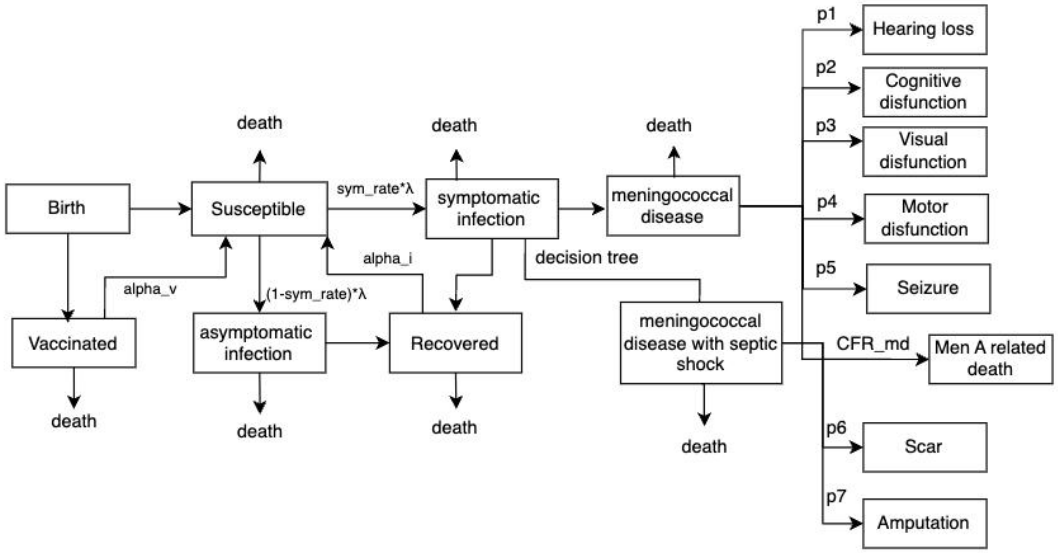
2) Important model parameters

Variable	Definition	Value	Source
Epidemiology			
λ	Force of infection	Fitted	
vac eff	Effectiveness of JE vaccine	100%	[3]
CFR	Case-fatality ratio	0.15	[87]
Risk of sequelae			
s1	Long-term sequelae rate	0.30	[87]
Cost (CNY)			
c1	Direct medical cost	21950.00	[87]

Variable	Definition	Value	Source
c2	Indirect cost	0-20: 18257.83	[87]
		20+: 9076.39	
c3	Loss of productivity due to death	0-20: 1814403.87	[32]
		21-40: 1305314.21	
		40+: 354141.67	
DALY weight			
u1	Base-case	0.10	[33]
u2	Sequelae	Below 1: 15.29	
		1-5: 16.58	
		6-20: 12.08	
		21-40: 8.28	
		40+: 3.88	
u3	Death	Below 1: 65.00	
		1-5: 63.05	
		6-20: 53.32	
		21-40: 37.08	
		40+: 16.90	

2.7 Meningitis A

1) Model structure



2) Natural history & assumptions

Meningococcal disease, caused by the bacterium *Neisseria meningitidis*, is a serious and potentially life-threatening infection. It can lead to meningitis, an inflammation of the membranes surrounding the brain and spinal cord, or septicemia, a bloodstream infection. The disease is characterized by sudden onset of symptoms such as fever, headache, stiff neck, and septic shock in severe cases. If not treated promptly, meningococcal disease can result in significant morbidity and mortality[88].

Our model captures the progression and outcomes of meningococcal disease, incorporating both vaccinated and unvaccinated populations. Individuals enter the model at birth and may either remain susceptible to infection or receive vaccination. Vaccinated individuals are protected, but their immunity wanes at a fixed annual rate. Susceptible individuals can either stay healthy or become infected, with infections potentially being asymptomatic or symptomatic. Asymptomatic infections may go undetected but can still contribute to disease transmission. Once an individual develops a symptomatic infection, the model considers several potential pathways and outcomes. A symptomatic infection can progress to meningococcal disease, characterized by severe symptoms that require medical intervention. In some cases, the infection escalates to meningococcemia, a critical and life-threatening condition often leading to organ failure and high mortality. Survivors of these severe forms of the disease faced substantial risks of long-term complications, including hearing loss, cognitive dysfunction (impairments in memory, attention, and problem-solving abilities), visual dysfunction (issues with vision, including blindness), motor dysfunction (physical impairments affecting movement and coordination), seizures (persistent seizures or epilepsy), scarring (resulting from severe skin infections or surgical interventions), and amputation (loss of limbs due to severe tissue damage and necrosis caused by septic shock).

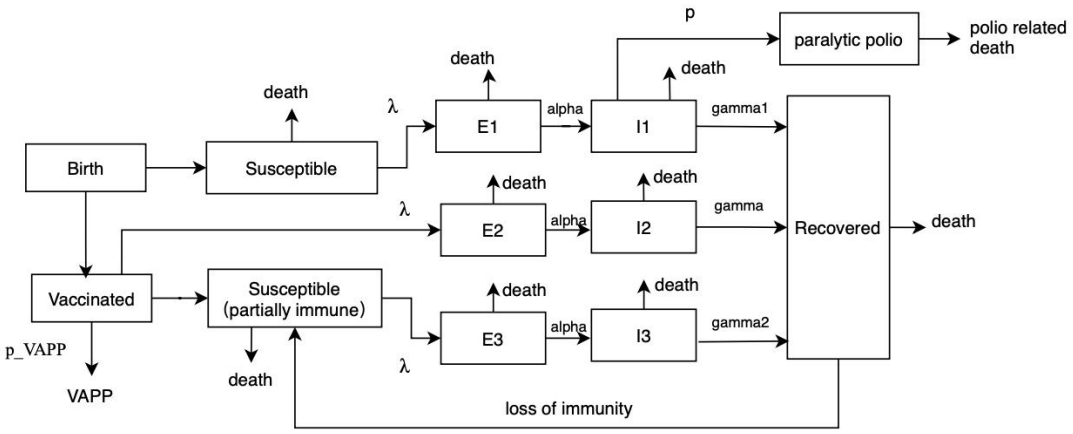
3) Important model parameters

Variable	Definition	Value	Source
Epidemiology			
Theta	Incubation period	4 days	[89,90]
Gamma	Time to recovery	7 weeks	[89,90]
sym_rate	Symptomatic rate	Below 1: 0.01	[91]
		1-5: 0.005	
		6-20: 0.005	
		21-40: 0.0005	
		40+: 0.0008	
Alpha_i	Annual natural immunity waning rate	0.02~0.05	Assumed
Alpha_v	Annual vaccinated immunity waning rate	0.1~0.2	Assumed
vac_eff	Effectiveness of Men A vaccine	90%	[92]
md	Meningococcal meningitis	0.651	[93,94]
mds	Meningococcemia	0.349	[93,94]
λ	Force of infection	Fitted	
md_death	Meningococcal disease death ratio	0.021	[93]
mds_death	Meningococcemia death ratio	0.130	[93]
Sequelae in MD			
p1	Hearing loss	0.046	[95]
p2	Cognitive disfunction	0.029	[95]
p3	Visual disfunction	0.027	[95]
p4	Motor disfunction	0.018	[95]
p5	Seizure	0.009	[95]
Sequelae in MDS			
p6	Skin scarring	0.090	[96]
p7	Amputation	0.286	[97,98]
Cost (CNY)			
c1	Direct cost (medical and non-medical)	53614.35	[31]
c2	Indirect cost	0-20: 6892.13	[31]
		20+: 70788.96	
c3	Hearing loss cost	163001.30	CHIRA
c4	Cognitive disfunction cost	263292.50	CHIRA
c4	Visual disfunction cost	46364.77	[99]
c5	Motor disfunction cost	12646.72	CHIRA
c6	Seizure cost	6000.88	CHIRA
c7	Amputation cost	33573.35	[100]
c9	Loss of productivity due to death	0-20: 1814403.87	[32]
		21-40: 1305314.21	
		40+: 354141.67	
DALY weight			
u1	Meningococcal disease	0.022	[33]

Variable	Definition	Value	Source
u2	Hearing loss	Below 1: 0.50	[33]
		1-5: 0.51	
		6-20: 0.48	
		21-40: 0.41	
		40+: 0.29	
u3	Cognitive disfunction	Below 1: 0.79	
		1-5: 0.80	
		6-20: 0.76	
		21-40: 0.66	
		40+: 0.46	
u4	Visual disfunction	Below 1: 0.57	
		1-5: 0.58	
		6-20: 0.55	
		21-40: 0.47	
		40+: 0.33	
u5	Motor disfunction	Below 1: 1.12	
		1-5: 1.14	
		6-20: 1.08	
		21-40: 0.93	
		40+: 0.65	
u6	Seizure	Below 1: 4.84	
		1-5: 4.92	
		6-20: 4.64	
		21-40: 4.01	
		40+: 2.80	
u7	Amputation	Below 1: 3.08	
		1-5: 3.12	
		6-20: 2.94	
		21-40: 2.54	
		40+: 1.78	
u8	Death	Below 1: 65.00	
		1-5: 63.05	
		6-20: 53.32	
		21-40: 37.08	
		40+: 16.90	

2.8 Poliomyelitis

1) Model structure



Abbreviation

VAPP: Vaccine-associated paralytic polio

2) Natural history & assumptions

Poliomyelitis, commonly known as polio, is a highly infectious viral disease that primarily affects young children. The virus is transmitted through contaminated water and food and multiplies in the intestine, from where it can invade the nervous system. The majority of infections are asymptomatic or result in mild illnesses, but a small proportion of cases lead to paralytic polio, characterized by severe muscle weakness and paralysis[101]. The model constructed in this study captures the natural history and progression of polio, which incorporates both vaccinated and unvaccinated populations.

In the early stages of immunization programs in China, individuals received oral polio vaccine (OPV), which was effective but carried a risk of vaccine-associated paralytic polio (VAPP). As the program evolved, a combination of OPV and inactivated polio vaccine (IPV) was adopted in China, mitigating the risk of VAPP. In the model, newborns can either remain susceptible or receive vaccination. Vaccinated individuals may still experience breakthrough infections or waning immunity over time, leading to a transition to the exposed state or partially immune susceptible state. These partially immune individuals can still get infected, but do not result in paralytic polio. Only those in the fully susceptible group, who have never been immunized, are at risk of developing paralytic polio.

3) Important model parameters

Variable	Definition	Value	Source
Epidemiology			
v	Effectiveness of Polio vaccine	100%	[102,103]
Alpha	Incubation period	2 days	[104]
Gamma1	Infectious period for fully susceptible individuals	35 days	
Gamma	Infectious period for vaccinated susceptible individuals	7 days	

Variable	Definition	Value	Source
Gamma2	Infectious period for partially susceptible individuals	9 days	[104]
λ	Force of infection	Fitted	
P_VAPP	VAPP rate	OPV: 3/1000000 IPV: 0	[105,106]
w	Waning rate for polio immunity	0.5 per year	[104]
Risk of complications			
P	Infection to paralysis rate	0.005	[107]
CFR	CFR for paralysis cases	0.05~0.10	[107,108]
Cost (CNY)			
c1	Direct medical cost	7893.00	[109]
c2	Indirect cost	Below 1: 168815.30 1-5: 188253.90 6-20: 294714.40 21-40: 326593.60 40+: 132445.90	[109]
c3	Loss of productivity due to death	0-20: 1814403.87 21-40: 1305314.21 40+: 354141.67	[109]
c4	Compensation for VAPP	870805.00	[110]
DALY weight			
u1	Paralysis cases	Below 1: 19.24 1-5: 18.66 6-20: 15.78 21-40: 10.97 40+: 5.00	[33]
u2	Death	Below 1: 65.00 1-5: 63.05 6-20: 53.32 21-40: 37.08 40+: 16.90	

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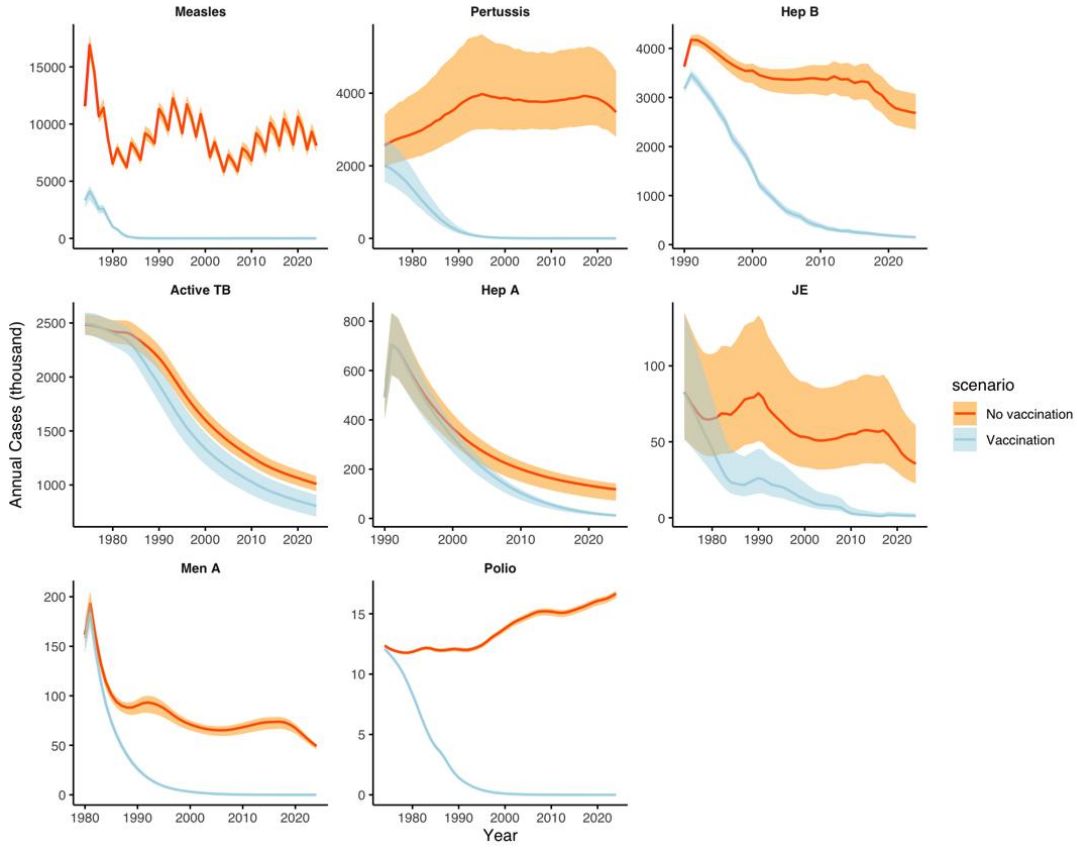
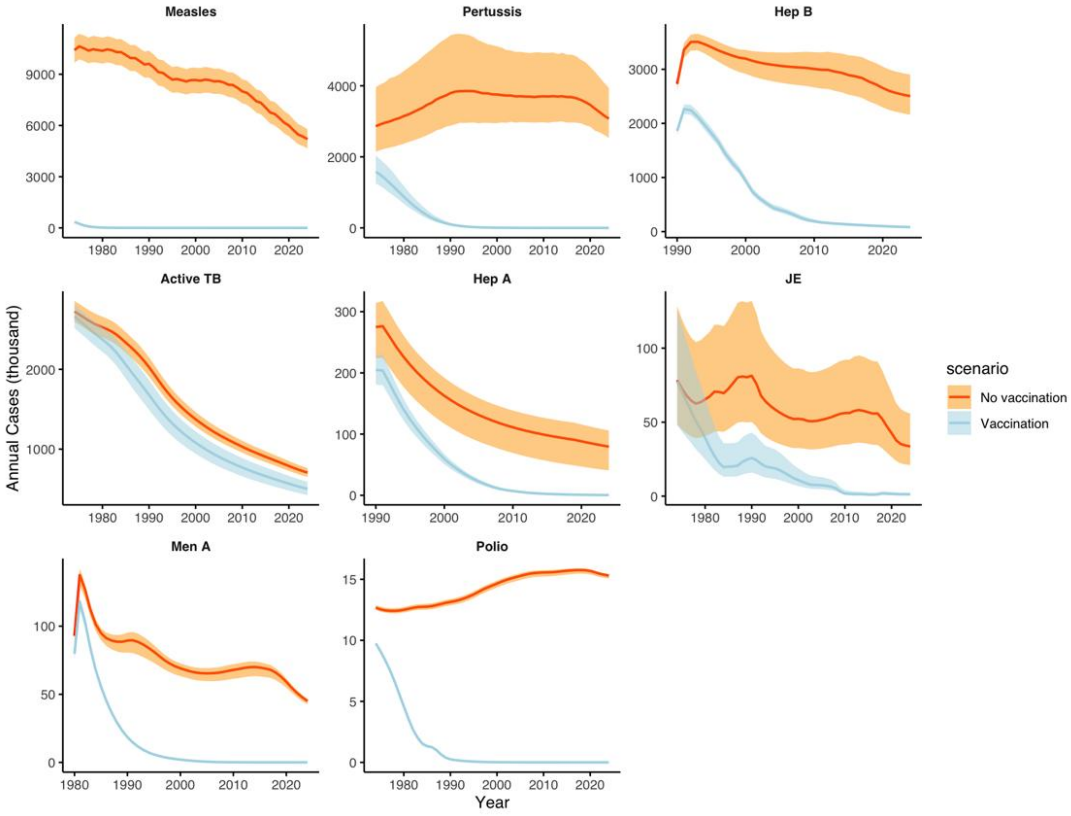
3. Supplementary results

3.1 Estimates of pathogen-specific cases, from 1974 to 2024, for reported and projected vaccine coverage (vaccination) and counterfactual coverage (no vaccination), based on the calendar year approach



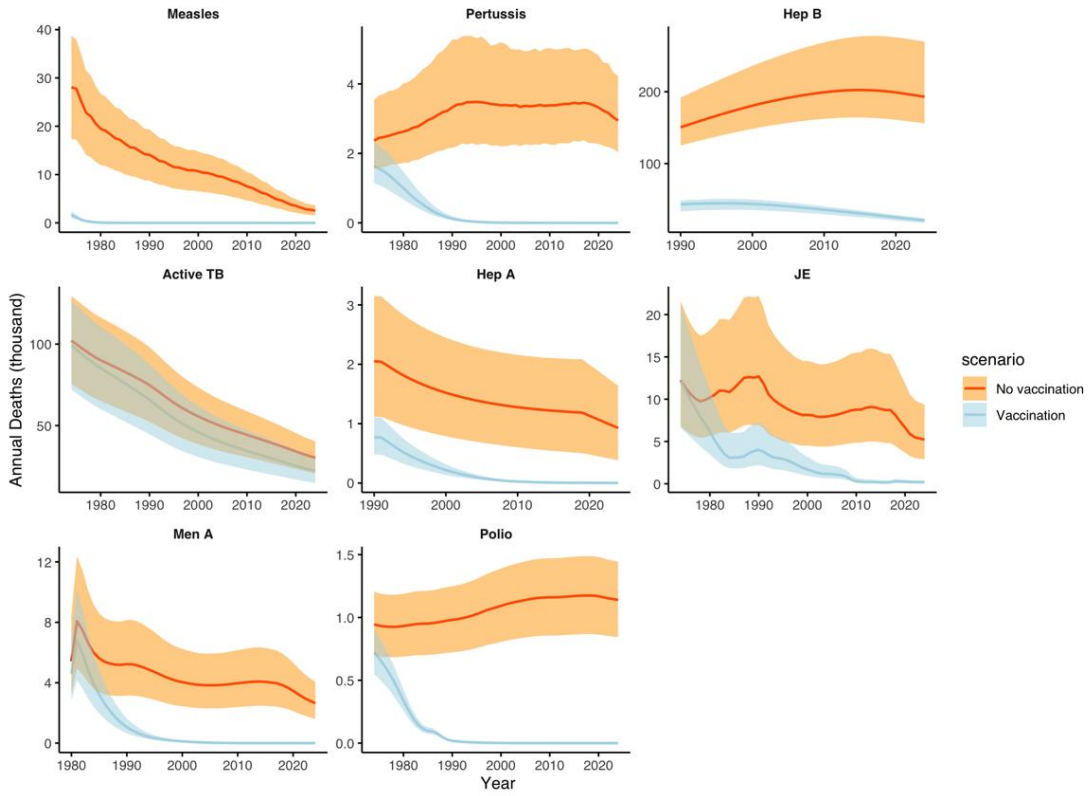
The lines represent the estimated medians for the scenarios, while the shaded areas show the 95% credible intervals (CIs). Gray shaded regions highlight where the 95% credible intervals (CIs) for the two scenarios overlap.

3.2 Estimates of pathogen-specific cases, from 1974 to 2024, for reported and projected vaccine coverage (vaccination) and counterfactual coverage (no vaccination), based on the birth cohort approach



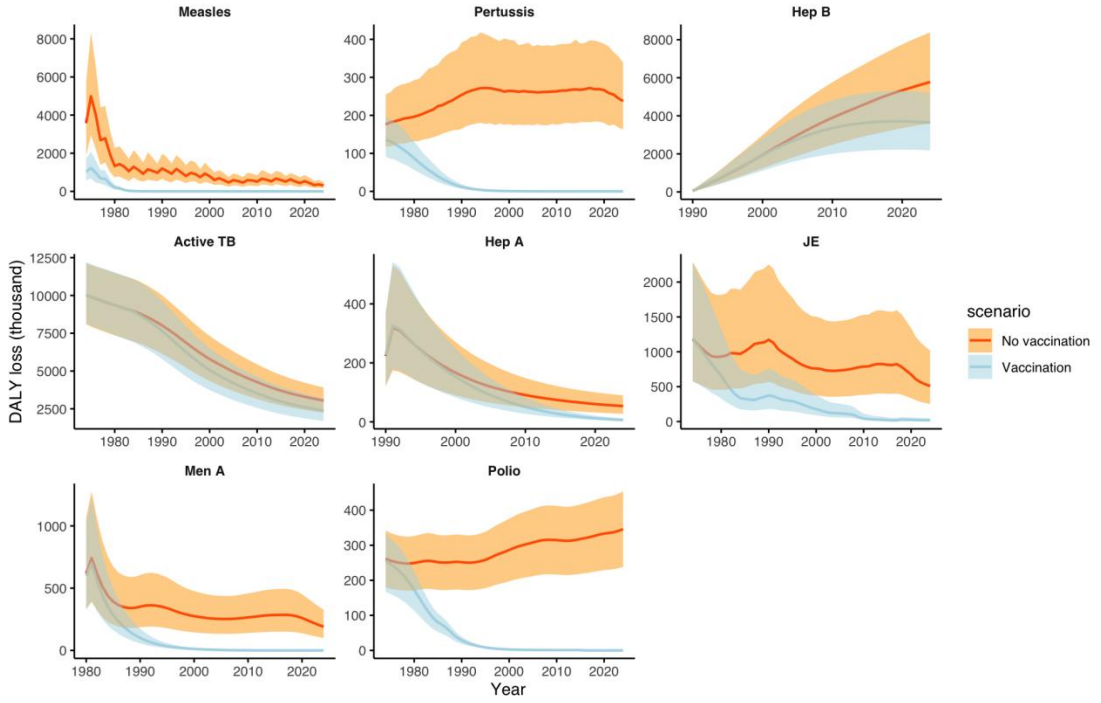
The lines represent the estimated medians for the scenarios, while the shaded areas show the 95% credible intervals (CIs). Gray shaded regions highlight where the 95% credible intervals (CIs) for the two scenarios overlap.

3.3 Estimates of pathogen-specific deaths, from 1974 to 2024 in China, for reported and projected vaccine coverage (vaccination) and counterfactual coverage (no vaccination), based on the birth cohort approach



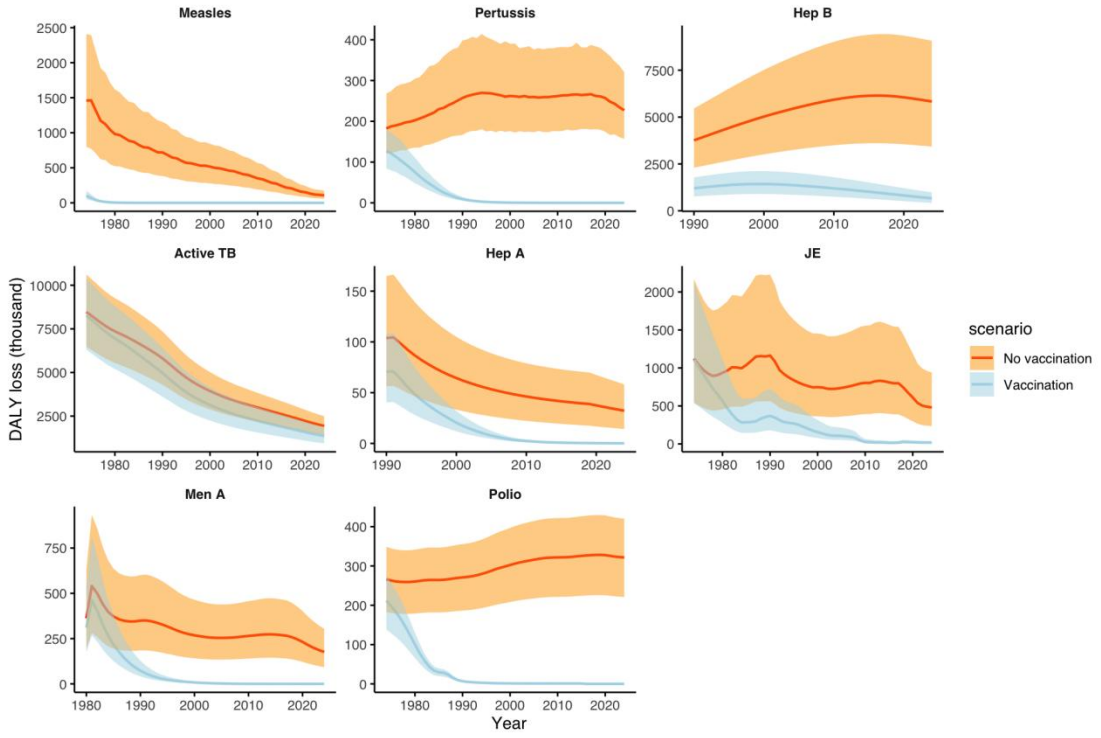
The lines represent the estimated medians for the scenarios, while the shaded areas show the 95% credible intervals (CIs). Gray shaded regions highlight where the 95% credible intervals (CIs) for the two scenarios overlap. The estimates based on the calendar year approach are shown in Figure 2 of the manuscript.

3.4 Estimates of pathogen-specific DALYs, from 1974 to 2024, for reported and projected vaccine coverage (vaccination) and counterfactual coverage (no vaccination), based on the calendar year approach



The lines represent the estimated medians for the scenarios, while the shaded areas show the 95% credible intervals (CIs). Gray shaded regions highlight where the 95% credible intervals (CIs) for the two scenarios overlap.

3.5 Estimates of pathogen-specific DALYs, from 1974 to 2024, for reported and projected vaccine coverage (vaccination) and counterfactual coverage (no vaccination), based on the birth cohort approach

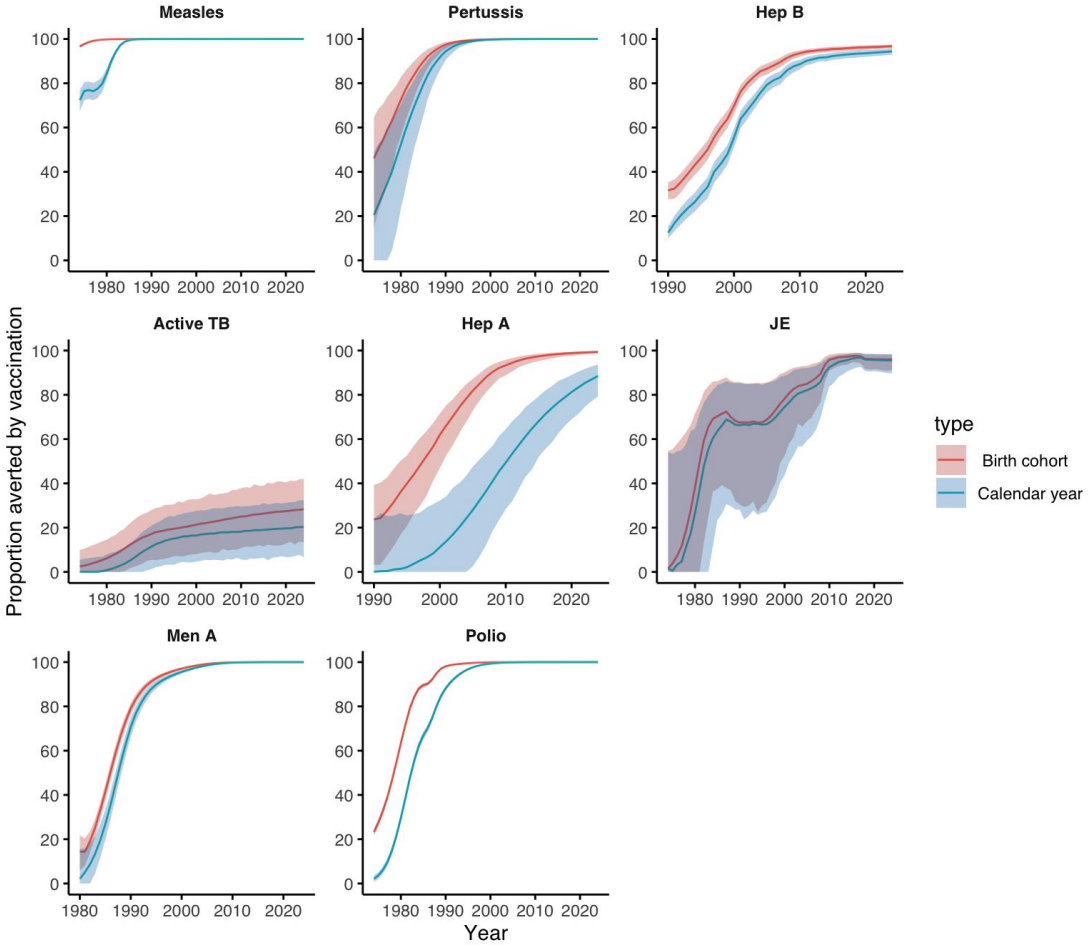


The lines represent the estimated medians for the scenarios, while the shaded areas show the 95% credible intervals (CIs). Gray shaded regions highlight where the 95% credible intervals (CIs) for the two scenarios overlap.

3.6 Deaths averted per 1,000 vaccinated individuals

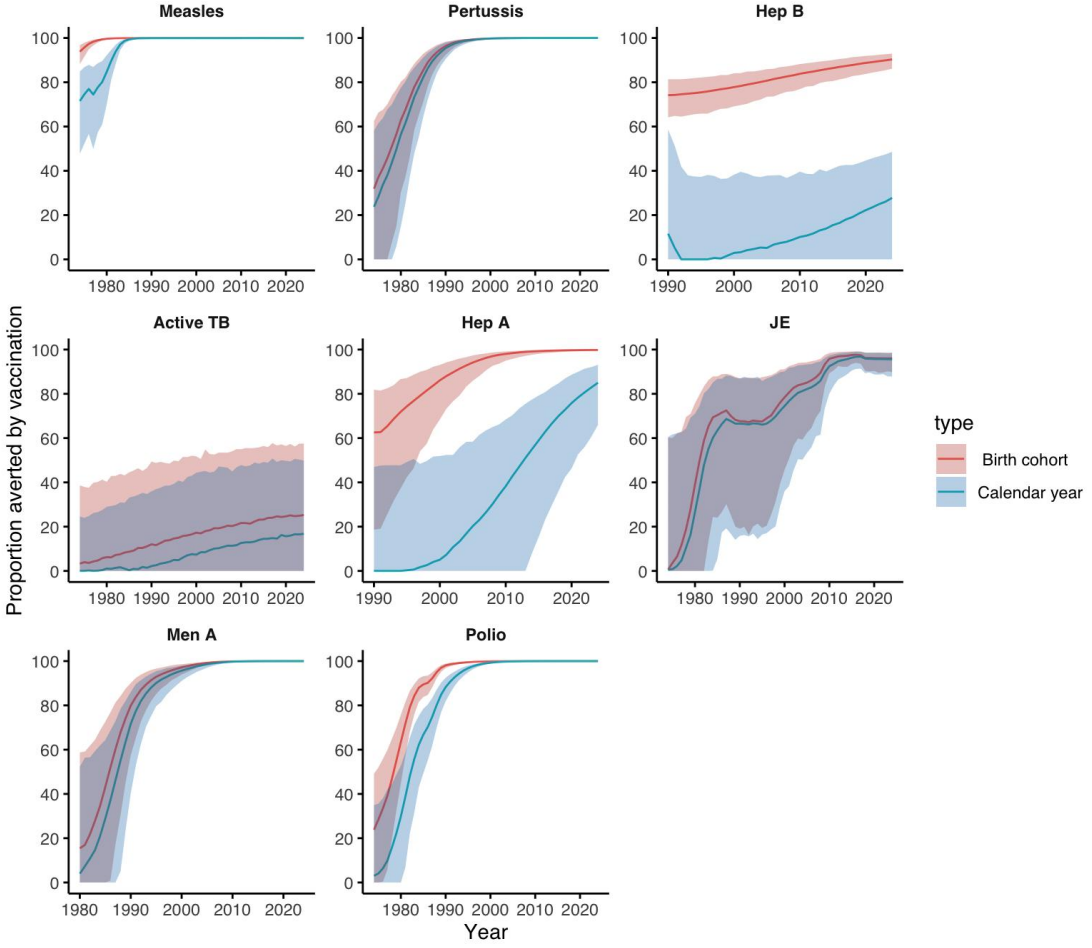
Pathogen	Death averted per 1,000 vaccinated individuals					
	Calendar year			Birth cohort		
	Median	Lower	Upper	Median	Lower	Upper
Measles	1.45	1.31	1.58	0.84	0.78	0.91
Pertussis	0.23	0.21	0.25	0.23	0.21	0.25
Hep B	1.22	0.57	1.88	12.69	11.79	13.60
Active TB	0.31	0.00	0.65	0.52	0.22	0.81
JE	0.87	0.72	1.00	0.89	0.76	1.02
Polio	0.06	0.05	0.06	0.06	0.06	0.07
Hep A	0.09	0.02	0.15	0.13	0.11	0.14
Men A	0.30	0.26	0.34	0.30	0.27	0.34

3.7 Proportion of pathogen-specific cases that would be prevented by vaccination based on the calendar year and birth cohort approaches



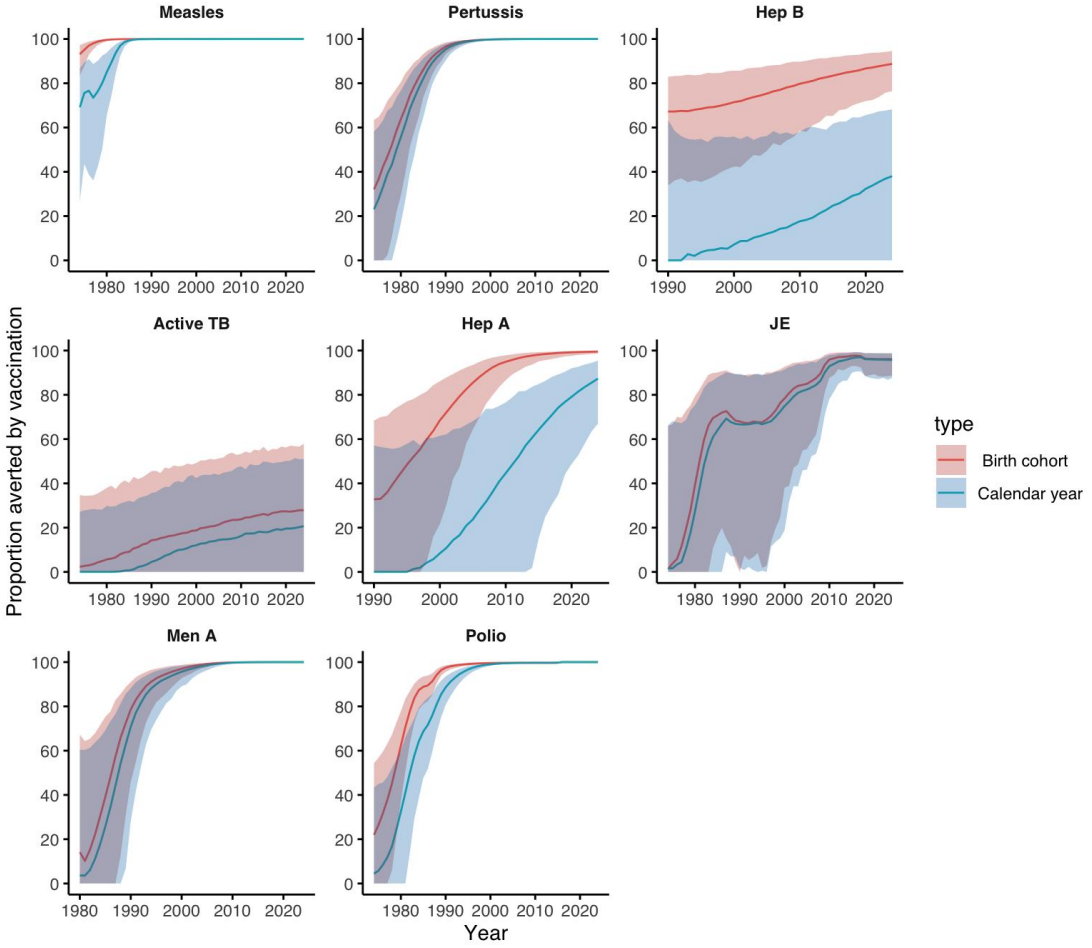
The lines represent the estimated proportion medians for the approaches, while the shaded areas show the 95% credible intervals (CIs). Gray shaded regions highlight where the 95% credible intervals (CIs) for the two approaches overlap.

3.8 Proportion of pathogen-specific deaths that would be prevented by vaccination based on the calendar year and birth cohort approaches



The lines represent the estimated proportion medians for the approaches, while the shaded areas show the 95% credible intervals (CIs). Gray shaded regions highlight where the 95% credible intervals (CIs) for the two approaches overlap.

3.9 Proportion of pathogen-specific DALYs that would be prevented by vaccination based on the calendar year and birth cohort approaches



The lines represent the estimated proportion medians for the approaches, while the shaded areas show the 95% credible intervals (CIs). Gray shaded regions highlight where the 95% credible intervals (CIs) for the two approaches overlap.

3.10 Cost decomposition based on the calendar year and birth cohort approaches

Indicator	Disease cost[1] (in billion USD)			Vaccination cost[2] (in billion USD)		
	Direct disease cost	Other disease cost	Total	Direct vaccination cost	Other vaccination cost	Total
Calendar year						
Vaccination	614.42	2030.11	2644.53	69.91	54.15	124.06
	(597.01,655.72)	(1966.67,2149.08)	(2591.80,2832.63)	(67.86,71.81)	(52.63,56.89)	(120.49,127.49)
No vaccination	892.90	3009.24	3902.14	0	0	0
	(879.07,945.93)	(2981.20,3256.79)	(3860.27,4146.54)	(0,0)	(0,0)	(0,0)
Averted	278.48	979.13	1257.61	\	\	\
	(241.96,330.93)	(854.68,1157.95)	(1096.64,1488.88)	\	\	\
Birth cohort						
Vaccination	272.49	1086.35	1358.84	69.91	54.15	124.06
	(267.80,295.21)	(1072.20, 1187.06)	(1339.52,1482.27)	(67.86,71.81)	(52.63,56.89)	(120.49,127.49)
No vaccination	832.87	2943.82	3776.69	0	0	0
	(823.34,890.04)	(2851.82, 3107.92)	(3483.72,4120.10)	(0,0)	(0,0)	(0,0)
Averted	560.38	1857.47	2417.85	\	\	\
	(539.54,611.92)	(1819.84,2098.43)	(2359.38,2710.35)	\	\	\

1. Direct disease costs encompass the direct medical expenses associated with treating vaccine-preventable diseases. Other disease costs include direct non-medical expenses such as transportation, nutrition, and nursing care, and indirect costs. Indirect costs account for labor productivity gains from reduced disease burden, the prevention of premature deaths, and the accompanying time and effort provided by guardians or relatives attending to patients. Total disease costs are the sum of direct disease costs and other disease costs.
2. Direct vaccination costs include expenses for vaccine procurement and vaccination administrative services. Other vaccination costs include transportation and time costs incurred by children's guardians for vaccination. Total vaccination costs are the sum of direct vaccination costs and other vaccination costs.
3. In economic evaluations, the healthcare provider's perspective considers only direct disease cost and direct vaccination cost. In contrast, the societal perspective adopts total costs, which encompass a broader range of expenses.

3.11 Benefit-cost ratios of eight vaccines from 1974 to 2024 from societal perspective, based on the calendar year approach

Vaccine	Total disease cost (in billion USD)				Total vaccination cost (in billion USD)	BCR
	No vaccination	Vaccination	Averted	Reduction (%)		
Measles	492.38 (304.45,735.32)	35.81 (20.46,57.78)	456.57 (425.51,519.55)	92.73 (90.48,94.32)	13.14 (8.08,18.22)	34.75 (31.89,40.52)
Pertussis	105.45 (72.03,157.09)	10.57 (7.15,15.66)	94.88 (92.83,108.32)	89.98 (88.51,91.46)	23.38 (14.16,33.14)	4.05 (3.84,4.75)
Hep B	1552.91 (1167.78,2014.74)	1271.74 (921.25,1633.25)	281.17 (185.48,421.76)	18.11 (12.33,25.59)	10.13 (6.22,14.05)	27.75 (18.18,42.28)
BCG	1361.57 (864.33,1913.41)	1202.32 (772.52,1765.23)	159.25 (1.28,264.67)	11.7 (0.10,18.44)	3.84 (2.23,5.07)	41.47 (0.00,74.43)
Hep A	37.34 (19.93,61.36)	29.56 (16.19,48.59)	7.78 (1.34,15.16)	20.84 (3.6,34.75)	8.36 (5.13,11.58)	0.93 (0.12,1.79)
JE	149.88 (72.67,312.65)	48.71 (24.11,107.84)	101.17 (95.4,142.11)	67.5 (58.7,72.67)	16.56 (10.13,22.98)	6.10 (5.60,8.74)
Men A	100.8 (60.23,155.67)	28.68 (17.33,44.13)	72.12 (64.88,86.13)	71.55 (65.91,76.91)	20.91 (12.84,29.05)	3.45 (3.02,4.22)
Polio	101.81 (66.92,133.66)	17.14 (11.75,23.28)	84.67 (76.9,89.34)	83.16 (80.63,84.81)	27.74 (16.91,38.55)	3.05 (2.71,3.33)
Aggregate	3902.14 (3860.27,4146.54)	2644.53 (2591.8,2832.63)	1257.61 (1096.64,1488.88)	32.23 (28.11,36.17)	124.06 (120.49,127.49)	10.13 (8.87,12.01)

BCR: Benefit-Cost Ratio, computed by dividing the total benefits by the total costs. A BCR exceeding 1 indicates that benefits outweigh costs, while a BCR below 1 suggests the intervention may not be economically viable.

3.12 Benefit-cost ratios of eight vaccines from 1974 to 2024 from societal perspective, based on the birth cohort approach

Vaccine	Total Disease cost (in billion USD)				Total Vaccination cost (in billion USD)	BCR
	No vaccination	Vaccination	Averted	Reduction (%)		
Measles	350.93 (221.21,516.43)	1.63 (0.96,2.59)	349.3 (333.36,387.87)	99.54 (99.38,99.65)	13.14 (8.08,18.22)	26.58 (24.79,30.45)
Pertussis	105.03 (72.02,156.01)	8.5 (5.79,12.25)	96.53 (94.72,109.63)	91.91 (90.9,93.1)	23.38 (14.16,33.14)	4.13 (3.91,4.82)
Hep B	1919.14 (1431.17,2707.07)	419.83 (304.1,545.42)	1499.31 (1459.12,1740.87)	78.12 (76.98,80.93)	10.13 (6.22,14.05)	148.01 (128.80,178.90)
BCG	1040.65 (662.29,1474.77)	850.92 (554.31,1262.82)	189.73 (65.48,274.02)	18.23 (6.49,24.36)	3.84 (2.23,5.07)	49.41 (17.27,74.73)
Hep A	16.31 (7.78,27.83)	4.88 (2.62,8.1)	11.43 (9.63,14.49)	70.08 (62.72,76.1)	8.36 (5.13,11.58)	1.37 (1.14,1.78)
JE	146.92 (71.05,304.61)	43.74 (21.35,93.18)	103.18 (99.42,145.75)	70.23 (62.53,75.86)	16.56 (10.13,22.98)	6.23 (5.88,8.86)
Men A	92.11 (55.49,142.16)	19.36 (11.71,29.27)	72.75 (67.5,85.87)	78.98 (75.1,83.01)	20.91 (12.84,29.05)	3.48 (3.15,4.20)
Polio	105.6 (69.23,138.7)	9.98 (6.8,13.58)	95.62 (88.35,100.41)	90.55 (88.99,91.55)	27.74 (16.91,38.55)	3.44 (3.09,3.74)
Aggregate	3776.69 (3483.72,4120.10)	1358.84 (1339.52,1482.27)	2417.85 (2359.38,2710.35)	64.02 (61.84,66.47)	124.06 (120.49,127.49)	19.48 (18.82,22.08)

BCR: Benefit-Cost Ratio, computed by dividing the total benefits by the total costs. A BCR exceeding 1 indicates that benefits outweigh costs, while a BCR below 1 suggests the intervention may not be economically viable.

3.13 Benefit-cost ratios of eight vaccines from 1974 to 2024 from healthcare provider's perspective, based on the calendar year approach

Vaccine	Direct Disease cost (in billion USD)				Direct Vaccination cost (in billion USD)	BCR
	No vaccination	Vaccination	Averted	Reduction (%)		
Measles	103.89	4.29	99.6	95.87	9.31	10.69
	(60.86,150.51)	(2.49,6.67)	(92.17,108.32)	(94.74,96.66)	(5.7,12.93)	(9.70,12.02)
Pertussis	34.7	3.56	31.14	89.74	12.66	2.46
	(23.79,52.57)	(2.42,5.45)	(30.59,35.86)	(88.08,91.14)	(7.64,17.9)	(2.35,2.90)
Hep B	464.65	376.81	87.84	18.90	5.69	15.44
	(343.44,608.46)	(262.52,500.67)	(54.05,130.54)	(11.87,26.49)	(3.51,7.9)	(9.65,22.83)
BCG	233.57	206.6	26.97	11.55	3.84	7.02
	(156.97,329.54)	(142.99,292.86)	(6.02,46.75)	(2.63,18.64)	(2.23,5.07)	(1.54,12.76)
Hep A	14.18	10.9	3.28	23.13	6.32	0.52
	(7.52,24.52)	(5.71,19.26)	(0.67,6.33)	(4.6,37.43)	(3.87,8.79)	(0.09,1.00)
JE	11.31	3.67	7.64	67.55	9.59	0.80
	(5.47,23.14)	(1.81,7.99)	(7.14,10.62)	(58.54,72.53)	(5.89,13.31)	(0.73,1.11)
Men A	29.84	8.46	21.38	71.65	9.82	2.18
	(18.25,42.28)	(5.14,11.67)	(18.95,24.44)	(66.99,76.65)	(6.06,13.62)	(1.91,2.57)
Polio	0.76	0.13	0.63	82.89	12.68	0.05
	(0.47,1.08)	(0.08,0.18)	(0.58,0.7)	(80.53,85.35)	(7.84,17.7)	(0.04,0.06)
Aggregate	892.9	614.42	278.48	31.19	69.91	3.98
	(879.07,945.93)	(597.01,655.72)	(241.96,330.93)	(27.25,35.29)	(67.86,71.81)	(3.47,4.72)

BCR: Benefit-Cost Ratio, computed by dividing the total benefits by the total costs. A BCR exceeding 1 indicates that benefits outweigh costs, while a BCR below 1 suggests the intervention may not be economically viable.

3.14 Benefit-cost ratios of eight vaccines from 1974 to 2024 from healthcare provider's perspective, based on the birth cohort approach

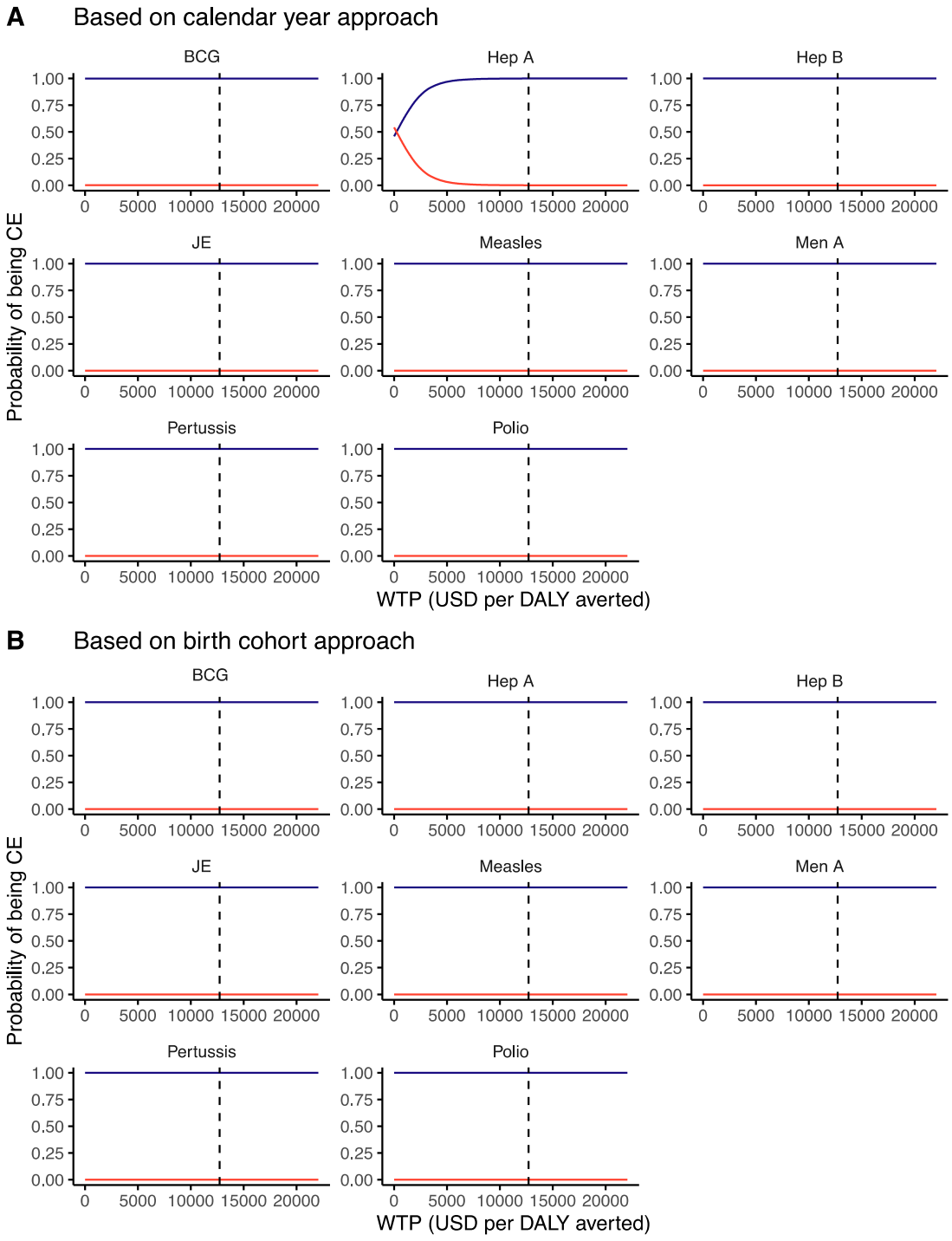
Vaccine	Direct Disease cost (in billion USD)				Direct Vaccination cost (in billion USD)	BCR
	No vaccination	Vaccination	Averted	Reduction (%)		
Measles	97.81 (57.38,142.86)	0.22 (0.13,0.35)	97.59 (91.55,106.46)	99.78 (99.7,99.82)	9.31 (5.7,12.93)	10.47 (9.56,11.80)
Pertussis	34.36 (23.73,51.77)	2.56 (1.78,3.68)	31.8 (31.44,36.55)	92.55 (91.63,93.64)	12.66 (7.64,17.9)	2.51 (2.40,2.96)
Hep B	446.79 (326.79,601.12)	86.28 (61.6,114.71)	360.51 (341.55,399.91)	80.69 (79.04,82.57)	5.69 (3.51,7.9)	63.36 (57.82,72.86)
BCG	207.89 (138.34,295.71)	172.08 (116.9,248.43)	35.81 (15.07,54.7)	17.23 (7.41,24.23)	3.84 (2.23,5.07)	9.33 (4.54,15.02)
Hep A	6.8 (3.29,12.06)	2.33 (1.2,4.02)	4.47 (3.79,6)	65.74 (57.18,73.53)	6.32 (3.87,8.79)	0.71 (0.58,0.97)
JE	11.09 (5.35,22.54)	3.3 (1.61,6.9)	7.79 (7.37,10.94)	70.24 (62.56,75.48)	9.59 (5.89,13.31)	0.81 (0.77,1.15)
Men A	27.34 (16.78,38.6)	5.64 (3.46,7.64)	21.7 (19.82,24.22)	79.37 (76.42,83.05)	9.82 (6.06,13.62)	2.21 (1.97,2.53)
Polio	0.79 (0.49,1.12)	0.08 (0.05,0.1)	0.71 (0.67,0.78)	89.87 (89.05,91.93)	12.68 (7.84,17.7)	0.06 (0.05,0.06)
Aggregate	832.87 (823.34,890.04)	272.49 (267.80,295.21)	560.38 (539.54,611.92)	67.28 (65.1,69.13)	69.91 (67.86,71.81)	8.02 (7.64,8.80)

BCR: Benefit-Cost Ratio, computed by dividing the total benefits by the total costs. A BCR exceeding 1 indicates that benefits outweigh costs, while a BCR below 1 suggests the intervention may not be economically viable.

3.15 Incremental cost-effectiveness ratios (ICERs) based on the calendar year and birth cohort approaches

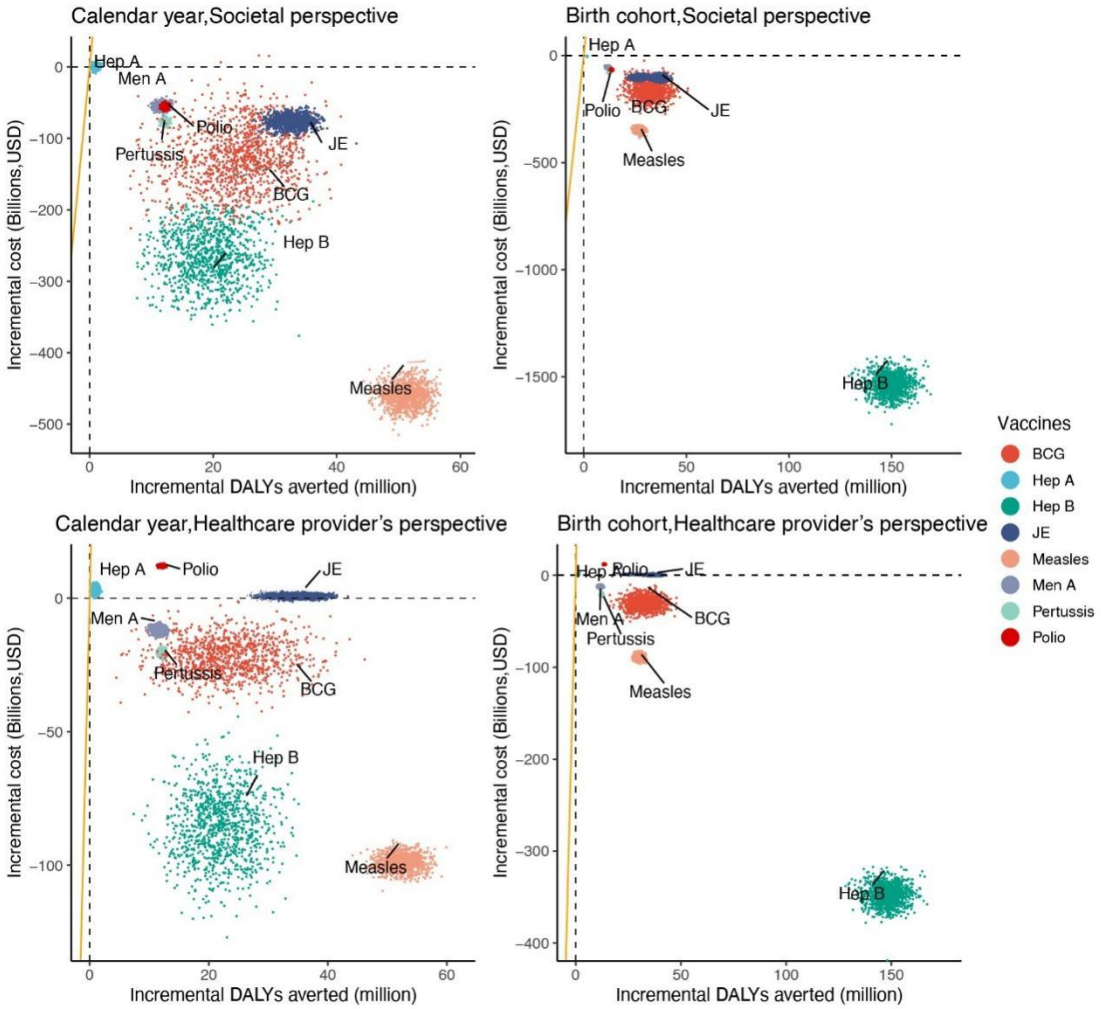
Vaccine	ICER (per DALY, in thousand USD)			
	Societal perspective		Healthcare provider's perspective	
	Calendar year	Birth cohort	Calendar year	Birth cohort
Measles	-8.96 (-10.40, -7.39)	-11.38 (-12.76, -9.72)	-1.82 (-2.06, -1.50)	-2.99 (-3.28, -2.51)
Pertussis	-6.32 (-7.37, -5.67)	-6.39 (-7.37, -5.75)	-1.63 (-1.99, -1.47)	-1.67 (-2.05, -1.52)
Hep B	-12.72 (-30.51, -6.00)	-10.08 (-12.17, -8.88)	-3.85 (-8.34, -1.70)	-2.40 (-2.77, -2.05)
BCG	-6.28 (-40.67, 0.27)	-5.42 (-11.28, -1.69)	-0.93 (-5.49, -0.03)	-0.93 (-2.05, -0.37)
Hep A	0.60 (-12.01, 15.95)	-2.18 (-4.33, -0.81)	3.13 (-0.04, 20.13)	1.31 (0.10, 1.88)
JE	-2.83 (-4.07, -2.19)	-2.84 (-3.99, -2.27)	0.07 (-0.04, 0.09)	0.06 (-0.04, 0.07)
Men A	-4.92 (-6.37, -3.65)	-4.90 (-6.14, -3.90)	-1.11 (-1.40, -0.78)	-1.12 (-1.34, -0.83)
Polio	-4.70 (-5.22, -3.98)	-5.01 (-5.50, -4.37)	1.00 (0.90, 1.11)	0.88 (0.81, 0.98)
Aggregate	-7.07 (-8.71, -5.50)	-8.22 (-9.32, -7.37)	-1.30 (-1.61, -0.98)	-1.76 (-1.95, -1.54)

3.16 Cost-effectiveness acceptability curves from societal perspective, based on the calendar year and birth cohort approaches

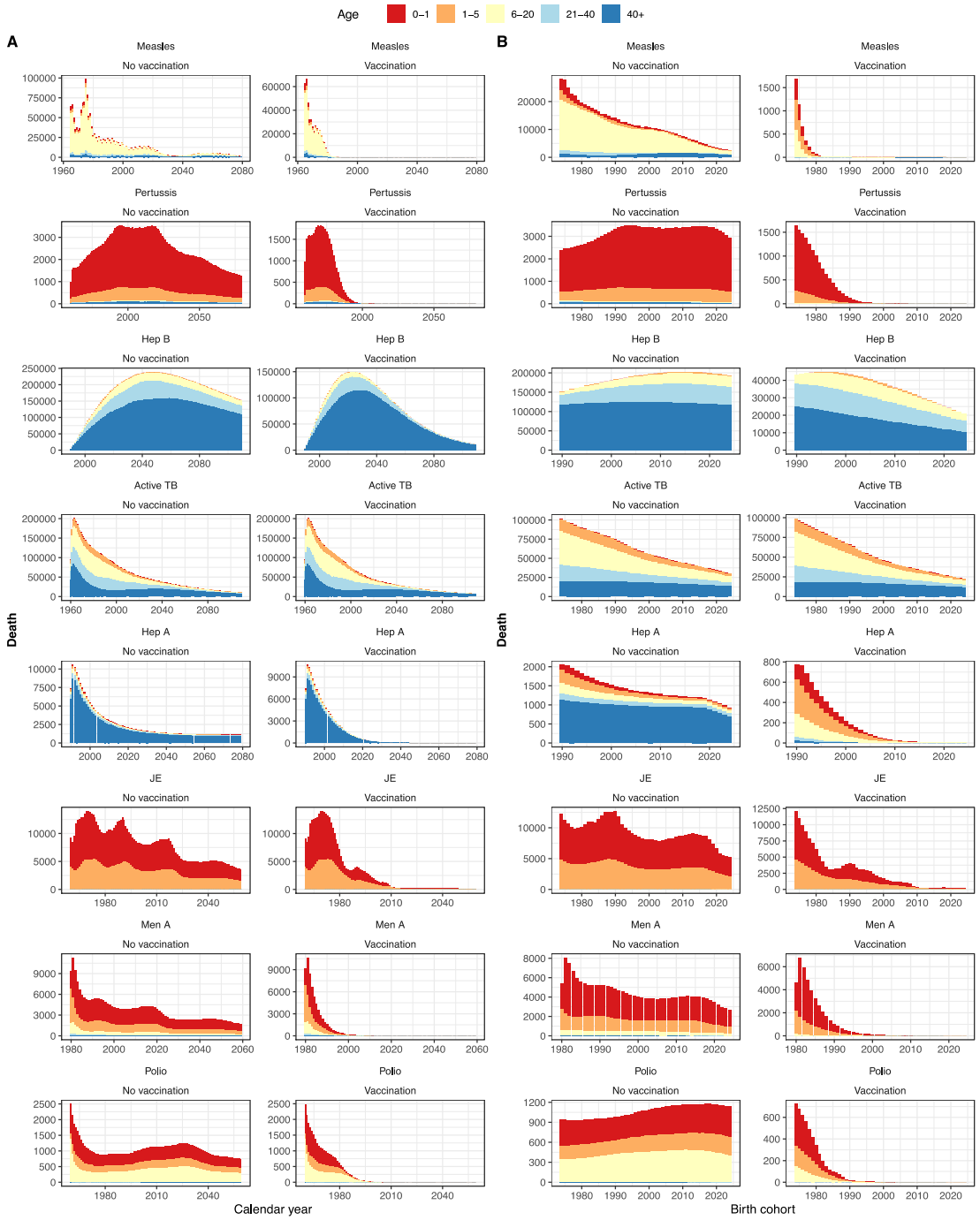


Vertical lines represent the estimated threshold of the 2022 national GDP per capita (US$ 12741). The probability that vaccination is cost-effective is over 99% for all eight EPI vaccines based on the calendar year and birth cohort approaches with a societal perspective.

3.17 Incremental cost-effectiveness ratio plot from societal and healthcare provider's perspectives, based on the calendar year and birth cohort approaches

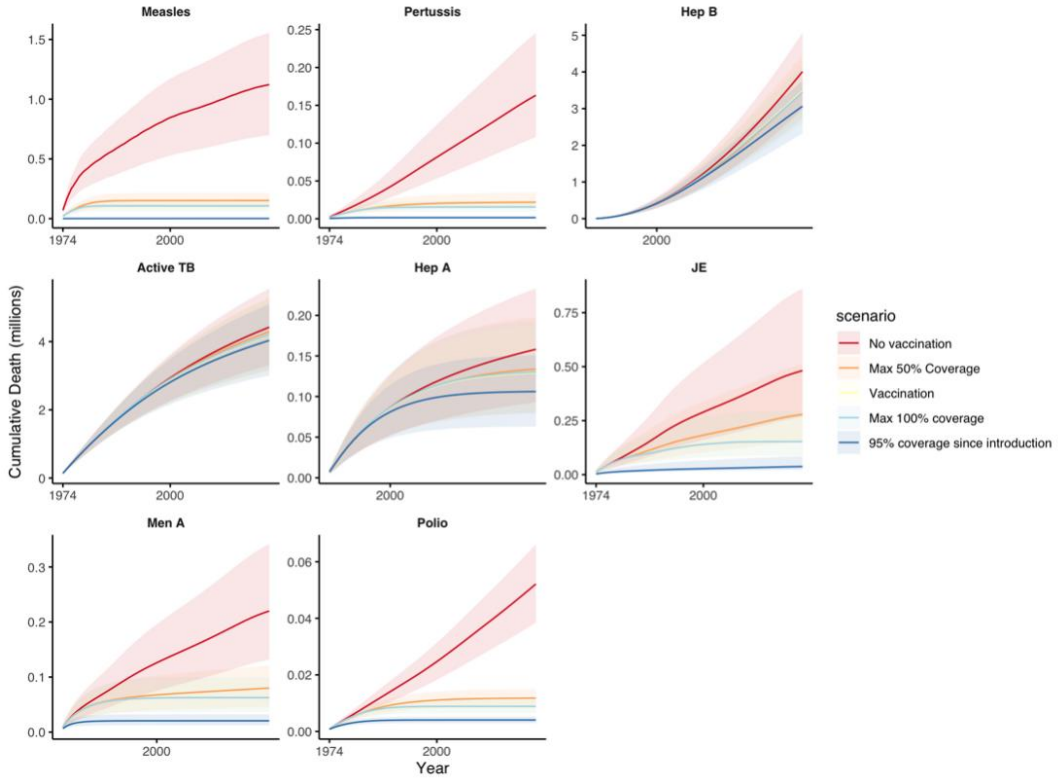


3.18 Number of deaths stratified by age groups, based on the calendar year and birth cohort approaches

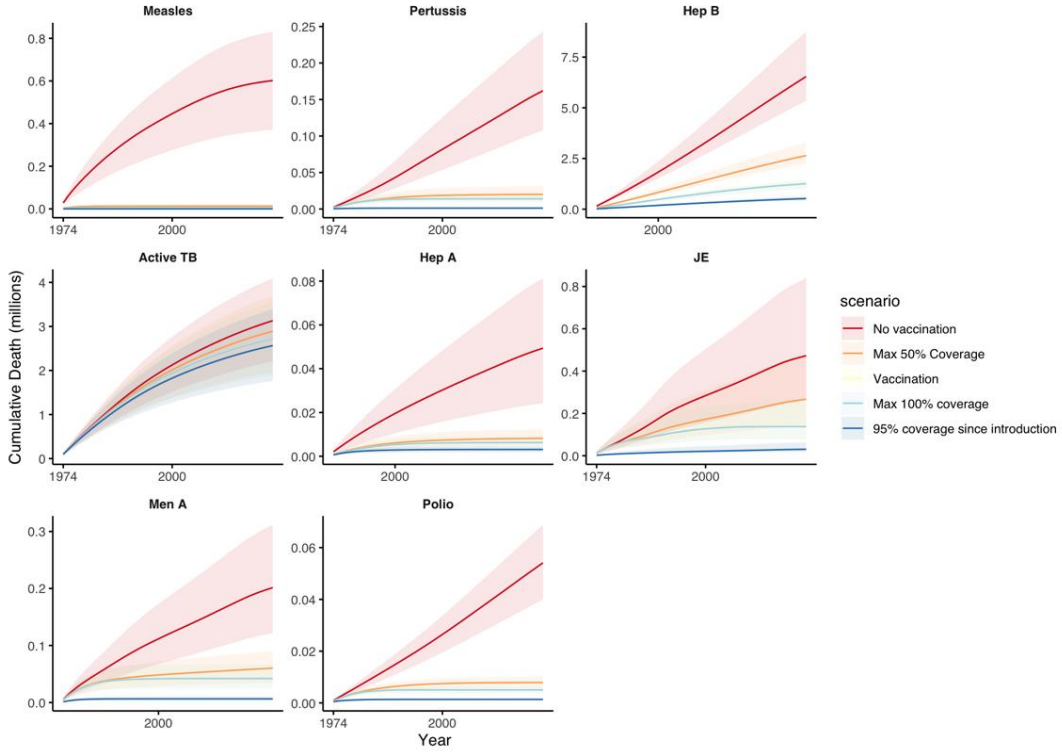


3.19 Sensitivity analyses comparing different coverage levels with counterfactual coverage (no vaccination), from 1974 to 2024

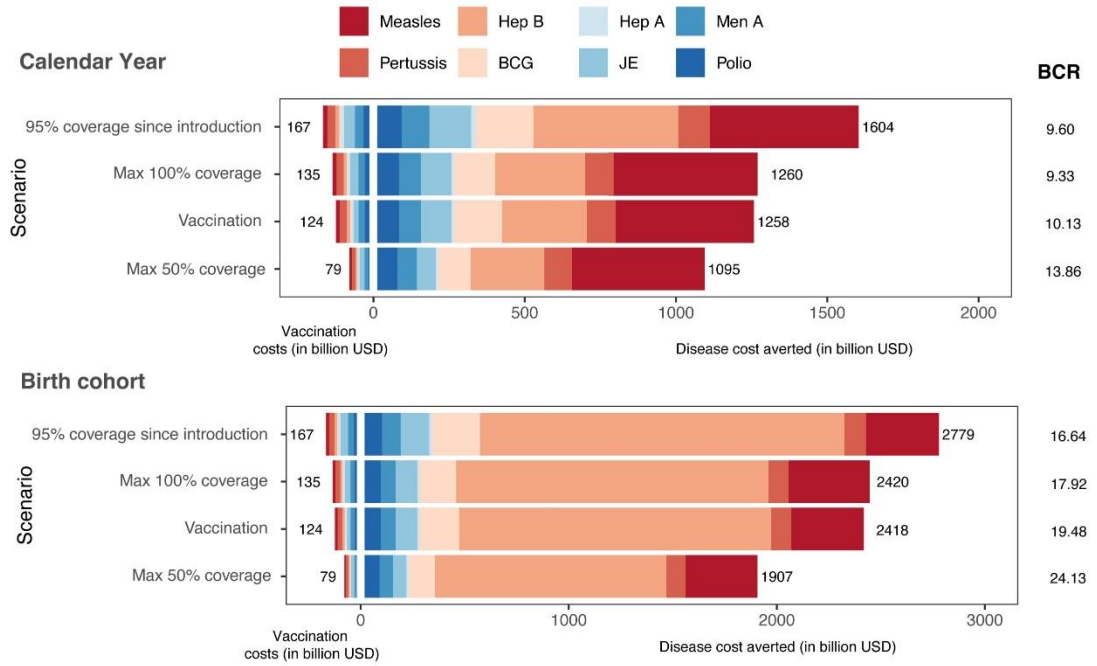
1) Cumulative deaths based on the calendar year approach



2) Cumulative deaths based on the birth cohort approach

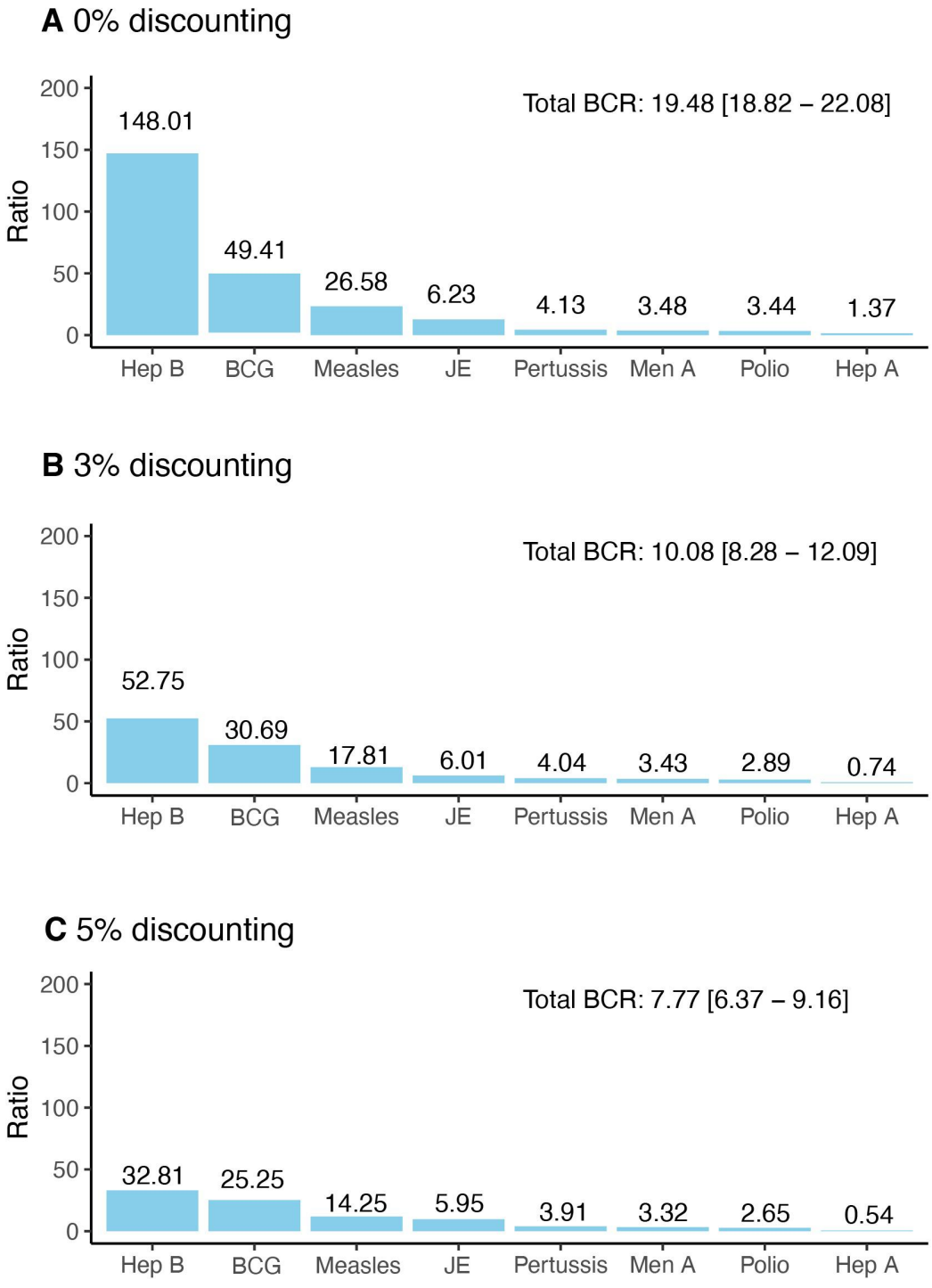


3) Benefit-cost ratios



In the scenarios, "Max 50% coverage" modeled the vaccination trend starting from vaccine introduction, assuming the vaccination rate would increase to 50% at the historical pace, then stabilize at that level. "Vaccination" represents the vaccination rate in the real-world scenario in China. "Max 100% coverage" modeled the vaccination rate initially increasing at the historical pace, then rising to 100% after reaching the historical peak, maintaining that level thereafter. "95% coverage since introduction" modeled the vaccination rate reaching 95% immediately after vaccine introduction and maintaining that level thereafter.

3.20 Sensitivity analyses comparing different discounting rates from societal perspective



3.21 Sensitivity analysis measuring benefits in opportunity costs (51% GDP per capita for one DALY averted), provider's perspective

Vaccine	DALY (millions)			Disease cost averted	Vaccination cost	BCR
	No vaccination	Vaccination	Averted	(billions USD)	(billions USD)	
Calendar year						
Measles	54.95 (29.70,90.05)	5.47 (2.92,9.14)	49.48 (45.60,59.43)	321.42 (297.49,387.03)	9.31 (5.70,12.93)	34.52 (32.03,40.18)
Pertussis	12.54 (8.37,18.63)	1.23 (0.80,1.83)	11.31 (11.01,12.81)	73.47 (71.26,83.5)	12.66 (7.64,17.90)	5.80 (4.67,6.5)
Hep B	110.84 (70.08,164.02)	89.53 (53.13,129.22)	21.31 (10.17,38.70)	138.43 (63.37,252.9)	5.69 (3.51,7.90)	24.33 (17.47,38.81)
BCG	321.15 (245.67,401.30)	296.39 (225.41,375.00)	24.76 (5.01,43.54)	160.84 (30.2,285.31)	3.84 (2.23,5.07)	41.89 (19.64,64.76)
Hep A	4.75 (2.57,7.79)	3.78 (2.07,6.21)	0.97 (0.15,1.85)	6.30 (0.92,12.08)	6.32 (3.87,8.79)	1.00 (0.46,1.64)
JE	44.15 (21.62,86.35)	14.26 (7.15,29.56)	29.89 (27.40,38.40)	194.17 (177.88,262.05)	9.59 (5.89,13.31)	20.25 (18.94,25.92)
Men A	14.55 (7.68,25.11)	4.15 (2.33,7.20)	10.40 (9.20,13.22)	67.56 (60.36,86.36)	9.82 (6.06,13.62)	6.88 (6.56,8.36)
Polio	14.57 (10.02,19.09)	2.47 (1.61,3.22)	12.10 (11.30,12.99)	78.60 (73.37,84.38)	12.68 (7.84,17.70)	6.20 (5.19,6.58)
Aggregate	577.50 (574.53,615.90)	417.28 (407.99,441.10)	160.22 (145.05,196.99)	1040.79 (939.11,1280.54)	69.91 (67.86,71.81)	14.89 (13.25,17.44)
Birth cohort						
Measles	29.82 (16.07,48.76)	0.27 (0.13,0.45)	29.55 (28.06,34.78)	191.96 (181.96,224.79)	9.31 (5.70,12.93)	20.62 (19.08,23.52)
Pertussis	12.51 (8.37,18.55)	1.07 (0.70,1.57)	11.44 (11.15,12.89)	74.31 (72.21,83.97)	12.66 (7.64,17.90)	5.87 (5.24,6.55)
Hep B	188.67 (112.02,285.60)	40.97 (25.86,60.78)	147.70 (134.22,172.96)	959.46 (874.05,1116.23)	5.69 (3.51,7.90)	168.62 (158.57,191.03)
BCG	235.24 (174.84,298.30)	200.92 (146.78,260.90)	34.32 (17.57,49.93)	222.94 (111.77,317.06)	3.84 (2.23,5.07)	58.06 (41.28,77.65)
Hep A	2.00 (1.01,3.34)	0.59 (0.34,0.91)	1.41 (1.24,1.78)	9.16 (7.97,11.47)	6.32 (3.87,8.79)	1.45 (1.37,1.75)
JE	43.32 (21.14,84.19)	12.86 (6.34,25.65)	30.46 (28.63,40.73)	197.87 (184.23,267.48)	9.59 (5.89,13.31)	20.63 (19.86,26.31)
Men A	13.45 (7.08,23.22)	2.87 (1.65,5.02)	10.58 (9.72,13.20)	68.73 (63.05,84.97)	9.82 (6.06,13.62)	7.00 (5.74,8.34)
Polio	15.05 (10.36,19.74)	1.49 (0.98,1.95)	13.56 (12.74,14.42)	88.09 (82.82,93.64)	12.68 (7.84,17.70)	6.95 (5.51,7.31)

Vaccine	DALY (millions)			Disease cost averted	Vaccination cost	BCR
	No vaccination	Vaccination	Averted	(billions USD)	(billions USD)	
Aggregate	540.06 (536.09,580.60)	261.04 (255.23,279.20)	279.02 (265.78,316.12)	1812.51 (1726.62,2061.42)	69.91 (67.86,71.81)	25.93 (24.33,28.60)

In this sensitivity analysis, the opportunity costs of health expenditure in China was used, applying the recommended 51% per capita GDP for one DALY averted (Pichon-Riviere A, Drummond M, Palacios A, Garcia-Marti S, Augustovski F. Determining the efficiency path to universal health coverage: cost-effectiveness thresholds for 174 countries based on growth in life expectancy and health expenditures. Lancet Glob Health. 2023;11(6):e833-e842).