The Economic Value of Routine Adult Vaccination:

A Global Positioning Assessment

Jeremy Otridge, Alyssa Agarwal, Robert Hecht, Dean Jamison

Pharos Technical Working Paper #1

Pharos
Global Health
Advisors

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ABSTRACT

Background: Vaccination has dramatically reduced child morbidity and mortality around the world over the past half-century, but comparable progress has not been achieved for adults. Despite the remaining burden of vaccine-preventable diseases among older populations, along with rapidly aging populations and the licensure of multiple new adult vaccines, large gaps in immunization coverage remain among older adults. These gaps are particularly pronounced in low- and middle-income countries (LICs and MICs), but they persist even in high-income countries (HICs). The absence of robust adult vaccination delivery platforms and limited economic evidence to support policymaking are major contributing factors. This paper aims to provide guidance on the circumstances and vaccines for which expanding coverage of adult vaccines is—and is not—likely to be attractive. We attempt to address the latter issue by developing and using a methodology to assess the economic value of expanded adult vaccination for several antigens across different age and country groupings. The constraints to adult vaccination due to other systems and policy factors are not considered in this report, but we are examining them elsewhere in a series of country case studies.

Methods: To address the large evidence gaps, we carried out a "positioning" exercise to estimate benefit-cost ratios (BCR) based on the number of persons needed to vaccinate (NNV) to avert a death or a year of life lost (YLL), using variables including disease burden, vaccination costs, and the economic value of mortality risk reduction. We applied this model to five antigens: seasonal influenza, pneumococcal disease, respiratory syncytial virus (RSV), COVID-19, and herpes zoster (HZ). Results are presented by adult age group (20–64, 65–74, 75+) and World Bank country income groups. Large confidence ranges were constructed to reflect uncertainty in the underlying data and variation in local circumstances.

Results: The existing literature largely points to favorable cost-effectiveness ratios for some adult vaccines, but evidence is heavily concentrated in high-income settings and focuses mainly on influenza and herpes zoster (shingles) vaccines. Our model suggests that expanded use of three of the five vaccines—for influenza, COVID-19, and pneumococcal disease—is likely to be economically attractive for adults aged 65+ in UMICs and HICs. For LMICs, our model suggests that expanding influenza and pneumococcal vaccines is economically attractive for adults aged 75+. Vaccination becomes economically attractive in older adults where mortality burden is high but is not attractive in lower age groups. Herpes zoster vaccination also appears to be less economically attractive in all age and income groupings, although our approach fails to capture the full benefits of HZ vaccination, which averts few deaths but reduces painful disability and is increasingly being found to reduce risk of old-age dementias.

Conclusions: As global populations age, the number of licensed adult vaccines increases, and adult vaccines of higher efficacy are developed, investment in adult immunization offers the prospect of attractive health and economic returns. These returns—expressed here as Benefit-Cost Ratios (BCRs)—currently look better for seasonal influenza, pneumococcal, and COVID-19 booster vaccination and less attractive for RSV. While modeled BCRs are high for the first three vaccines in the oldest age groups of those aged 75+ and for high- and upper-middle-income countries (HICs and UMICs), they are lower and more uncertain for younger adults and for lower-middle- and low-income countries (LMICs and LICs). We identify price thresholds at which these adult vaccines might become economically attractive, especially as many countries that procure vaccines centrally have not yet negotiated a "public sector price" with manufacturers for the newest adult vaccines for RSV and HZ. Caveats to our conclusions result from limitations in data on adult vaccine-preventable disease burden, on current coverage of adult vaccines, and on vaccine costs and efficacy.

Our modeling approach and results presented here can help to target and stimulate in-depth national assessments of adult vaccination using more complete and high-quality country-specific data.

1. Introduction

Vaccination is a powerful tool to avert morbidity and mortality. A landmark Lancet study estimates that 154 million child lives have been saved in the 50 years since the launch of the Expanded Programme on Immunization by the WHO in 1974 (Shattock et al. 2024). Most of the lives saved were those of infants—children born today have a 40% increase in survival for each year of infancy and childhood (Shattock et al. 2024).

While under-five mortality from lower-respiratory infections (LRIs) has plummeted—largely due to successful childhood immunization programs—adult mortality from LRIs has only marginally decreased since 1990. Vaccine-preventable diseases remain a significant cause of death among adults ages 65+. Seasonal influenza and pneumococcal disease alone account for 1-3% of annual deaths in adults 65+ across World Bank income groups (Table 1.1), placing them among the top 10 causes of death for this age group. Expanding adult vaccination coverage could substantially reduce these burdens.

TABLE 1.1

Deaths from vaccine-preventable diseases as a percentage of all deaths, by adult age group and country income group

	Percent of all deaths			
	All ages	**Age 20-64**	**Age 65-74**	**Age 75+**
Seasonal flu				
LIC	0.85%	0.04%	0.78%	1.20%
LMIC	0.69%	0.11%	0.50%	0.74%
UMIC	0.46%	0.08%	0.31%	0.63%
HIC	0.63%	0.04%	0.36%	0.83%
Pneumococcal Disease				
LIC	1.90%	0.11%	1.30%	1.60%
LMIC	1.70%	0.33%	1.00%	1.20%
UMIC	0.66%	0.16%	0.43%	0.73%
HIC	0.48%	0.06%	0.31%	0.56%
RSV				
LIC	0.37%	0.00%	0.03%	0.04%
LMIC	0.31%	0.01%	0.02%	0.03%
UMIC	0.07%	0.01%	0.02%	0.04%
HIC	0.05%	0.00%	0.03%	0.05%
Herpes zoster				
LIC	0.06%	0.00%	0.02%	0.07%
LMIC	0.04%	0.01%	0.02%	0.05%
UMIC	0.01%	0.00%	0.00%	0.01%
HIC	0.01%	0.00%	0.00%	0.02%

SOURCE: IHME, GBD 2021

Despite the high burden of vaccine-preventable diseases among older populations, along with rapidly aging populations around the world and the licensure of multiple new adult vaccines, large gaps in immunization coverage remain among older adults

These differing trends can be attributed in part to age-related immunosenescence and lower vaccine efficacy in older adults (Bender et al. 2024). However, the persistently low coverage of adult vaccines and the lack of robust adult immunization systems comparable to those for children are major contributors to adult disease and deaths.

Take the example of influenza. While seasonal influenza vaccines are available in 74% of WHO Member States, only 66% have adopted clear seasonal influenza policies (Goldin et al. 2024). Just 33% of countries reported flu vaccine coverage data, and only 28% reported coverage specifically for older adults. In countries that did report data for older adults, the proportion of the population with access to flu vaccines ranged from 19% in low-income countries to 95% in high-income countries, with median coverage of 55%. Just 13 of the 194 WHO Member States reported achieving the global target of 75% coverage (Goldin et al. 2024).

Even fewer countries report having policies for pneumococcal and herpes zoster (Sauer et al. 2021), and data on vaccination coverage for these two antigens is less frequently reported (Sauer et al. 2021; Tunnicliffe et al. 2025).

The importance of adult immunization will grow as the global population ages. There are now more adults over the age of 60 than children under 5 globally, and this gap is projected to widen (WHO 2024).

The global failure to reach adult vaccination coverage targets has been attributed to several factors: vaccine hesitancy, inadequate infrastructure, competing priorities within resource-limited health systems, differing valuations of adult and child health, and the complexities of an adult vaccination schedule (Aguado et al. 2018; Tunnicliffe et al. 2025).

An additional issue, the focus of our work, is the limited information on the economic value of adult vaccination (Aguado et al. 2018). Although there are studies of its cost-effectiveness, they are focused on high- and upper-middle-income countries (HICs and UMICs) and do not cover all adult vaccines, especially the newer RSV and herpes zoster vaccines.

The purpose of this paper is to develop and apply a model to estimate benefit-cost ratios for the major adult vaccines across several age groups and all country income categories. Given limitations in available data, we rely on averages and ranges for the four country income groupings. Thus, our results should be viewed as an important first approximation of the economic value of adult vaccination, helping to "position" each vaccine by its economic attractiveness across age groups and country settings. By doing so, our analysis provides BCRs for an expanded set of antigens that are not currently well-represented in the existing literature on the economics of routine adult vaccination.

This positioning is intended to better equip health analysts to inform government officials as they consider whether to invest in adult immunization. We therefore prioritize straightforward analysis and easily interpretable cost and outcome variables, while using wide confidence intervals to appropriately reflect uncertainty.

Decisions about which, if any, adult vaccines to introduce and for what age groups will ultimately be made at the national level and take into account a range of factors beyond cost-effectiveness, including budget impact, consumer demand/vaccine hesitancy, provider awareness and support, and the capacity of existing platforms to procure, supply, and deliver adult vaccines. Nevertheless, prospective economic valuation of adult vaccination remains a critical consideration, and this report aims to contribute evidence to inform such economic assessments.

2. Literature Review

2.1 Methods: Literature Review of Economic Evaluations of Routine Adult Vaccination

We conducted a literature search to better understand the status of published economic evaluations of routine adult immunization, and to answer questions including: How many studies have been published? For what adult age groups, country income groups, and vaccines? What methods were used? And what were the main results reported?

We focused our search on the antigens included in this paper: seasonal influenza, pneumococcal, respiratory syncytial virus (RSV), COVID-19, and herpes zoster (HZ).

We searched PubMed and Google Scholar with the following criteria ("adult" OR "elderly") AND ("vaccination" OR "immunization") AND ("cost-effectiveness" OR "number needed to immunize" OR "cost" OR "benefit cost analysis" OR "evaluation").

We filtered the initial selection according to the following criteria:

- Reports cost-effectiveness results (e.g. cost per death averted or $/Quality-Adjusted Life Year (QALY)) and conclusion (likely cost-effective or not cost-effective)
- Scenario(s) include vaccination of adults
- Results reported specifically for adult age groups (>18 years old)

For each study, we recorded the country, the antigen of focus, age group(s), analytic models, cost-effectiveness results (e.g., $/QALY gained) and conclusions (cost-effective vs. not cost-effective).

2.2 Results of the Literature Review

A total of 49 unique studies met our inclusion criteria. Nearly three-quarters (69%) included results for high-income countries (HIC), 27% had results for upper-middle-income countries (UMIC), and just two studies (4%) reported results for lower-middle-income countries (LMIC). None of the studies covered low-income countries (LIC). 45% of studies included data for European countries and 41% for Asian countries. The United States (8 studies), China, Japan, the Netherlands, and France (4 studies each) were the most represented nations. Most studies identified were for either seasonal influenza (41%) or for HZ (35%) (Table 2.1), with far fewer studies for pneumococcal disease and RSV. The full list can be found in Appendix E. We did not find any studies of routine adult COVID-19 vaccination that matched our criteria.

For seasonal influenza, three-quarters (75%) reported incremental cost-effectiveness using cost per QALY gained. Alternative outcomes reported included cost per death averted, cost per DALY averted/saved, and cost per life-year saved/gained. Studies varied in their cost perspective, including societal, third-party payer, or public healthcare provider perspectives. We note that the literature focuses on evaluation of cost-effectiveness (e.g. evaluating results against QALY and DALY thresholds) rather than economic attractiveness (e.g. presenting results as benefit-cost ratios).

Overall, the literature points to the cost-effectiveness of these adult vaccines for elderly populations and risk groups (e.g., immunocompromised persons). However, the results come from only a small number of countries, most of which are high- and upper-middle-income.

The need for more economic evaluations of adult vaccines is growing as populations age and new vaccine technologies become more effective, with potential for lower costs due to larger production volumes, manufacturing efficiencies, and tiered pricing practices.

TABLE 2.1

Literature review of adult vaccination economic analysis studies, by antigen and World Bank income group

	LIC	LMIC	UMIC	HIC	Total[1]
Seasonal influenza	-	2	7	11	**20**
Respiratory syncytial virus (RSV)	-	-	-	4	**4**
Pneumococcal	-	-	5	6	**11**
Herpes zoster	-	-	2	15	**17**
Total[1]	**0**	**2**	**14**	**36**	**52**

NOTES:
1. Some studies included results for multiple income groups, so were included across multiple columns. This double counting gives a total of 52 in this table, but only 49 unique studies were included.

Seventeen of twenty (85%) studies found seasonal influenza vaccination to be cost-effective against selected thresholds for adult age groups (50+). Only three studies pointed to doubtful cost-effectiveness. One study found seasonal influenza vaccination to be cost-effective for all high-risk adults over 50 but unlikely to be cost-effective for adults under 50 and low-risk adults 50-64 years old. Two studies found that seasonal influenza vaccination was unlikely to be cost-effective, one for 50-64 year olds, another for 65+ year olds.

Seven of the 11 studies for pneumoniae (64%) reported results in cost per QALY gained. Other measures used included life years gained, cases averted, deaths averted, and disease-free life years gained. These were either in high-income (55%) or upper-middle-income countries (45%); none of these studies included low-income countries. Nine studies compared their cost-effectiveness outcomes to thresholds, and all found that vaccination was cost-effective for adults 60+ years old.

The 4 studies for RSV reported results in cost per QALY gained. They did not always compare cost-effectiveness results against discrete thresholds. When compared, it was found that RSV vaccination is likely cost-effective but dependent on the price per dose.

All 17 studies of HZ zoster report results in cost per QALY gained, and 4 included the cost per case avoided. Most were in HICs (88%) with the remainder in UMICs (12%). The majority (53%) concluded that herpes zoster vaccination was cost-effective. Four studies (24%) found that herpes zoster was only cost-effective in some instances (for certain age groups, at a certain dose price, and/or certain vaccine durability). Two studies concluded that the cost-effectiveness of herpes zoster vaccination depended on the threshold used, and one study found that it was not cost-effective to vaccinate 65+ year olds.

Based on this review, we see a strong need for more economic evaluations of adult vaccines. This need is growing as populations age and new vaccine technologies become more effective, with potential for lower costs due to larger production volumes, manufacturing efficiencies, and tiered pricing practices. Future evaluations should include a broader range of countries across all income levels and regions, with particular focus on low- and lower-middle-income countries, where the cost-effectiveness of routine adult vaccination remains largely understudied.

2.3 Extended Review – Indirect Effects of Vaccination

Among the studies that fit our inclusion criteria for cost-effectiveness, we further assessed how they approached the analysis of indirect effects of vaccination. We consider indirect effects to be the transmission-blocking effects of vaccination, which can reduce case rates and prevent deaths in both vaccinated and unvaccinated people. Because indirect effects may increase the benefits of vaccination for certain antigens, they may, in some cases, be relevant to our cost-benefit evaluation. We sorted studies into four categories: (i) explicitly excludes indirect effects; (ii) does not mention indirect effects; (iii) mentions or includes them but does not report their relative magnitude; or (iv) provides results on their relative magnitude.

Of the 49 studies, only 9 (18%) included transmission effects and just 5 (10%) explicitly provided results on the relative magnitude of indirect effects (Table 2.2).

The literature indicates that transmission can play an important role for antigens with herd (indirect) effects—most clearly for influenza and COVID-19, and to a lesser extent for pneumococcal disease and RSV. For influenza, community studies show that vaccinating one group can reduce infections among the unvaccinated, with reported indirect effects ranging from roughly 20% to 60% (Loeb et al., 2010; Grijalva et al., 2024).

For COVID-19, effectiveness of vaccination against transmission has been estimated to range anywhere from 16% to 95% with variations based on factors such as strain, vaccine type, and study design (Oordt-Speets et al., 2023). For pneumococcal vaccines, there is also an impact on transmission, but quantifying indirect effects is challenging due to serotype diversity, serotype replacement, and widespread asymptomatic carriage. For RSV, community benefits of vaccination have also been noted, particularly for maternal vaccination to protect against onward transmission to infants. However, there is no published information on vaccine effectiveness against transmission beyond maternal-infant dynamics, and data remain insufficient for quantitative modeling analysis. Based on the literature, herpes zoster vaccination shows no meaningful indirect benefits, as the vaccine primarily protects against reactivation of disease rather than onward transmission.

Given this evidence, accounting for transmission could, in principle, improve benefit–cost ratios for influenza, pneumococcal, and RSV to varying degrees across age groups and country income levels. However, a rigorous assessment would require transmission-dynamic models and better parameter data than are currently available in most settings. We therefore conduct our economic evaluation using direct effects only and note that consideration of transmission-blocking effects of vaccination should be a priority in future assessments or country-level analyses.

TABLE 2.2

Inclusion of indirect effects in literature review

	Explicitly do not include	Do not mention indirect effects	Mention/include, but do not provide results on relative magnitude	Provide results on relative magnitude
Seasonal influenza	8	6	1	2
RSV	4	-	-	-
Pneumococcal	2	5	1	3
Herpes zoster	4	11	2	-

3. Methods and Data

3.1 Approach to Economic Evaluation

Our basic calculations for our positioning assessment of adult vaccination globally begin by using available information on vaccine characteristics and epidemiological conditions to calculate the number of individuals needed to be vaccinated to avert one death (NNV).

The NNV incorporates the death rate (*m*), vaccine effectiveness against death (E_d), and the number of years of protection provided by the vaccine (*y*) (Appendix B provides further details):

$$NNV = \frac{1}{E_d * m * y}.$$

We multiply NNV by the incremental cost of vaccinating one person, C, to obtain an incremental cost per death averted (CDA).

$$CDA = NNV \times C.$$

We quantify the benefits from reducing mortality risk by using a well-established body of empirical literature on the economic value of small reductions in mortality risk, such as those achieved through immunization. This literature typically expresses results by aggregating the value of many small risk reductions until one 'statistical' death is averted, a concept known as the *value of a statistical life* (VSL). Dividing a country's VSL by the cost of averting a death results in a benefit-to-cost ratio (BCR). VSLs are often expressed as multiples of per capita income, ranging from 50 to 160 times per capita income. The Harvard reference case for benefit cost analysis recommends exploring consequences of a range of values for the VSL—a "standardized sensitivity analysis" (Robinson, Hammitt, Cecchini, et al. 2019; Robinson, Hammitt, Jamison, et al. 2019). The base-case VSL proposed by the reference case has an 'income elasticity' of 1.5, which implies a ratio of a country's VSL to its income per capita, *y*, given by:

$$\mathrm{VSL/y} = .655 \times \sqrt{\mathrm{y}}.$$

where *y* is expressed in I$. The VSLs for each country income group can be found in Appendix A.

In this paper, we calculate BCRs using VSL as a multiple of GNI per capita (I$) and CDA as a multiple of GNI per capita (US$) for the corresponding World Bank income group. Hence, BCR is calculated as:

$$BCR = \frac{VSL\ (multiple\ of\ GNI\ per\ capita)}{CDA\ (multiple\ of\ GNI\ per\ capita)}.$$

Averting the death of an elderly person yields fewer additional life years than averting the death of a 20-year-old, say, with a potentially different VSL associated with averting deaths at different ages. VSL is often estimated in studies based on populations with an average age of around 40. However, when doing cost-benefit or economic evaluation of health interventions that affect mortality risks at different ages, it can be important to adjust VSL to reflect remaining life expectancy at different ages. Hence our economic evaluation allows an explicit variation of VSL with age, denoted VSL(*a*). In this paper, we let VSL(*a*) be: VSL(40) times the ratio of life expectancy (LE) remaining at age *a* to life expectancy at age 40:

$$VSL\left(a\right) = VSL\left(40\right) \times \frac{LE(a)}{LE(40)}.$$

For example, if someone at age *a* has fewer expected remaining years than someone aged 40, their VSL is proportionally lower. This accords with general practice for economic evaluation in health, but national analyses can easily be configured to vary this assumption (for example, by holding VSL(*a*) constant across ages). The remaining life expectancy for each age group and World Bank country income group can be found in Appendix A.

A BCR greater than 1 is generally considered the minimum threshold for a public sector investment to be deemed economically attractive. However, many unrealized interventions in the health sector have BCRs well above this threshold. For example, The Lancet Commission on Tuberculosis (Reid et al. 2023) concluded that expanding access to uncomplicated TB treatment would yield a BCR of about 10 with a cost per TB death averted on the order of $7,000. For this reason, we consider in this paper that BCRs should exceed 5 for a vaccine to be rated as "very economically attractive". BCR values of more than 1 and less than five are counted as "moderately attractive", while values less than 1 are deemed "not attractive" based on the key current variables (disease burden, deaths averted, cost per death averted, VSL).

Since mortality constitutes the vast majority of the disease burden from influenza, pneumococcal, RSV, and COVID-19—accounting for 99% of the burden in seasonal influenza and pneumococcal disease, and 98% for RSV among adults aged 65 and older (IHME, GBD 2025)—we only consider disability in the case of herpes zoster. Given the relatively large contribution of disability and suffering to the overall disease burden of HZ (with mortality accounting for only 45% of total DALYs), we present its results differently. In addition to deaths averted and life-years gained, we calculate the cost-effectiveness of averting an HZ case and use this—together with a brief account of the nature, severity, and burden of HZ infection, as well as the cost-effectiveness and BCR of averting a DALY—to inform judgements about the priority of HZ vaccination. See discussion in footnote 3 of Table 3.1, arguing in the case of HZ for economic evaluations of HZ to quantify cost per case averted but use a qualitative approach to judging the value of a case averted.

Our approach to economic evaluation involves initially constructing a 'dashboard' listing four domains of outcomes listed in Table 3.1: costs, mortality outcomes, disability outcomes, and economic outcomes. We placed metrics into each of these categories that are commonly included in health economics literature. Within our constrained perspective, we aggregated some of these metrics into figures of merit that provide important, if incomplete, indicators of attractiveness that will depend on (1) vaccine costs and characteristics and (2) the nature and epidemiology of the disease being prevented. We emphasize key figures of merit including: the number needed to vaccinate (NNV) to avert a death, cost per death averted (CDA), and the benefit-to-cost ratios (BCRs) associated with the incremental expansion of a vaccine program in different age groups.

3.2 Choice of Age and Country Groupings

We generate results for three "adult" age groups—young adults (ages 20-64), younger elderly (ages 65-74) and elderly (ages 75+). We chose these three groups based on a study of influenza mortality by Iuliano et al. (2018), which found pronounced differences in burden among the three groupings. Country-specific studies would, of course, utilize naturally relevant age groups.

We likewise examine the effects of national per capita income on vaccine cost-effectiveness by conducting separate analyses for each of the World Bank's four country income groups: low-income (LIC, income range < $1,085 in 2023), lower-middle-income (LMIC, income range $1,086-$4,255), upper-middle-income (UMIC, income range $4,256- $13,205), and high-income (HIC, income range > $13,205) (Hamadeh, et al. 2023). This grouping helps us fill in the gaps in cost-effectiveness analyses in the existing literature on adult vaccination, which focuses on HICs and UMICs.

3.3 Sources of Data on Disease Burden

We used mortality rate estimates from the Institute of Health Metrics and Evaluation Global Burden of Disease 2021 Study (GBD) for influenza, *Streptococcus pneumonia*, RSV, and HZ. We exported country-level data by 5-year age groups and then aggregated the results into the four World Bank income groups and three age groups of focus (20-64, 65-74, 75+).

Because GBD lacks COVID-19 data beyond the pandemic, we used a global estimate of the COVID-19 mortality rate in 2024 from the WHO. WHO stopped requiring countries to report COVID-19 data in August 2023, and as of the latest update on March 22, 2025, only 41 countries were still reporting data to WHO. There was significant variation in COVID-19 data reporting even in 2023, so we elected to use a global estimate. WHO reported

TABLE 3.1

Outcome dashboard for economic evaluation of adult vaccines

Variable	Definition
Costs	
Vaccine cost	This is what the buyer needs to pay for the vaccine, which will depend on: whether (and how much) monopoly profit the vaccine manufacturer is able to include from patent protection; the marginal cost of manufacture and packaging; and the extent of effective purchasing power the buyer(s) are able to exercise.
Delivery cost to health system[1]	This includes movement of the vaccine along the cold chain to point of delivery and the cost of vaccine administration itself.
Delivery cost to recipient[1]	This includes time, inconvenience, vaccine risk, and transport costs to the recipient.
Alternative mortality outcomes	
Deaths averted	Deaths averted at all ages, or by age group.
Life years gained	Life expectancy gained from averting a death at a given age.
Changes in death rates	By age group.
Alternative disability outcomes	
Years lost from disability (YLD)[2]	An attempt to measure lives lost from disability or loss of function from a condition calculated from the product of a "disability weight" and the duration in years of the condition.
Cases[3]	"Case" is used to indicate a short verbal description of the nature, severity and duration of an episode of disability or illness.
Economic outcomes	
Vaccination externalities	Vaccination of an individual can result not only in protection of that individual against infection or death but also keep that individual from infecting others. The size (or existence) of vaccination externalities can affect decisions concerning public financing or intervention.
Health system resources freed	This paper uses "resources freed" for other health system uses, rather than costs averted, as a more realistic description of the same metric.
Patient and caregiver time freed	This paper uses "patient time freed" as an indicator of productivity gains, broadly defined. Preventing illness can free the time of patients, family members, and unpaid caregivers that would otherwise be lost to the illness, or to treating it, that can be deployed in paid labor, unpaid labor, or leisure.

NOTES:

1. The division of costs between those to the health system and those to the vaccine recipient is, in part, a decision variable for the health system. Providing more dispersed vaccine distribution points and better hours of access, for example, would increase costs to the system and reduce them to the recipient. How that balance is struck affects vaccine uptake.

2. YLDs are often added to YLLs to obtain the disability adjusted life year (DALY). DALYs have been used since 1993 to measure the overall burden of disease (World Bank 1993; Murray, Lopez, and Jamison 1994) and they are often used as effectiveness measures in cost-effectiveness analyses. A frequent source of confusion is that burden of disease DALYs can differ from those typically used in cost-effectiveness analyses by about a factor of two for younger age groups. For practical purposes, the concept of the quality-adjusted life year (QALY) is about the same as the cost-effectiveness DALY and is often used as an effectiveness measure in high-income countries.

3. For clarity of exposition, and to avoid the range of implicit value judgements underpinning DALYs, the concept of a verbally described case of illness can be used. For example, herpes zoster vaccination results in a substantial reduction in pain and suffering from shingles, as well as a reduction in old-age dementia risk. Its impact on mortality is real but modest. Many analysts and decision-makers might reasonably judge that the small YLD value assigned to a case of shingles by burden of disease assessments suggests an inadequacy of the YLD assignment and, hence, the potential superiority of using qualitative judgement to assess whether the value of averting a case was worth the cost. In addition to assessing the cost per DALY averted of herpes zoster vaccination, this paper also highlights the cost per case averted and provides a verbal description of the value of averting a case.

age-group-specific COVID-19 deaths for 0-4, 5-14, 15-64, and 65+ year olds. We only report the data for 65+ and use the same value for all income groups due to incompleteness in the available COVID-19 data.

Mortality rates (per 100,000 population) for each antigen are shown in Table 3.2. More information can be found in Appendix C.

We calculated sensitivity intervals for mortality rates using range estimates from IHME. Although the ranges as a percent difference from the central estimate varied across antigens, age groups, and income groups, most fell at around 50%. To standardize, we used a 50% confidence interval for all antigens except for RSV. For RSV, we used 50% as the downward estimate but applied a 10x multiple for the upper estimate. We did so because the mortality rate that we extracted from the IHME GBD was lower than what we found in other publications. For example, Du et al. (2023) found a 10x higher death rate for adults over 70 years old using the GBD 2019 study versus our extracted estimates. Published estimates of country-level RSV mortality rates are also larger than our estimates by a factor of about 10, including those from Norway (Casas et al. 2025) and the United States (Hansen et al. 2022).

3.4 Sources of Data on Vaccine Effectiveness

Vaccine effectiveness data for the five antigens of interest are drawn from the published literature and presented as ranges (Table 3.3). We use the midpoint of the range for point estimates and present the range as our sensitivity interval. The vaccine effectiveness is calculated for the duration of effectiveness, which takes into account waning protection. Vaccines can be effective against death by preventing infection, reducing the probability of death once infected, or a combination

TABLE 3.2

Global burden of mortality from diseases addressed by selected adult vaccines

	Deaths globally, 2018[1]				Death rate globally, per 10^5 population per year, 2018				Mortality as a fraction of total burden, age 65+ (%)[4]
	Total	Ages 20-64	Ages 65-74	Ages 75+	Total	Ages 20-64	Ages 65-74	Ages 75+	
COVID-19[2]	64,000	7,000	57,000		0.78	0.76	29		-
RSV	98,000	3,800	2,500	9,000	1.3	0.09	0.57	3.3	98%
Seasonal influenza[3]	340,000	77,000	43,000	165,000	4.5	1.1	10	61	99%
Herpes zoster	15,000	1,700	950	5,400	0.19	0.04	0.22	2	55%
Pneumococcal	590,000	110,000	68,000	179,000	7.8	2.5	16	66	99%

NOTES:

1. Estimates from all antigens except COVID-19 are from IHME GBD (2021). COVID-19 estimates are from the WHO (2025). The numbers from IHME represent estimates caused by the indicated pathogen but are not included in the estimates of mutually inclusive and collectively exhaustive causes of death. Hence it would be inappropriate to interpret this number in terms of a fraction of total deaths. However, it is appropriate to view it as the potential number of deaths that could be addressed by a vaccine.

2. COVID-19 data are for 2024. WHO stopped requiring countries to report data in August 2023. As of the latest data update on March 22, 2025, only 41 countries reported data to the WHO. WHO provides age-specific deaths for 0-4, 5-14,15-64, and 65+ years old. We report the latter two age groups and total.

3. Iuliano et al. (2018) also present credible estimates using the WHO GHE. Their numbers are very similar to those in IHME GBD, which we use in our calculations for consistency with the other antigens.

4. Mortality as a fraction of total burden comes from IHME (2021) and is defined as the years of life lost (YLL) component of the DALY over the total DALY (YLL + YLD), expressed as a percentage.

TABLE 3.3

Adult vaccine effectiveness[1]

	Year of first availability	Duration of effectiveness[2] (# of doses in full course)	Effectiveness against death	Selected vaccine types available in 2025
COVID-19	2020	≤1 year (1)	50-80%	Moderna (mRNA), Pfizer (mRNA), Novavax (protein adjuvant)
RSV	2023	2 years (1)	70-90%	GSK (Arexvy), Pfizer (Abrysvo)
Seasonal influenza	1945	1 year (1)	40-60%	AstraZeneca (multiple), GSK (multiple), Sanofi (multiple), CSL Seqirus (multiple)–all Trivalent vaccines
Herpes zoster	2006	4-7 years (2)	Primarily uses against disability and pain. Effectiveness = 89-97%	GSK (Shingrix)
Pneumococcal pneumonia	1977	7 years (1)	40-72%	PCV21 (Merck, Capavaxie), PCV20 (Pfizer, Prevnar 20), PCV15 (Merck, Vaxneeuvancee), PPSV23 (Merck, Pneumovax)

SOURCE: Feikin et al., 2022; ECDC, 2024; de Gier et al. 2023; CDC, 2025; Payne et al., 2024; Chung et al., 2020; White et al., 2024; Immunize, 2024; CDC, 2024; Nakafero et al., 2024; Vila-Córcoles et al., 2005.

NOTES:

1. Two factors limit duration of effectiveness. One is evolution of the prevalent variant of the pathogen toward being less susceptible to a given vaccine formulation. The other is waning effectiveness of an administered vaccine to the targeted pathogen. For both COVID-19 and seasonal influenza, pathogen evolution plays a particularly significant role.

2. Vaccines affect outcomes along multiple dimensions, among them are infection, mild disease, progression to death or severe disease once infected, and onward transmission once infected (Appendix B). To the extent we can ascertain from available sources, we report overall protection against death, E_d in the nomenclature of Appendix B, which results from both protection against infection (e_1) and progression to death once infected (e_2). For further discussion of dimensions of vaccine effectiveness, also see Halloran et al (2010).

of both. They prevent infection both by reducing infection probability in the vaccinated individual and by preventing onward transmission and, thereby, reducing infection and mortality probabilities in the unvaccinated (externalities or indirect effects). When we could not find a direct report of vaccine effectiveness against death, we calculated it via the vaccine's impacts on infection and death once infected. For more on modelling vaccination impact, see Appendix B.

3.5 Sources of Data on Vaccine Cost

We calculate vaccination cost as a sum of the vaccine dose cost (for a full course) and the associated delivery costs for transport, warehousing, health care personnel time, information systems, and reporting (Table 3.4). In this sense, we attempt to take a broader view of vaccine cost than many studies in the literature, which only focus on vaccine procurement prices or assume negligible delivery costs. We treat vaccines as tradeable with costs that are uniform globally but that also follow the established patterns of tiered pricing across markets (GAVI, 2010). Vaccine dose costs are calculated as averages of the procurement cost for a full course of doses for each antigen and for each World Bank income group from the 2024 Market Information for Access to Vaccines (MI4A) database, which includes reporting of vaccine purchases by 168 countries in 2023 (WHO, 2024).

Where data were not available for a given income group and vaccine, we estimated the cost based on the ratio between the cost of COVID-19 vaccination in high-income countries and the other income groups (of the vaccines considered in this paper, COVID-19 was the only one with purchasing data for all income groups). This is further described in Appendix D.

Vaccine delivery costs are viewed as local and calculated as a percentage of GNI per capita (World Bank, 2023). This makes them lower in LICs and MICs than in HICs because of major differences in labor costs, the main component in delivering vaccines by doctors, nurses, and other health care providers. Our cost estimates omit the private costs incurred by patients, including their time (and earnings foregone), transportation to health facilities, and side-effect costs to their health.

All calculations of NNV, CDA, and BCR incorporate ranges for the key variables outlined above, reflecting both uncertainty in parameter estimates and inherent variability across environments. The methods used to define and apply parameter ranges are described in Appendix B. Results incorporating parameter variability for NNV, CDA, and BCR are presented in detail for each antigen in Appendices F-J.

TABLE 3.4

Adult vaccination costs, estimated for early 2020s, by World Bank income group

	Costs in 2023 US dollars[1,2]			
	Low-income	**Lower-middle income**	**Upper-middle income**	**High-income**
1. Vaccine Costs[3]				
Seasonal influenza	$1.70 ($0.42-2.00)	$2.80 ($0.42-3.40)	$3.40 ($2.70-4.10)	$4.20 ($3.40-5.00)
COVID-19	$7.00 ($1.70-8.40)	$7.30 ($1.70-8.80)	$7.80 ($6.20-9.40)	$17 ($14-20)
RSV	$89 ($22-110)	$93 ($22-110)	$99 ($79-120)	$220 ($180-260)
Pneumococcal	$49 ($12-59)	$51 ($12-61)	$54 ($43-65)	$120 ($96-140)
Herpes zoster	$100 ($25-120)	$110 ($25-130)	$110 ($88-130)	$250 ($200-300)
2. Delivery Costs				
	$0.92 ($0.69-1.15)	$3.50 ($2.63-4.38)	$15 ($11-19)	$67 ($50-84)
3. Total Costs				
Seasonal influenza	$2.60 ($1.10-3.20)	$6.30 ($3.00-7.80)	$18 ($14-23)	$71 ($54-89)
COVID-19	$7.90 ($2.40-9.60)	$11 ($4.30-13)	$23 ($17-28)	$84 ($64-100)
RSV	$90 ($23-110)	$97 ($25-110)	$110 ($90-140)	$290 ($230-340)
Pneumococcal	$50 ($13-60)	$55 ($15-65)	$69 ($54-84)	$190 ($150-220)
Herpes zoster	$100 ($26-120)	$110 ($28-130)	$130 ($99-150)	$380 ($300-470)

NOTES:

1. Costs are expressed in 2023 exchange rate dollars and as a % of per capita income per day. Costs reflect a full course of immunization. The number of doses in a full course can be found in Table 3.3. All costs are rounded to two significant figures.

2. Daily per capita income is calculated by dividing the 2023 annual GNI per capita, Atlas method (US$) for each income group by 365. Delivery cost is equivalent to 100% of daily GNI per capita, with a range from 75-125%.

3. Vaccine prices are calculated from the MI4A database. Where values were not available for a given vaccine and a given income group, we estimated a value by using COVID-19 to establish a ratio of dose costs between high income groups and other income groups. We used this ratio to complete the gaps. We provide a range of vaccine dose prices across antigens and income groups. More detail is provided in Appendix D.

4. Results

4.1 Economic Analysis of Select Adult Vaccines

We report economic results across age groups and World Bank income categories for five high-burden antigens: seasonal influenza, pneumococcal disease, respiratory syncytial virus, COVID-19, and herpes zoster. Antigens were evaluated based on three primary metrics including number needed to vaccinate (NNV), cost per death averted (or case/DALY averted for HZ), and benefit-cost ratios (BCRs).

Across the antigens assessed, influenza and pneumococcal vaccination look moderately to highly economically attractive for those over 75 years of age and at best moderately attractive for adults in the 65-74 age band—warranting serious consideration for financing in most country income groups (Table 4.1). RSV vaccination does not look economically attractive based on our point estimates, but it appears more attractive at the upper end of our confidence intervals, which consider estimates of mortality rate based on several country-specific studies (as opposed to the IHME global

TABLE 4.1

Summary of BCRs for antigens, age groups, and World Bank income groups[1]

	LIC	LMIC	UMIC	HIC
Influenza				
Age 20-64	.077 (.01-.61)	.16 (.02-1.1)	.27 (.036-1.2)	.34 (.045-1.5)
Age 65-74	.45 (.06-3.6)	.83 (.11-5.9)	1.2 (.15-5.2)	1.8 (.23-7.8)
Age 75+	.91 (.12-7.3)	2.1 (.28-15)	3.8 (.50-17)	8.4 (1.1-37)
Pneumococcal				
Age 20-64	.042 (.020-.65)	.19 (.089-2.7)	.74 (.34-3.1)	1.1 (.53-4.2)
Age 65-74	.16 (.077-5.8)	.67 (.32-21)	2.2 (1.0-20)	3.3 (1.6-25)
Age 75+	.28 (.12-18)	1.5 (.70-78)	5.8 (2.7-92)	13 (6.1-160)
RSV				
Age 20-64	<.001 (<.001-.031)	.0026 (<.01-.17)	.016 (.0037-.33)	.036 (.0089-.76)
Age 65-74	.0017 (<.001-.11)	.0089 (.0023-.58)	.044 (.01-.91)	.11 (.028-2.4)
Age 75+	.0028 (<.001-.19)	.019 (.0049-1.2)	.12 (.027-2.4)	.48 (.12-10)
COVID-19				
Age 65+	.082 (.017-.75)	.42 (.091-3.0)	1.5 (.32-5.8)	3.9 (.84-14)
Herpes Zoster[2]				
Age 20-64	.0022 (<.001-.02)	.011 (.0029-.10)	.045 (.012-.14)	.12 (.031-.35)
Age 65-74	.0078 (.0021-.07)	.035 (.0095-.32)	.12 (.033-.37)	.29 (.075-.87)
Age 75+	.027 (.0073-.25)	.12 (.033-1.1)	.32 (.087-.98)	.75 (.19-2.2)

NOTES:
1. Yellow indicates a moderately attractive BCR (1≤BCR≤5) and green indicates a highly attractive BCR (BCR>5)

2. Herpes zoster's measure of benefit is DALYs averted. All other antigens use deaths averted as measure of benefit.

estimates, which are lower). Herpes zoster vaccination does not appear economically attractive in our analysis in any of the country income groupings when assessed in terms of cost per death or DALY averted. However, this is not the only—nor necessarily the most appropriate—method for assessing the benefits of HZ (see more below in Section 4.1.5). COVID-19 vaccination appears to be moderately economically attractive for adults aged 65+ in HICs and UMICs, but not economically attractive in LMICs and LICs. Detailed results by antigen are outlined in the following sections.

4.2 Detailed Results by Antigen

4.2.1 Influenza Vaccination

Expanding routine coverage of seasonal influenza vaccination is moderately attractive in adults 75+ in LMICs and UMICs (BCRs 2.1 and 3.8, respectively), and highly attractive in HICs (BCR 8.4) (Table 4.2). For UMICs and HICs, expanding vaccination for adults 65-74 is moderately attractive (BCRs 1.2 and 1.8, respectively). It is also on the threshold of becoming moderately attractive for ages 75+ in LICs (BCR 0.91). All other age and income group combinations for influenza do not appear attractive (BCR = .077-.83).

TABLE 4.2

Economic analysis of seasonal influenza vaccination

Indicator	LICs	LMICs	UMICs	HICs
1. NNV[1]				
Age 20-64	78,000	110,000	160,000	280,000
Age 65-74	6,000	9,400	18,000	28,000
Age 75+	1,600	2,200	3,100	3,400
2.1 CDA[2] - $				
Age 20-64	$200,000	$680,000	$2,900,000	$20,000,000
Age 65-74	$15,000	$59,000	$320,000	$2,000,000
Age 75+	$4,100	$14,000	$56,000	$240,000
2.2 CDA – Multiple of per capita income				
Age 20-64	270	270	280	410
Age 65-74	20	24	30	41
Age 75+	5.4	5.4	5.3	5.0
3. Benefit-to-cost ratio				
Age 20-64	.077	.16	.27	.34
Age 65-74	.45	.83	1.2	1.8
Age 75+	.91	2.1	3.8	8.4

NOTES:

[1] Number needed to vaccinate to avert a death. NNV incorporates the death rate, vaccine effectiveness against death, and the number of years of protection provided by the vaccine (details in Methods and Appendix B).

[2] Cost per death averted, defined as the NNV multiplied by the incremental cost of vaccinating one person.

The low end of the confidence ranges for all estimates is below 1 (the lower threshold of moderately attractive), except for ages 75+ in HICs (.01 among ages 20-64 in LICs up to .50 among ages 75+ in UMICs) (Table 4.1, Appendix F). The high end of the confidence range exceeds 1 for all age and country income groups (high end BCR ranging 1.1-37) except ages 20-64 in LICs (high end BCR of .61). Further, the high end of the confidence range exceeds 5 (threshold of highly attractive) for all income groups among adults aged 65-74 and 75+ (high end BCR ranging 5.9 – 37), except for adults 65-74 in LICS (high-end BCR of 3.6).

4.2.2 Pneumococcal Vaccination

Our modeling suggests that pneumococcal vaccination is highly economically attractive for adults aged 75+ in UMICs and HICs (BCRs 5.9 and 13, respectively) (Table 4.3) and moderately attractive for adults aged 75+ in LMICs (BCR 1.5), adults aged 65-74 in UMICs and HICs (BCRs 2.2 and 3.3, respectively), and adults aged 20-64 in HICs (BCR 1.1). Expanded pneumococcal vaccination does not appear economically attractive for adults of any age in LICs (BCRs .042-.28).

As with seasonal influenza vaccination, there were wide confidence ranges (Table 4.1, Appendix G). BCRs were greater than or equal to 1 at the lower end of the interval for adults aged 65-74 and 75+ for UMICs and HICs (low end BCRs 1.0-6.1). Similar to influenza, the high end of the confidence range exceeds 1 for all age and country income groups (high end BCR ranging 2.7-160) except ages 20-64 in LICs (high end BCR of .65).

TABLE 4.3

Economic analysis of pneumococcal vaccination

Indicator	LICs	LMICs	UMICs	HICs
1. NNV[1]				
Age 20-64	7,500	10,000	16,000	33,000
Age 65-74	840	1300	2500	5500
Age 75+	270	360	540	860
2.1 CDA[2] **- $**				
Age 20-64	$370,000	$560,000	$1,100,000	$6,200,000
Age 65-74	$42,000	$71,000	$170,000	$1,000,000
Age 75+	$13,000	$19,000	$37,000	$160,000
2.2 CDA – Multiple of per capita income				
Age 20-64	490	220	100	130
Age 65-74	56	28	16	22
Age 75+	18	7.7	3.5	3.4
3. Benefit-to-cost ratio				
Age 20-64	.042	.19	.74	1.1
Age 65-74	.16	.67	2.2	3.3
Age 75+	.28	1.5	5.8	13

NOTES:

1. Number needed to vaccinate to avert a death. NNV incorporates the death rate, vaccine effectiveness against death, and the number of years of protection provided by the vaccine (details in Methods and Appendix B).

2. Cost per death averted, defined as the NNV multiplied by the incremental cost of vaccinating one person.

4.2.3 RSV Vaccination

Expanded routine RSV immunization was not found to be economically attractive for any income or age group (BCRs <.001-.48) (Table 4.4). This lackluster attractiveness is driven both by the low mortality rate used in our analysis based on the currently available global data, and the high cost of the RSV vaccine at present ($90-290 per delivered dose, no public sector pooled procurement price for Gavi and other MICs). If mortality turns out to be higher than in the IHME figures (as we suspect is the case) and countries can negotiate lower RSV prices for larger public sector tenders, the BCR results could change from unattractive to attractive. For example, if the price of the RSV vaccine in HIC is lowered from the $290 estimate used in our model to $135, the BCR for ages 75+ becomes moderately attractive.

As described in the methods section of this paper, other studies find significantly higher RSV mortality rates in older adults than the numbers we use. To account for this, the confidence range for RSV includes a mortality rate 10x higher (as opposed to 20% higher for other antigens) than our point estimate. The confidence range also includes potential effects of future tiered pricing for LICs and LMICs, which could potentially lower vaccine dose costs by up to 90%. The upper end of our BCR confidence ranges reflects the potential benefit of these two factors, in which case RSV looks similarly attractive to the values we find for seasonal influenza. If examining the upper estimates, RSV vaccination appears highly attractive for adults aged 75+ in HICs (high end BCR of 10) and moderately economically attractive in adults aged 75+ in LMICs and UMICs (high end BCRs of 1.2 and 2.4, respectively) and in adults aged 65-74 in HICs (high end BCR of 2.4) (Table 4.1, Appendix H). However, the upper end of our BCR estimates never exceed 1 for adults aged 20-64 in any income group (high end BCRs .031-.76), pointing to low cost-effectiveness in younger adults.

TABLE 4.4

Economic analysis of RSV vaccination

Indicator	LICs	LMICs	UMICs	HICs
1. NNV[1]				
Age 20-64	370,000	410,000	450,000	650,000
Age 65-74	45,000	57,000	78,000	110,000
Age 75+	15,000	16,000	17,000	15,000
2.1 CDA[2] **- $**				
Age 20-64	$33,000,000	$40,000,000	$50,000,000	$180,000,000
Age 65-74	$4,000,000	$5,500,000	$8,500,000	$30,000,000
Age 75+	$1,300,000	$1,500,000	$1,800,000	$4,100,000
2.2 CDA – Multiple of per capita income				
Age 20-64	44,000	16,000	4,700	3,800
Age 65-74	5,400	2,200	810	620
Age 75+	1,700	600	170	86
3. Benefit-to-cost ratio				
Age 20-64	<.001	.0026	.016	.036
Age 65-74	.0017	.0089	.044	.11
Age 75+	.0028	.019	.12	.48

NOTES:

1. Number needed to vaccinate to avert a death. NNV incorporates the death rate, vaccine effectiveness against death, and the number of years of protection provided by the vaccine (details in Methods and Appendix B).

2. Cost per death averted, defined as the NNV multiplied by the incremental cost of vaccinating one person.

4.2.4 COVID-19 Vaccination

Expanded COVID-19 vaccination appears moderately attractive for adults aged 65+ in UMICs and HICs (BCR 1.5 and 3.9, respectively). Based on our assumptions, expanding COVID-19 vaccination does not appear economically attractive for adults 65+ in LMICs and LICs (BCRs .082 and .42, respectively) (Table 4.5).

COVID-19 is different from the other antigens in this analysis because we use the same mortality rate for all income groups. As a result, variation in BCRs is driven more by the relationship between vaccine price and VSL than by disease burden. Since the VSL-to-price ratio increases with income for this particular vaccine, the BCR for COVID-19 vaccination rises with country income level and is higher for HICs than for LICs.

At the top of their confidence ranges, UMICs and HICs reach high attractiveness (BCRs 5.8 and 14, respectively) and LMICs reach moderate attractiveness (BCR of 3.0). LICs have a BCR of 5.0 at the top of their confidence range despite a point estimate of .082 (Table 4.1), which reflects our wide sensitivity interval that incorporates variations in dose costs among LICs and LMICs (described in Appendix D).

4.2.5 Herpes Zoster Vaccination

Unlike the other four antigens analyzed, morbidity accounts for a substantial share (55%) of the burden of HZ (Table 3.2). As described in the methods, we therefore present results for herpes zoster in terms of DALYs—and their economic value—and cases averted, adding a qualitative dimension to the value of benefit. We find that in no country income or age group does expanding HZ vaccination appear economically attractive when analyzed by DALYs averted (BCRs range from <.01 to .75) (Table 4.6). Nonetheless, the NNVs to avert a case shown in Table 4.6 are low and, for reasons outlined in the following paragraph, many countries may judge that outcomes judged in terms only of deaths or DALYs averted fail to adequately capture the benefits of HZ immunization. For this reason, we view our calculations of NNVs and costs per cases averted to be the relevant part of our economic evaluation for HZ. Others may, however, differ on this point, and for that reason, we also report our calculations of NNV to avert a DALY, the cost of averting a DALY, and benefit-to-cost ratios based on those calculations. Table 4.6 presents those results in light type.

TABLE 4.5

Economic analysis of COVID-19 vaccination

Indicator	LICs	LMICs	UMICs	HICs
1. NNV[1]				
Age 65+	11,000	11,000	11,000	11,000
2.1 CDA[2] **- $**				
Age 65+	$84,000	$120,000	$240,000	$890,000
2.2 CDA – Multiple of per capita income				
Age 65+	110	47	23	18
3. Benefit-to-cost ratio				
Age 65+	.082	.42	1.5	3.9

NOTES:

1. Number needed to vaccinate to avert a death. NNV incorporates the death rate, vaccine effectiveness against death, and the number of years of protection provided by the vaccine (details in Methods and Appendix B).

2. Cost per death averted, defined as the NNV multiplied by the incremental cost of vaccinating one person.

TABLE 4.6

Economic analysis of herpes zoster vaccination

Indicator	LICs	LMICs	UMICs	HICs
Cases Averted[1]				
1. NNV				
Age 20-64	350	320	330	280
Age 65-74	120	120	130	120
Age 75+	96	91	100	92
2.1 CCA - $				
Age 20-64	$35,000	$35,000	$43,000	$110,000
Age 65-74	$12,000	$13,000	$17,000	$44,000
Age 75+	$9,600	$10,000	$13,000	$35,000
DALYs[2]				
1. NNV				
Age 20-64	2,800	3,400	4,600	4,500
Age 65-74	810	1,100	1,700	1,800
Age 75+	230	300	650	720
2.1 C(DALY)A - $				
Age 20-64	$280,000	$380,000	$600,000	$1,700,000
Age 65-74	$80,000	$120,000	$220,000	$700,000
Age 75+	$23,000	$33,000	$85,000	$270,000
2.2 C(DALY)A – Multiple of per capita income				
Age 20-64	370	150	57	35
Age 65-74	110	46	21	14
Age 75+	30	13	8	5.6
3. Benefit-to-cost ratio				
Age 20-64	.0022	.011	.045	.12
Age 65-74	.0078	.035	.12	.29
Age 75+	.027	.12	.32	.75

NOTES:

1. Here, NNV is the number needed to vaccinate to avert a *case*. CCA is the cost per case averted, defined as the NNV multiplied by the incremental cost of vaccinating one person (details in Methods and Appendix B).

2. Here, NNV is the number needed to vaccinate to avert a *DALY*. C(DALY)A is the cost per *DALY* averted, defined as the NNV multiplied by the incremental cost of vaccinating one person (details in Methods and Appendix B).

The cost *per case averted* ranges from a low of $9,600 for adults aged 75+ in LMICs to $110,000 for adults aged 20-64 in HICs (Table 4.6). Costs per case averted generally increase from LICs to HICs due to both higher vaccine costs and larger NNVs to avert a case. A typical case of herpes zoster lasts 3-5 weeks. It can result in intense pain, rashes, and fluid-filled blisters that break open and crust over. Severe cases can lead to postherpetic neuralgia, which causes excruciating pain long after blisters clear due to damaged nerve fibers, vision loss, neurological problems such as facial paralysis and skin infections. The risk of serious complications from herpes zoster infection increases with age (Cleveland Clinic 2023). Considering these disabling consequences of a herpes zoster infection, some may judge these costs per case averted to be attractive, especially for adults aged 65+. In addition, recently published studies point to the potential for HZ vaccination to delay the onset and slow the progression of dementia, as further described in the Discussion (Section 5.2.2) of this report.

5. Discussion

5.1 Significance of This Study

As the global population ages and new vaccines targeting major causes of disease in older adults enter the market, the economic value of adult vaccination is an issue and opportunity of growing importance that remains underexplored and almost certainly underutilized. The majority of existing studies suggest that cost-effectiveness could be high, at least for the two vaccines (seasonal influenza and pneumococcal vaccines) that have been examined in multiple studies. However, these findings from the existing literature are incomplete and have not been communicated effectively to national authorities. Significant data and analytical gaps remain.

This study begins filling such gaps by developing and applying a modeling tool that generates comparable results on the economic value of five major adult vaccines in different age groups across the world's major country income categories. This tool focuses on three metrics: number needed to vaccinate to avert a death, cost per death averted, and benefit-cost ratio. Where appropriate, it also reports related metrics such as life years gained, DALYs averted, and cases averted.

To our knowledge, this paper presents the first, and only, global estimates of the economic value of routine adult vaccination against seasonal influenza, pneumococcal disease, RSV, herpes zoster, and COVID-19, disaggregated by age groups and national income categories. While these estimates are subject to considerable uncertainty, due mainly to limitations in the underlying data on disease burden and vaccination cost, we use wide confidence intervals to show the plausible range of benefit-cost ratios.

The results of our modeling analysis can serve to broadly position the five adult vaccines across age and country income groupings, assisting national analysts and policy makers in deciding whether to look more deeply into these vaccines and, eventually, whether it makes sense from an economic perspective to adopt and finance them. Given the potential to lower vaccine prices—through technology advances, large-scale manufacturing, and negotiations between suppliers and the largest national purchasers—our modeling tool can help to explore vaccine price points and vaccination cost thresholds that countries must achieve to consider an adult vaccine as an economically attractive investment. The tool can also accommodate new data on disease burden and on improved vaccine effectiveness which may emerge as a result of R&D breakthroughs.

5.2 Gaps in Existing Literature

The existing literature points to the cost-effectiveness of expanded adult vaccination for several antigens in some age and country groupings but is incomplete and largely neglects low-income countries and overlooks several promising new adult vaccines.

The existing literature on cost-effectiveness of adult vaccination focuses primarily on seasonal influenza and HZ vaccines, and to a lesser degree, pneumococcal vaccines, and is focused in high (HICs) and upper middle-income countries (UMICs). It broadly reports the positive economic value of expanded use of these vaccines among the elderly. There are fewer existing studies that examine RSV vaccination, but those we identified also report good cost-effectiveness in higher- income countries and for older age groups.

Wider use of the modeling approach we have adopted could help orient and drive further economic evaluation of adult vaccination globally and facilitate sound investment decisions.

There are very few studies evaluating the cost-effectiveness of adult vaccination in low-income (LIC) and lower-middle-income countries (LMICs). Additional studies are especially needed for the vaccines, age ranges, and country income groups where our positioning analysis suggests potentially high benefit-cost ratios—for example, seasonal influenza vaccination among adults aged 75+ in LMICs.

5.2.1 Use of Modeling to Guide Global Adult Vaccination Economics

Wider use of the modeling approach we have adopted could help orient and drive further economic evaluation of adult vaccination globally and facilitate sound investment decisions.

Most published studies present results in costs per QALY gained, with few including alternative cost-effectiveness measures such as cost per death averted or case avoided. Moreover, few studies convert metrics for health gains (e.g., lives or life-years gained) into economic values to produce benefit-cost ratios. While QALY/DALY metrics are widely used by health economists and frequently shape analysis by health technology assessment agencies, these metrics are often less familiar to health and finance ministry officials tasked with deciding whether to promote and pay for new vaccines. The more straightforward and intuitive methodology used in this study, based on deaths/health life years lost, the cost of averting a death, and BCRs, could prove more accessible and useful to country decision-makers.

5.2.2 Importance of Further Economic Assessments of Adult Vaccination

Our results support additional analysis of the economic value of routine adult vaccination, especially in areas where our modeling suggests that there is good economic attractiveness (BCRs of >5) or moderate attractiveness (BCRs of 1-5).

Our modeling shows that expanded routine seasonal *influenza* vaccination is economically attractive for adults aged 75+ in LMICs, UMICs, and HICs. Expanded routine *pneumococcal* vaccination is attractive for adults aged 65+ in UMICs and HICs, and attractive for adults 75+ in LMICs. COVID-19 vaccination is attractive for adults aged 65+ in UMICs and HICs. For no antigen or country income group did expanding routine vaccination appear economically attractive for adults aged 20-64. For these reasons, country-focused analysis could have an important impact on national vaccination policies and programs if it targets the antigens and age groups that our analysis "positions" as having higher benefit-cost ratios.

RSV vaccination does not appear attractive from our BCR point estimates. However, our data on RSV mortality burden taken from IHME are significantly lower than those reported elsewhere in the literature for older adults in specific countries. When we use these latter high mortality rates, expanded adult routine RSV appears more economically attractive for adults 65+, following similar age and income patterns as influenza and pneumococcal vaccination. Therefore, further country-specific evaluations of RSV in the high age groups are also merited.

Our estimates for HZ vaccination do not appear economically attractive when valuing the deaths or even the disability-weighted losses (DALYs) averted. However, this approach may underestimate the benefits of HZ vaccination. Recent research leveraging natural experiments has found a 20% relative reduction in dementia diagnosis among those vaccinated and a 52.3 percentage point reduction in dying from dementia among women who were vaccinated. Mounting evidence indicates that beyond protection from shingles, HZ vaccination can meaningfully prevent and protect against dementia, which is becoming a growing burden in aging populations (Eyting et al. 2025; Polisky et al. 2025; Xie et al. 2025).

5.3 Limitations

There are several limitations to our modeling approach and analysis of the economic value of adult vaccination.

Disease burden data for the diseases amenable to adult vaccination that we include here—influenza, pneumococcal disease, RSV, HZ, and COVID-19—suffer from incompleteness and quality issues. Many countries do not publicly report burden data for our antigens of interest, and the severity of diseases like seasonal influenza can vary widely from year to year. Increased surveillance and better reporting are needed.

Disease burden is also impacted by vaccine coverage. Thus, if a country has a low disease burden due to a robust vaccination program, the NNV may be high, and indicate that a vaccination program is not cost-effective, when in fact, the success of the program is what is driving a high NNV. Because most countries still have low adult vaccination rates, this is not yet a significant confounder.

Data on vaccine prices and the cost of adult immunization are limited across nearly all income groups and regions. This is especially true for vaccines like RSV and HZ in LICs and LMICs since only small quantities of these vaccines have been purchased and used in these markets. Unlike childhood vaccines, there is no established public sector price nor is there a price obtained by Gavi/UNICEF or PAHO.

While the cost of immunizing children has been closely studied (Vaughn et al. 2019), we do not have systematic information on the costs of delivering adult vaccines in the different country groupings. More work is needed to document adult vaccine prices globally and to estimate the costs of adult vaccine delivery.

We assumed that vaccine effectiveness was the same for all adults, regardless of age. We made this simplified assumption due to a general lack of data on vaccine effectiveness against death for different adult age groups. A future analysis might re-assess the younger adult age group (20-64) with a differentiated vaccine effectiveness. However, given the lower disease burden for the younger age group, a higher vaccine effectiveness on its own is unlikely to change our conclusion about cost-effectiveness.

We quantified the economic benefits of adult vaccination by focusing on each vaccine's ability to reduce mortality, and we valued the lives saved or healthy life years gained using a VSL approach. We acknowledge that disability averted may be important for some adult vaccines, such as HZ, and more work is needed to quantify these non-fatal outcomes.

It is important to note that our NNV calculations do not account for the potential transmission-blocking (indirect) benefits of vaccination. For antigens where indirect effects are substantial—most notably influenza—NNV may in fact be lower due to protection of the unvaccinated by the vaccinated population, which, in turn would raise the BCR. Due to drivers of transmission like age-specific contact rates, the magnitude of these indirect effects is expected to vary across age groups: vaccinating younger populations may provide greater protection to the unvaccinated elderly than the reverse (vaccinated elderly may have a smaller impact on the unvaccinated younger population). Evidence for such indirect benefits is strongest for influenza, although highly variable across studies, with some suggesting the indirect benefits exceed the cases and deaths averted by direct vaccination (Charu et al. 2011; Arinaminpathy et al. 2017). These effects are less understood for the other vaccines.

Though VSLs are well established and widely used for making resource allocation decisions in countries around the world, we recognize that some may raise technical or ethical concerns about this approach. The OECD is about to update its earlier estimates of VSLs for many countries, and the new values may be different from the ones we have used here from 2012 (OECD 2012).

Our estimates of the economic value of adult vaccination do not account for improvements in labor productivity, increased time spent by elderly persons performing household chores or unpaid volunteer services, reductions in health care spending from avoided hospitalization, or health care sector resources freed. However, our use of VSLs captures most of the economic value of the adult vaccines that we modeled.

While this paper helps to elucidate the economic attractiveness of routine adult vaccination, countries may wish to supplement their assessments with other economic evaluation methods, such as examining costs per DALY/QALY gained, the key metric used by many Health Technology Assessment agencies.

Countries must also weigh other important factors when making vaccination policy decisions, including affordability, vaccine hesitancy and demand, provider capacity, patient knowledge, and the strength of delivery infrastructure. Economic value is only one of many key variables to consider when making evidence-based policy decisions for adopting and financing adult vaccination programs.

References

Aballéa, Samuel, Jeremy Chancellor, Monique Martin, Peter Wutzler, Fabrice Carrat, Roberto Gasparini, Joao Toniolo-Neto, Michael Drummond, and Milton Weinstein. "The Cost-Effectiveness of Influenza Vaccination for People Aged 50 to 64 Years: An International Model." Value in Health 10, no. 2 (2007/3//): 98-116. https://doi.org/10.1111/j.1524-4733.2006.00157.x.

Adler, Matthew D. "Social Welfare Functions and Health Policy: A New Approach." SSRN Electronic Journal (2024). https://doi.org/10.2139/ssrn.4847730.

Aguado, Teresa M., Jane Barratt, John R. Beard, Bonnie B. Blomberg, Wilbur H. Chen, Julian Hickling, Terri B. Hyde, et al. "Report on WHO Meeting on Immunization in Older Adults: Geneva, Switzerland, 22–23 March 2017." Vaccine 36, no. 7 (February 2018): 921–931. https://doi.org/10.1016/j.vaccine.2017.12.029.

Aljunid, Syed Mohamed, Nur Syazana Mad Tahir, Aniza Ismail, Aznida Firzah Abdul Aziz, Amirah Azzeri, S. A. Zafirah, and Azimatun Noor Aizuddin. "Cost Effectiveness of Quadrivalent Influenza Vaccines in the Elderly Population of Malaysia." Scientific Reports 13, no. 1 (2023/10/31/). https://doi.org/10.1038/s41598-023-46079-y.

Ament, A., R. Baltussen, G. Duru, C. Rigaud-Bully, D. de Graeve, A. ortqvist, B. Jonsson, et al. "Cost-Effectiveness of Pneumococcal Vaccination of Older People: A Study in 5 Western European Countries." Clinical Infectious Diseases 31, no. 2 (2000/8/1/): 444-50. https://doi.org/10.1086/313977.

Annemans, L., X. Bresse, C. Gobbo, and M. Papageorgiou. "Health Economic Evaluation of a Vaccine for the Prevention of Herpes Zoster (Shingles) and Post-Herpetic Neuralgia in Adults in Belgium." Journal of Medical Economics 13, no. 3 (2010/8/16/): 537-51. https://doi.org/10.3111/13696998.2010.502854.

Arinaminpathy, Nimalan, Inkyu Kevin Kim, Paul Gargiullo, Michael Haber, Ivo M. Foppa, Manoj Gambhir, and Joseph Bresee. "Estimating Direct and Indirect Protective Effect of Influenza Vaccination in the United States." American Journal of Epidemiology 186, no. 1 (March 25, 2017): 92–100. https://doi.org/10.1093/aje/kwx037.

Banhawi, Hania, Sulayman Chowdhury, Margherita Neri, Priscila Radu, Sian Hodgson, Eleanor Bell, Simon Brassel, and Lotte Steuten. "Socio-Economic Value of Adult Immunisation Programmes." (2024/4/17/). https://www.ohe.org/publications/the-socio-economic-value-of-adult-immunisation-programmes/.

Barbieri, Marco, Stefano Capri, Chiara de Waure, Sara Boccalini, and Donatella Panatto. "Age- and Risk-Related Appropriateness of the Use of Available Influenza Vaccines in the Italian Elderly Is Advantageous: Results from a Budget Impact Analysis." Journal of Preventive Medicine and Hygiene 58, no. 4 (2017/12/27/): E279-E79. https://doi.org/10.15167/2421-4248/jpmh2017.58.4.867. http://www.jpmh.org/index.php/jpmh/article/view/867.

Belchior, Emmanuel, Daniel Lévy-Bruhl, Yann Le Strat, and Magid Herida. "Cost-Effectiveness of a Herpes Zoster Vaccination Program among the French Elderly People." Human Vaccines & Immunotherapeutics 12, no. 9 (2016/8/2/): 2378-82. https://doi.org/10.1080/21645515.2016.1184801.

Bender, Rose Grace, Sarah Brooke Sirota, Lucien R. Swetschinski, Regina-Mae Villanueva Dominguez, Amanda Novotney, Eve E. Wool, Kevin S. Ikuta, et al. "Global, Regional, and National Incidence and Mortality Burden of Non-Covid-19 Lower Respiratory Infections and Aetiologies, 1990–2021: A Systematic Analysis from the Global Burden of Disease Study 2021." The Lancet Infectious Diseases 24, no. 9 (2024): 974-1002. https://doi.org/10.1016/S1473-3099(24)00176-2.

Betancourt-Cravioto, Miguel, Jorge Abelardo Falcón-Lezama, Rodrigo Saucedo-Martínez, Myrna María Alfaro-Cortés, and Roberto Tapia-Conyer. "Public Health and Economic Benefits of Influenza Vaccination of the Population Aged 50 to 59 Years without Risk Factors for Influenza Complications in Mexico: A Cross-Sectional Epidemiological Study." Vaccines 9, no. 3 (2021/2/24/): 188. https://doi.org/10.3390/vaccines9030188.

Bilcke, Joke, Christiaan Marais, Benson Ogunjimi, Lander Willem, Niel Hens, and Philippe Beutels. "Cost-Effectiveness of Vaccination against Herpes Zoster in Adults Aged over 60 Years in Belgium." Vaccine 30, no. 3 (2012/1//): 675-84. https://doi.org/10.1016/j.vaccine.2011.10.036.

Birck, Anders Muusfeldt, Liv Nordin Christensen, Mikkel H. Pedersen, Jens Olsen, Kelly D. Johnson, Goran Bencina, Thomas Holtkøtter Clausen, and Carsten Schade Larsen. "Health Economic Evaluation of Introducing a Ppsv23-Based Vaccination Programme to Adults Aged 65 and above, and an Extension to the 60-64 Age Group in Denmark." Expert Review of Vaccines 20, no. 10 (2021/9/16/): 1327-37. https://doi.org/10.1080/14760584.2021.1977627.

Boardman, Anthony E., David H. Greenberg, Aidan R. Vining, and David L. Weimer. Cost-Benefit Analysis: Concepts and Practice. Cambridge University Press, 2018/7/19/.

Bresse, X., L. Annemans, K. Bloch, G. Duru, and A. Gauthier. "Pin63 Vaccination against Herpes Zoster and Post-Herpetic Neuralgia in France: A Cost-Effectiveness Analysis." Value in Health 15, no. 7 (2012/11//): A396. https://doi.org/10.1016/j.jval.2012.08.1130.

Brisson, Marc, James M. Pellissier, Stéphanie Camden, Caroline Quach, and Philippe De Wals. "The Potential Cost-Effectiveness of Vaccination against Herpes Zoster and Post-Herpetic Neuralgia." Human Vaccines 4, no. 3 (2008/5//): 238-45. https://doi.org/10.4161/hv.4.3.5686.

Carrico, Justin, Sandra E. Talbird, Elizabeth M. La, Sara Poston, Jean-Etienne Poirrier, Jessica K. DeMartino, and Cosmina Hogea. "Cost-Benefit Analysis of Vaccination against Four Preventable Diseases in Older Adults: Impact of an Aging Population." Vaccine 39, no. 36 (2021/8//): 5187-97. https://doi.org/10.1016/j.vaccine.2021.07.029.

Casas, Maribel, Tor Molden, Caihua Liang, Robin Bruyndonckx, Worku Biyadgie Ewnetu, Pimnara Peerawaranun, Solomon Molalign Moges, et al. "P-680. Estimated Respiratory Syncytial Virus (Rsv)-Related Hospitalizations and Deaths among Adults in Norway between 2010–2019." Open Forum Infectious Diseases 12, no. Supplement_1 (2025/1/29/). https://doi.org/10.1093/ofid/ofae631.876.

CDC. "Staying up to Date with Covid-19 Vaccines." (2025/1/7/). https://www.cdc.gov/covid/vaccines/stay-up-to-date.html.

CDC. "Shingles Vaccination." (2024/10/3/). https://www.cdc.gov/shingles/vaccines/index.html.

Charu, Vivek, Cécile Viboud, Lone Simonsen, Katharine Sturm-Ramirez, Masayoshi Shinjoh, Gerardo Chowell, Mark Miller, and Norio Sugaya. "Influenza-Related Mortality Trends in Japanese and American Seniors: Evidence for the Indirect Mortality Benefits of Vaccinating Schoolchildren." PLOS ONE 6, no. 11 (November 7, 2011). https://doi.org/10.1371/journal.pone.0026282.

Chung, Hannah, Sarah A. Buchan, Aaron Campigotto, Michael A. Campitelli, Natasha S. Crowcroft, Vinita Dubey, Jonathan B. Gubbay, et al. "Influenza Vaccine Effectiveness against All-Cause Mortality Following Laboratory-Confirmed Influenza in Older Adults, 2010–2011 to 2015–2016 Seasons in Ontario, Canada." Clinical Infectious Diseases 73, no. 5 (2020/12/23/): e1191-e99. https://doi.org/10.1093/cid/ciaa1862.

Cleveland, Clinic. "Shingles." (2023/8/24/). https://my.clevelandclinic.org/health/diseases/11036-shingles.

Cookson, Richard, Susan Griffin, Ole F. Norheim, Anthony J. Culyer, and Kalipso Chalkidou. "Distributional Cost-Effectiveness Analysis Comes of Age." Value in Health 24, no. 1 (2021/1//): 118-20. https://doi.org/10.1016/j.jval.2020.10.001.

de Boer, Pieter T., Joel K. Kelso, Nilimesh Halder, Thi-Phuong-Lan Nguyen, Jocelyn Moyes, Cheryl Cohen, Ian G. Barr, Maarten J. Postma, and George J. Milne. "The Cost-Effectiveness of Trivalent and Quadrivalent Influenza Vaccination in Communities in South Africa, Vietnam and Australia." Vaccine 36, no. 7 (2018/2//): 997-1007. https://doi.org/10.1016/j.vaccine.2017.12.073.

de Boer, Pieter T., Koen B. Pouwels, Juul M. Cox, Eelko Hak, Jan C. Wilschut, and Maarten J. Postma. "Cost-Effectiveness of Vaccination of the Elderly against Herpes Zoster in the Netherlands." Vaccine 31, no. 9 (2013/2//): 1276-83. https://doi.org/10.1016/j.vaccine.2012.12.067.

de Boer, Pieter T., Cornelis H. van Werkhoven, Albert Jan van Hoek, Mirjam J. Knol, Elisabeth A. M. Sanders, Jacco Wallinga, Hester E. de Melker, and Anneke Steens. "Higher-Valency Pneumococcal Conjugate Vaccines in Older Adults, Taking into Account Indirect Effects from Childhood Vaccination: A Cost-Effectiveness Study for the Netherlands." BMC Medicine 22, no. 1 (2024/2/16/). https://doi.org/10.1186/s12916-024-03277-3.

de Gier, Brechje, Liselotte van Asten, Tjarda M. Boere, Annika van Roon, Caren van Roekel, Joyce Pijpers, C. H. Henri van Werkhoven, et al. "Effect of Covid-19 Vaccination on Mortality by Covid-19 and on Mortality by Other Causes, the Netherlands, January 2021–January 2022." Vaccine 41, no. 31 (2023/7//): 4488-96. https://doi.org/10.1016/j.vaccine.2023.06.005.

Doherty, T. Mark, Fiona Ecarnot, Jacques Gaillat, and Lois Privor-Dumm. "Nonstructural Barriers to Adult Vaccination." Human Vaccines & Immunotherapeutics 20, no. 1 (2024/4/17/). https://doi.org/10.1080/21645515.2024.2334475.

Du, Yuxia, Rui Yan, Xiaoyue Wu, Xiaobao Zhang, Can Chen, Daixi Jiang, Mengya Yang, et al. "Global Burden and Trends of Respiratory Syncytial Virus Infection across Different Age Groups from 1990 to 2019: A Systematic Analysis of the Global Burden of Disease 2019 Study." International Journal of Infectious Diseases 135 (2023/10//): 70-76. https://doi.org/10.1016/j.ijid.2023.08.008.

ECDC. "Covid-19 Vaccine Effectiveness against Hospitalisation and Death Using Electronic Health Records in Eight European Countries in the Vebis Monitoring Network - October 2023 to April 2024." (2024/12/3/). https://www.ecdc.europa.eu/en/publications-data/covid-19-vaccine-effectiveness-hospitalisation--death-health-records.

Eichner, Martin, Markus Schwehm, Linda Eichner, and Laetitia Gerlier. "Direct and Indirect Effects of Influenza Vaccination." BMC Infectious Diseases 17, no. 1 (April 26, 2017): 1–8. https://doi.org/10.1186/s12879-017-2399-4.

Edoka, Ijeoma, Ciaran Kohli-Lynch, Heather Fraser, Karen Hofman, Stefano Tempia, Meredith McMorrow, Wayne Ramkrishna, et al. "A Cost-Effectiveness Analysis of South Africa's Seasonal Influenza Vaccination Programme." Vaccine 39, no. 2 (2021/1//): 412-22. https://doi.org/10.1016/j.vaccine.2020.11.028.

Eyting, Markus, Min Xie, Felix Michalik, Simon Heß, Seunghun Chung, and Pascal Geldsetzer. "A Natural Experiment on the Effect of Herpes Zoster Vaccination on Dementia." Nature 641, no. 8062 (2025/4/2/): 438-46. https://doi.org/10.1038/s41586-025-08800-x.

Feikin, Daniel, Melissa M. Higdon, Laith J. Abu-Raddad, Nick Andrews, Rafael Araos, Yair Goldberg, Michelle Groome, et al. "Duration of Effectiveness of Vaccines against Sars-Cov-2 Infection and Covid-19 Disease: Results of a Systematic Review and Meta-Regression." SSRN Electronic Journal (2021). https://doi.org/10.2139/ssrn.3961378.

Garland, Suzanne M., Susanne K. Kjaer, Nubia Muñoz, Stan L. Block, Darron R. Brown, Mark J. DiNubile, Brianna R. Lindsay, et al. "Impact and Effectiveness of the Quadrivalent Human Papillomavirus Vaccine: A Systematic Review of 10 Years of Real-World Experience." Clinical Infectious Diseases 63, no. 4 (2016/5/26/): 519-27. https://doi.org/10.1093/cid/ciw354.

Gavi. "Gavi Approach Creates Tiered Pricing for Vaccines." (2010/7/21/). https://www.gavi.org/news/media-room/gavi-approach-creates-tiered-pricing-vaccines.

Gharpure, Radhika, Anna N. Chard, Maria Cabrera Escobar, Weigong Zhou, Molly M. Valleau, Tat S. Yau, Joseph S. Bresee, et al. "Costs and Cost-Effectiveness of Influenza Illness and Vaccination in Low- and Middle-Income Countries: A Systematic Review from 2012 to 2022." PLOS Medicine 21, no. 1 (2024/1/5/): e1004333. https://doi.org/10.1371/journal.pmed.1004333.

Giglio, Norberto D., Vanesa E. Castellano, Patricia Mizrahi, and Paula V. Micone. "Cost-Effectiveness of Pneumococcal Vaccines for Adults Aged 65 Years and Older in Argentina."

Value in Health Regional Issues 28 (2022/3//): 76-81. https://doi.org/10.1016/j.vhri.2021.08.003.

Goldin, Shoshanna, Donald Brooks, Pernille Jorgensen, Pushpa Wijesinghe, Heeyoun Cho, Rania Attia, Reena Doshi, et al. "Seasonal Influenza Vaccination: A Global Review of National Policies in 194 Who Member States in 2022." Vaccine 42, no. 26 (2024/12//): 126274. https://doi.org/10.1016/j.vaccine.2024.126274.

Gourzoulidis, George, Charalampos Tzanetakos, Argyro Solakidi, Eleftherios Markatis, Marios Detsis, Diana Mendes, and Myrto Barmpouni. "Cost-Effectiveness of Bivalent Respiratory Syncytial Virus Prefusion F Vaccine for Prevention of Respiratory Syncytial Virus among Older Adults in Greece." Vaccines 12, no. 11 (2024/10/29/): 1232. https://doi.org/10.3390/vaccines12111232.

Grijalva, Carlos G., Huong Q. Nguyen, Yuwei Zhu, Alexandra M. Mellis, Trey McGonigle, Jennifer K. Meece, Jessica E. Biddle, Natasha B. Halasa, Carrie Reed, Alicia M. Fry, Yang Yang, Edward A. Belongia, H. Keipp Talbot, and Melissa A. Rolfes. "Estimated Effectiveness of Influenza Vaccines in Preventing Secondary Infections in Households." JAMA Network Open 7, no. 11 (2024/11/21): e2446814. https://doi.org/10.1001/jamanetworkopen.2024.46814.

Hadler, Stephen C., Abigail M. Shefer, Kathleen F. Cavallaro, Malembe Ebama, Catherine Tencza, Erin D. Kennedy, Sidy Ndiaye, et al. "Supporting National Immunization Technical Advisory Groups (Nitags) in Development of Evidence-Based Vaccine Recommendations and Nitag Assessments – New Tools and Approaches." Vaccine 42 (2024/10//): 125610. https://doi.org/10.1016/j.vaccine.2024.01.035.

Halloran, M. Elizabeth, Ira M. Longini, and Claudio J. Struchiner. Design and Analysis of Vaccine Studies. Springer Science & Business Media, 2009/10/27/.

Hamadeh, Nada, Catherine Van Rompaey, and Eric Metreau. "World Bank Group Country Classifications by Income Level for Fy24 (July 1, 2023- June 30, 2024)." (2023/6/30/). https://blogs.worldbank.org/en/opendata/new-world-bank-group-country-classifications-income-level-fy24.

Hansen, Chelsea L., Sandra S. Chaves, Clarisse Demont, and Cécile Viboud. "Mortality Associated with Influenza and Respiratory Syncytial Virus in the Us, 1999-2018." JAMA Network Open 5, no. 2 (2022/2/28/): e220527. https://doi.org/10.1001/jamanetworkopen.2022.0527.

Hashim, Ahmed, Vica Dang, Shelly Bolotin, and Natasha S. Crowcroft. "How and Why Researchers Use the Number Needed to Vaccinate to Inform Decision Making—a Systematic Review." Vaccine 33, no. 6 (2015/2//): 753-58. https://doi.org/10.1016/j.vaccine.2014.12.033.

Hornberger, John, and Katherine Robertus. "Cost-Effectiveness of a Vaccine to Prevent Herpes Zoster and Postherpetic Neuralgia in Older Adults." Annals of Internal Medicine 145, no. 5 (2006/9/5/): 317-25. https://doi.org/10.7326/0003-4819-145-5-200609050-00004.

Hoshi, Shu-Ling, Masahide Kondo, Yasushi Honda, and Ichiro Okubo. "Cost–Effectiveness Analysis of Influenza Vaccination for People Aged 65 and over in Japan." Vaccine 25, no. 35 (2007/8//): 6511-21. https://doi.org/10.1016/j.vaccine.2007.05.067.

Hutton, David W., Lisa Prosser, Angela M. Rose, Kerra Mercon, Ismael R. Ortega-Sanchez, Andrew J. Leidner, Fiona P. Havers, et al. Cost-Effectiveness of Vaccinating Adults Aged 60 Years and Older against Respiratory Syncytial Virus. Elsevier BV (2024). https://doi.org/10.2139/ssrn.4866672.

Immunize. "Influenza Vaccine Products for the 2024-2025 Influenza Season." https://www.immunize.org/wp-content/uploads/catg.d/p4072.pdf.

Iuliano, A. Danielle, Katherine M. Roguski, Howard H. Chang, David J. Muscatello, Rakhee Palekar, Stefano Tempia, Cheryl Cohen, et al. "Estimates of Global Seasonal Influenza-Associated Respiratory Mortality: A Modelling Study." The Lancet 391, no. 10127 (2018/3//): 1285-300. https://doi.org/10.1016/s0140-6736(17)33293-2.

Jamison, Dean T. "7.4 Cost-Effectiveness Analysis: Concepts and Applications." In Oxford Textbook of Public Health: Oxford University Press, 2009.

Jamison, Dean T., Lawrence H. Summers, Angela Y. Chang, Omar Karlsson, Wenhui Mao, Ole F. Norheim, Osondu Ogbuoji, et al. "Global Health 2050: The Path to Halving Premature Death by Mid-Century." The Lancet 404, no. 10462 (2024/10//): 1561-614. https://doi.org/10.1016/s0140-6736(24)01439-9.

Jiang, Minghuan, Pengchao Li, Weihua Wang, Mingyue Zhao, Naveel Atif, Shan Zhu, and Yu Fang. "Cost-Effectiveness of Quadrivalent Versus Trivalent Influenza Vaccine for Elderly Population in China." Vaccine 38, no. 5 (2020/1//): 1057-64. https://doi.org/10.1016/j.vaccine.2019.11.045.

Jiang, Minghuan, Xuelin Yao, Jin Peng, Liuxin Feng, Yue Ma, Xinke Shi, Yu Fang, and Hai Fang. "Cost-Effectiveness of Recombinant Zoster Vaccine for Adults Aged ≥50 Years in China." American Journal of Preventive Medicine 65, no. 5 (2023/11//): 818-26. https://doi.org/10.1016/j.amepre.2023.05.007.

Kim DeLuca, Ellen, Acham Gebremariam, Angela Rose, Matthew Biggerstaff, Martin I. Meltzer, and Lisa A. Prosser. "Cost-Effectiveness of Routine Annual Influenza Vaccination by Age and Risk Status." Vaccine 41, no. 29 (2023/6//): 4239-48. https://doi.org/10.1016/j.vaccine.2023.04.069.

Kitano, Taito. "The Estimated Burden of 15 Vaccine-Preventable Diseases from 2008 to 2020 in Japan: A Transition by the Covid-19 Pandemic." Journal of Infection and Chemotherapy 27, no. 10 (2021/10//): 1482-88. https://doi.org/10.1016/j.jiac.2021.06.021.

Le, Phuc, and Michael B. Rothberg. "Cost-Effectiveness of the Adjuvanted Herpes Zoster Subunit Vaccine in Older Adults." JAMA Internal Medicine 178, no. 2 (2018/2/1/): 248. https://doi.org/10.1001/jamainternmed.2017.7431.

Leidner, Andrew J., Neil Murthy, Harrell W. Chesson, Matthew Biggerstaff, Charles Stoecker, Aaron M. Harris, Anna Acosta, Kathleen Dooling, and Carolyn B. Bridges. "Cost-Effectiveness of Adult Vaccinations: A Systematic Review." Vaccine 37, no. 2 (2019/1//): 226-34. https://doi.org/10.1016/j.vaccine.2018.11.056.

Loeb, Mark, Margaret L. Russell, Lorraine Moss, Kevin Fonseca, Julie Fox, David J. D. Earn, Fred Aoki, Gregory Horsman, Paul Van Caeseele, Khami Chokani, Mark Vooght, Lorne Babiuk, Richard Webby, and Stephen D. Walter. "Effect of Influenza Vaccination of Children on Infection Rates in Hutterite

Communities: A Randomized Trial." JAMA 303, no. 10 (2010/3/10): 943–950. https://doi.org/10.1001/jama.2010.250

Lugner, A. K., M. van Boven, R. de Vries, M. J. Postma, and J. Wallinga. "Cost Effectiveness of Vaccination against Pandemic Influenza in European Countries: Mathematical Modelling Analysis." BMJ 345, no. jul12 3 (2012/7/12/): e4445-e45. https://doi.org/10.1136/bmj.e4445.

McMillan, Mark, Abira Chandrakumar, Hua Lin Rachael Wang, Michelle Clarke, Thomas R. Sullivan, Ross M. Andrews, Mary Ramsay, and Helen S. Marshall. "Effectiveness of Meningococcal Vaccines at Reducing Invasive Meningococcal Disease and Pharyngeal Neisseria Meningitidis Carriage: A Systematic Review and Meta-Analysis." Clinical Infectious Diseases 73, no. 3 (2020/11/19/): e609-e19. https://doi.org/10.1093/cid/ciaa1733.

Meeyai, Aronrag, Naiyana Praditsitthikorn, Surachai Kotirum, Wantanee Kulpeng, Weerasak Putthasri, Ben S. Cooper, and Yot Teerawattananon. "Seasonal Influenza Vaccination for Children in Thailand: A Cost-Effectiveness Analysis." PLOS Medicine 12, no. 5 (2015/5/26/): e1001829. https://doi.org/10.1371/journal.pmed.1001829.

Moore, Lee, Vanessa Remy, Monique Martin, Maud Beillat, and Alistair McGuire. "A Health Economic Model for Evaluating a Vaccine for the Prevention of Herpes Zoster and Post-Herpetic Neuralgia in the Uk." Cost Effectiveness and Resource Allocation 8, no. 1 (2010/4/30/). https://doi.org/10.1186/1478-7547-8-7.

Murray, C. J., A. D. Lopez, and D. T. Jamison. "The Global Burden of Disease in 1990: Summary Results, Sensitivity Analysis and Future Directions." Bulletin on the World Health Organization 72, no. 3 (1994): 495-509.

Najafzadeh, Mehdi, Carlo A. Marra, Eleni Galanis, and David M. Patrick. "Cost Effectiveness of Herpes Zoster Vaccine in Canada." PharmacoEconomics 27, no. 12 (2009/12//): 991-1004. https://doi.org/10.2165/11314010-000000000-00000.

Nakafero, Georgina, Matthew J. Grainge, Tim Card, Christian D. Mallen, Jonathan S. Nguyen Van-Tam, and Abhishek Abhishek. "Effectiveness of Pneumococcal Vaccination in Adults with Common Immune-Mediated Inflammatory Diseases in the Uk: A Case–Control Study." The Lancet Rheumatology 6, no. 9 (2024/9//): e615-e24. https://doi.org/10.1016/s2665-9913(24)00128-0.

Nakamura, Shigeki, Masashi Mikami, Tomoyuki Hayamizu, Naohiro Yonemoto, Camille Moyon, Mark Gouldson, Catriona Crossan, Jeffrey Vietri, and Kazumasa Kamei. "Cost-Effectiveness Analysis of Adult Pneumococcal Conjugate Vaccines for Pneumococcal Disease in Japan." Expert Review of Vaccines 23, no. 1 (2024/5/9/): 546-60. https://doi.org/10.1080/14760584.2024.2350246.

Neto, Joao Tonolio, Gabriela Tannus Branco de Araujo, Anna Gagliardi, Amanda Pinho, Laure Durand, and Marcelo Fonseca. "Cost-Effectiveness Analysis of Pneumococcal Polysaccharide Vaccination from Age 60 in São Paulo State, Brazil." Human Vaccines 7, no. 10 (2011/10//): 1037-47. https://doi.org/10.4161/hv.7.10.15987.

Newall, Anthony T., and Juan Pablo Dehollain. "The Cost-Effectiveness of Influenza Vaccination in Elderly Australians: An Exploratory Analysis of the Vaccine Efficacy Required." Vaccine 32, no. 12 (2014/3//): 1323-25. https://doi.org/10.1016/j.vaccine.2014.01.017.

Newall, Anthony T., James G. Wood, and C. Raina MacIntyre. "Influenza-Related Hospitalisation and Death in Australians Aged 50 Years and Older." Vaccine 26, no. 17 (2008/4//): 2135-41. https://doi.org/10.1016/j.vaccine.2008.01.051.

Ngamprasertchai, Thundon, Chayanis Kositamongkol, Saranath Lawpoolsri, Pinyo Rattanaumpawan, Viravarn Luvira, Piriyaporn Chongtrakool, Jaranit Kaewkungwal, Kulkanya Chokephaibulkit, and Pochamana Phisalprapa. "A Cost-Effectiveness Analysis of the 13-Valent Pneumococcal Conjugated Vaccine and the 23-Valent Pneumococcal Polysaccharide Vaccine among Thai Older Adult." Frontiers in Public Health 11 (2023/6/29/). https://doi.org/10.3389/fpubh.2023.1071117.

Oordt-Speets, Anouk; Julia Spinardi; Carlos Mendoza; Jingyan Yang; Graciela Morales; John M. McLaughlin; Moe H. Kyaw. "Effectiveness of COVID-19 Vaccination on Transmission: A Systematic Review." COVID 3, no. 10 (2023): 1516–27. https://doi.org/10.3390/covid3100103.

Organisation for Economic Co-operation and Development (OECD). Mortality Risk Valuation in Environment, Health and Transport Policies. Paris: OECD Publishing, 2012. https://doi.org/10.1787/9789264130807-en.

Ortega-Sanchez, Ismael. "Economics of Respiratory Syncytial Virus (Rsv) Vaccination in All U.S. Adults >= 75 Years-Old, and Adults Aged 60-74 and 50-59 Years at Increased Risk: Summary Comparing Models From: Gsk, Moderna and University of Michigan-Cdc." 2024/6/26/.

Ortega-Sanchez, Ismael R., Joshua A. Mott, Wanitchaya Kittikraisak, Viengphone Khanthamaly, Margaret McCarron, Soukphadeth Keokhonenang, Phonepaseuth Ounaphom, et al. "Cost-Effectiveness of Seasonal Influenza Vaccination in Pregnant Women, Healthcare Workers and Adults >= 60 years of Age in Lao People's Democratic Republic." Vaccine 39, no. 52 (2021/12//): 7633-45. https://doi.org/10.1016/j.vaccine.2021.11.011.

Ozawa, Sachiko, Allison Portnoy, Hiwote Getaneh, Samantha Clark, Maria Knoll, David Bishai, H. Keri Yang, and Pallavi D. Patwardhan. "Modeling the Economic Burden of Adult Vaccine-Preventable Diseases in the United States." Health Affairs 35, no. 11 (2016/11//): 2124-32. https://doi.org/10.1377/hlthaff.2016.0462.

Palmer, Tim J., Kimberley Kavanagh, Kate Cuschieri, Ross Cameron, Catriona Graham, Allan Wilson, and Kirsty Roy. "Invasive Cervical Cancer Incidence Following Bivalent Human Papillomavirus Vaccination: A Population-Based Observational Study of Age at Immunization, Dose, and Deprivation." JNCI: Journal of the National Cancer Institute 116, no. 6 (2024/1/22/): 857-65. https://doi.org/10.1093/jnci/djad263.

Parellada, C., Bs Riveros, Tnf Moreira, A. Deb, K. Owusu-Edusei, S. Yande, R. Chitale, and Kd Johnson. "Ee212 Cost-Effectiveness of Pneumococcal Vaccination Implementation in Older Adult Immunization Schedule in the Brazilian National Program." Value in Health 25, no. 7 (2022/7//): S375. https://doi.org/10.1016/j.jval.2022.04.461.

Payne, Amanda B., Janet A. Watts, Patrick K. Mitchell, Kristin Dascomb, Stephanie A. Irving, Nicola P. Klein, Shaun J. Grannis, et al. "Respiratory Syncytial Virus (Rsv) Vaccine Effectiveness against Rsv-Associated Hospitalisations and Emergency Department Encounters among Adults Aged

60 Years and Older in the USA, October, 2023, to March, 2024: A Test-Negative Design Analysis." The Lancet 404, no. 10462 (2024/10//): 1547-59. https://doi.org/10.1016/s0140-6736(24)01738-0.

Polisky, Vitaly, Maria Littmann, Aleksei Triastcyn, Max Horn, Andreas Georgiou, Robyn Widenmaier, Bruno Anspach, Halima Tahrat, Sanjay Kumar, Carolyn Buser-Doepner, Pascal Geldsetzer, Cornelia M. Van Duijn, and Patrick Schwab. "Varicella-Zoster Virus Reactivation and the Risk of Dementia." Nature Medicine (2025). https://doi.org/10.1038/s41591-025-03972-5.

Portnoy, Allison, Kelsey Vaughan, Emma Clarke-Deelder, Christian Suharlim, Stephen C Resch, Logan Brenzel, and Nicolas A Menzies. "Producing Standardized Country-Level Immunization Delivery Unit Cost Estimates." PharmacoEconomics 38, no. 9 (September 2020): 995–1005. https://doi.org/10.1007/s40273-020-00930-6.

Pretorius, Carel, Nimalan Arinaminpathy, Sandip Mandal, Suvanand Sahu, Madhukar Pai, Roland Mathiasson, and Brad Wong. "One Million Lives Saved Per Year: A Cost–Benefit Analysis of the Global Plan to End Tuberculosis, 2023–2030 and Beyond." Journal of Benefit-Cost Analysis 14, no. S1 (2023): 337-54. https://doi.org/10.1017/bca.2023.13.

Privor-Dumm, Lois, Prarthana Vasudevan, Kana Kobayashi, and Jaya Gupta. "Archetype Analysis of Older Adult Immunization Decision-Making and Implementation in 34 Countries." Vaccine 38, no. 26 (2020/5//): 4170-82. https://doi.org/10.1016/j.vaccine.2020.04.027.

Privor-Dumm, Lois A., Gregory A. Poland, Jane Barratt, David N. Durrheim, Maria Deloria Knoll, Prarthana Vasudevan, Mark Jit, Pablo E. Bonvehí, and Paolo Bonanni. "A Global Agenda for Older Adult Immunization in the Covid-19 Era: A Roadmap for Action." Vaccine 39, no. 37 (2021/8//): 5240-50. https://doi.org/10.1016/j.vaccine.2020.06.082.

Raviotta, Jonathan M., Kenneth J. Smith, Jay DePasse, Shawn T. Brown, Eunha Shim, Mary Patricia Nowalk, and Richard K. Zimmerman. "Cost- Effectiveness and Public Health Effect of Influenza Vaccine Strategies for U.S. Elderly Adults." Journal of the American Geriatrics Society 64, no. 10 (2016/10//): 2126-31. https://doi.org/10.1111/jgs.14323.

Reid, Michael, Yvan Jean Patrick Agbassi, Nimalan Arinaminpathy, Alyssa Bercasio, Anurag Bhargava, Madhavi Bhargava, Amy Bloom, et al. "Scientific Advances and the End of Tuberculosis: A Report from the Lancet Commission on Tuberculosis." The Lancet 402, no. 10411 (2023/10//): 1473-98. https://doi.org/10.1016/s0140-6736(23)01379-x.

Robinson, Lisa A., James K. Hammitt, Michele Cecchini, Kalipso Chalkidou, Karl Claxton, Maureen L. Cropper, Patrick Eozenou, et al. "Reference Case Guidelines for Benefit-Cost Analysis in Global Health and Development." SSRN Electronic Journal (2019). https://doi.org/10.2139/ssrn.4015886.

Robinson, Lisa A., James K. Hammitt, Dean T. Jamison, and Damian G. Walker. "Conducting Benefit-Cost Analysis in Low- and Middle-Income Countries: Introduction to the Special Issue." Journal of Benefit-Cost Analysis 10, no. S1 (2019): 1-14. https://doi.org/10.1017/bca.2019.4.

Rothberg, M. B., A. Virapongse, and K. J. Smith. "Cost-Effectiveness of a Vaccine to Prevent Herpes Zoster and Postherpetic Neuralgia in Older Adults." Clinical Infectious Diseases 44, no. 10 (2007/5/15/): 1280-88. https://doi.org/10.1086/514342.

Sauer, Molly, Prarthana Vasudevan, Ankita Meghani, Karuna Luthra, Cristina Garcia, Maria Deloria Knoll, and Lois Privor-Dumm. "Situational Assessment of Adult Vaccine Preventable Disease and the Potential for Immunization Advocacy and Policy in Low- and Middle-Income Countries." Vaccine 39, no. 11 (2021/3//): 1556-64. https://doi.org/10.1016/j.vaccine.2021.01.066.

Shah, Nitin, Mma Faridi, Monjori Mitra, Ashish Bavdekar, Archana Karadkhele, Gaurav Puppalwar, and Rishi Jain. "Review of Long Term Immunogenicity and Tolerability of Live Hepatitis a Vaccine." Human Vaccines & Immunotherapeutics 16, no. 11 (2020/4/3/): 2816-21. https://doi.org/10.1080/21645515.2020.1741997.

Shattock, Andrew J., Helen C. Johnson, So Yoon Sim, Austin Carter, Philipp Lambach, Raymond C. W. Hutubessy, Kimberly M. Thompson, et al. "Contribution of Vaccination to Improved Survival and Health: Modelling 50 Years of the Expanded Programme on Immunization." The Lancet 403, no. 10441 (2024/5//): 2307-16. https://doi.org/10.1016/s0140-6736(24)00850-x.

Shin, Gyeongseon, Daewon Kang, Hee Jin Cheong, and Sang-Eun Choi. "Cost-Effectiveness of Extending the National Influenza Vaccination Program in South Korea: Does Vaccination of Older Adults Provide Health Benefits to the Entire Population?". Vaccines 10, no. 6 (2022/6/10/): 932. https://doi.org/10.3390/vaccines10060932.

Shoukat, Affan, Carolyn E. Bawden, Gergely Röst, Jason J. LeBlanc, Alison P. Galvani, Joanne M. Langley, and Seyed M. Moghadas. "Impact and Cost-Effectiveness Analyses of Vaccination for Prevention of Respiratory Syncytial Virus Disease among Older Adults in Ontario: A Canadian Immunization Research Network (Cirn) Study." Vaccine 42, no. 7 (2024/3//): 1768-76. https://doi.org/10.1016/j.vaccine.2024.02.041.

Sisk, Jane E. "Cost-Effectiveness of Vaccination against Pneumococcal Bacteremia among Elderly People." JAMA: The Journal of the American Medical Association 278, no. 16 (1997/10/22/): 1333. https://doi.org/10.1001/jama.1997.03550160053038.

Sugishita, Yoshiyuki, and Tamie Sugawara. "Effectiveness and Cost-Effectiveness of Influenza Vaccination for Elderly People." Vaccine 39, no. 52 (2021/12//): 7531-40. https://doi.org/10.1016/j.vaccine.2021.09.054.

Sun, Xiaodong, Yuekun Tang, Xiaoying Ma, Xiang Guo, Zhuoying Huang, Jia Ren, Jing Qiu, Hongli Jiang, and Yihan Lu. "Cost-Effectiveness Analysis of 23-Valent Pneumococcal Polysaccharide Vaccine Program for the Elderly Aged 60 Years or Older in Shanghai, China." Frontiers in Public Health 9 (2021/5/24/). https://doi.org/10.3389/fpubh.2021.647725.

Szucs, Thomas D., Reto W. Kressig, Manto Papageorgiou, Werner Kempf, Jean-Pierre Michel, Anton Fendl, and Xavier Bresse. "Economic Evaluation of a Vaccine for the Prevention of Herpes Zoster and Post-Herpetic Neuralgia in Older Adults in Switzerland." Human Vaccines 7, no. 7 (2011/7//): 749-56. https://doi.org/10.4161/hv.7.7.15573.

Talbird, Sandra E., Elizabeth M. La, Justin Carrico, Sara Poston, Jean-Etienne Poirrier, Jessica K. DeMartino, and

Cosmina S. Hogea. "Impact of Population Aging on the Burden of Vaccine-Preventable Diseases among Older Adults in the United States." Human Vaccines & Immunotherapeutics 17, no. 2 (2020/8/6/): 332-43. https://doi.org/10.1080/21645515.2020.1780847.

Thorrington, Dominic, Leo van Rossum, Mirjam Knol, Hester de Melker, Hans Rümke, Eelko Hak, and Albert Jan van Hoek. "Impact and Cost-Effectiveness of Different Vaccination Strategies to Reduce the Burden of Pneumococcal Disease among Elderly in the Netherlands." PLOS ONE 13, no. 2 (2018/2/9/): e0192640. https://doi.org/10.1371/journal.pone.0192640.

Tsuzuki, Shinya, Marc Baguelin, Richard Pebody, and Edwin van Leeuwen. "Modelling the Optimal Target Age Group for Seasonal Influenza Vaccination in Japan." Vaccine 38, no. 4 (2020/1//): 752-62. https://doi.org/10.1016/j.vaccine.2019.11.001.

Tunnicliffe, Ellie, Helen Hayes, Phill O'Neill, Soo Chin Yen, Simon Brassel, and Lotte Steuten. "Analysing Global Immunisation Expenditure." Office of Health Economics (2025/4//). https://www.ohe.org/wp-content/uploads/2025/04/Analysing-Global-Immunisation-Expenditure.pdf.

UNDP. "World Population Prospects." (2024). https://population.un.org/wpp/downloads?folder=Special%20Aggregates&group=Economic%20and%20trading%20groups.

van Hoek, A. J., N. Gay, A. Melegaro, W. Opstelten, and W. J. Edmunds. "Estimating the Cost-Effectiveness of Vaccination against Herpes Zoster in England and Wales." Vaccine 27, no. 9 (2009/2//): 1454-67. https://doi.org/10.1016/j.vaccine.2008.12.024.

van Lier, Alies, Albert Jan van Hoek, Wim Opstelten, Hein J. Boot, and Hester E. de Melker. "Assessing the Potential Effects and Cost-Effectiveness of Programmatic Herpes Zoster Vaccination of Elderly in the Netherlands." BMC Health Services Research 10, no. 1 (2010/8/13/). https://doi.org/10.1186/1472-6963-10-237.

Vaughan, K., A. Ozaltin, M. Mallow, F. Moi, C. Wilkason, J. Stone, and L. Brenzel. "The Costs of Delivering Vaccines in Low- and Middle-Income Countries: Findings from a Systematic Review." [In eng]. Vaccine X 2 (Aug 9 2019): 100034. https://doi.org/10.1016/j.jvacx.2019.100034.

Verguet, Stéphane, Ramanan Laxminarayan, and Dean T. Jamison. "Universal Public Finance of Tuberculosis Treatment in India: An Extended Cost- Effectiveness Analysis." Health Economics 24, no. 3 (2014/2/4/): 318-32. https://doi.org/10.1002/hec.3019.

Vila-Córcoles, A., O. Ochoa-Gondar, C. Llor, I. Hospital, T. Rodríguez, and A. Gómez. "Protective Effect of Pneumococcal Vaccine against Death by Pneumonia in Elderly Subjects." European Respiratory Journal 26, no. 6 (2005/12//): 1086-91. https://doi.org/10.1183/09031936.05.00030205.

Wang, Jiaqi, Pengfei Jin, Hui Jin, Qiang Wang, Fengcai Zhu, and Jingxin Li. "Cost-Effectiveness Analysis of Herpes Zoster Vaccination in a Chinese Population: Recombinant Subunit Vaccine Versus Live Attenuated Vaccine." Vaccines 12, no. 8 (2024/8/1/): 872. https://doi.org/10.3390/vaccines12080872. https://doi.org/10.3390/vaccines12080872.

Wang, Sen-Te, Long-Teng Lee, Li-Sheng Chen, and Tony Hsiu-Hsi Chen. "Economic Evaluation of Vaccination against Influenza in the Elderly: An Experience from a Population-Based Influenza Vaccination Program in Taiwan." Vaccine 23, no. 16 (2005/3//): 1973-80. https://doi.org/10.1016/j.vaccine.2004.10.011.

White, Elizabeth B., Lauren Grant, Josephine Mak, Lauren Olsho, Laura J. Edwards, Allison Naleway, Jefferey L. Burgess, et al. "Influenza Vaccine Effectiveness against Illness and Asymptomatic Infection in 2022–2023: A Prospective Cohort Study." Clinical Infectious Diseases (2024/10/24/). https://doi.org/10.1093/cid/ciae491.

Whittington, Dale, and Joseph Cook. "Valuing Changes in Time Use in Low- and Middle-Income Countries." Journal of Benefit-Cost Analysis 10, no. S1 (2018/12/19/): 51-72. https://doi.org/10.1017/bca.2018.21.

WHO. "Who Recommendations for Routine Immunization - Summary Tables." https://www.who.int/teams/immunization-vaccines-and-biologicals/policies/who-recommendations-for-routine-immunization---summary-tables.

WHO. "Who Covid-19 Dashboard." (2025). https://data.who.int/dashboards/covid19/deaths.

WHO. "Mi4a Vaccine Purchase Data." (2024). https://www.who.int/teams/immunization-vaccines-and-biologicals/vaccine-access/mi4a/mi4a-vaccine-purchase-data.

WHO. "Ageing and Health." World Health Organization: WHO, 2024. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health.

Williams, Sarah R., Amanda J. Driscoll, Hanna M. LeBuhn, Wilbur H. Chen, Kathleen M. Neuzil, and Justin R. Ortiz. "National Routine Adult Immunisation Programmes among World Health Organization Member States: An Assessment of Health Systems to Deploy Covid-19 Vaccines." Eurosurveillance 26, no. 17 (2021/4/29/). https://doi.org/10.2807/1560-7917.es.2021.26.17.2001195.

Wolff, Ellen, Katarina Widgren, Gianpaolo Scalia Tomba, Adam Roth, Tiia Lep, and Sören Andersson. "Cost-Effectiveness of Varicella and Herpes Zoster Vaccination in Sweden: An Economic Evaluation Using a Dynamic Transmission Model." PLOS ONE 16, no. 5 (2021/5/13/): e0251644. https://doi.org/10.1371/journal.pone.0251644.

World Bank. World Development Report 1993. World Bank, 1993/6/1/. doi:10.1596/978-0-1952-0890-0. https://doi.org/10.1596/978-0-1952-0890-0.

World Bank. "Gni Per Capital, Atlas Method (Current Us$)." (2024). https://data.worldbank.org/indicator/NY.GNP.PCAP.CD.

World Bank. "Gni Per Capita, Ppp (Current International $)." (2024). https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD.

World Bank. "Population, Total." (2024). https://data.worldbank.org/indicator/SP.POP.TOTL.

World Bank. "Gdp Per Capita (Current Us$)." (2023). https://data.worldbank.org/indicator/NY.GDP.PCAP.CD.

Xie, Min, Markus Eyting, Christian Bommer, Haroon Ahmed, and Pascal Geldsetzer. "The Effect of Shingles Vaccination at Different Stages of the Dementia Disease Course." Cell (2025). https://doi.org/10.1016/j.cell.2025.11.007.

Yemeke, Tatenda T, Elizabeth Mitgang, Patrick T Wedlock, Colleen Higgins, Hui-Han Chen, Sarah W Pallas, Taiwo Abimbola, et al. "Promoting, Seeking, and Reaching Vaccination Services: A Systematic Review of Costs to Immunization Programs, Beneficiaries, and Caregivers." Vaccine 39, no. 32 (July 22, 2021): 4437–49. https://doi.org/10.1016/j.vaccine.2021.05.075.

Yue, Mu, Borame L. Dickens, Joanne Su-yin Yoong, Mark I-Cheng Chen, Yot Teerawattananon, and Alex R. Cook. "Cost-Effectiveness Analysis for Influenza Vaccination Coverage and Timing in Tropical and Subtropical Climate Settings: A Modeling Study." Value in Health 22, no. 12 (2019/12//): 1345-54. https://doi.org/10.1016/j.jval.2019.07.001.

Yun, Jae-Won, Min Joo Choi, Gyeong-Seon Shin, Jae-Ok Lim, Ji Yun Noh, Yun-Kyung Kim, Joon Young Song, et al. "Cost-Effectiveness of Influenza Vaccine Strategies for the Elderly in South Korea." PLOS ONE 14, no. 1 (2019/1/25/): e0209643. https://doi.org/10.1371/journal.pone.0209643.

Appendices

Note: Supplementary Appendices E-J can be found at pharosglobalhealth.com. These include literature review results and economic analyses results broken down by antigen.

APPENDIX A.
KEY VALUES FOR WORLD BANK COUNTRY INCOME GROUPS

Country group	Total population, 2018 (billions)	Life expectancy at indicated age, 2018				Per capita GNI, 2023		VSL (as multiple of per capita GNI)
		Birth	50	70	80	US$	I$	
Low-income	.74	63	25	11	6	760	2400	33
Lower-middle income	3.1	68	26	12	7	2500	9200	64
Upper-middle income	2.8	76	30	14	8	11,000	23,000	100
High income	1.4	81	33	17	10	48,000	63,000	170

SOURCE: Calculated from data in World Population Prospects 2024 (UNDP, 2024); (World Bank, 2024)

NOTES:
1. 50 is chosen as the representative age of death for the age group 20-64; 70 for the age group 65-74; and 80 for the age group 75+.

2. The ratio of VSL to income is calculated using the Harvard BCA Reference case (Harvard, 2019) preferred base case assumption for extrapolation of VSL to different income levels of countries. The starting reference is VSL/y = 160 for the United States where y is per capita GNI international dollars (I$) with the value of y for the United States of $57,900. Extrapolation is done with an income elasticity of VSL of 1.5 We summarize this extrapolation with the formula $VSL/y = .665\sqrt{y}$. For our sensitivity analysis we use a range from 2/3 of this calculated value to 1.5 times the calculated value.

APPENDIX B. VACCINE EFFECTIVENESS

It is useful to think in terms of five different concepts of vaccine effectiveness.

i. e_1 = effectiveness in preventing an individual from becoming infected.

ii. e_2 = effectiveness in prevention of severe disease or death in an individual who has become infected.

iii. e_3 = effectiveness in reducing infectiousness of an individual who has become infected.

iv. E_d = overall effectiveness in preventing death.

v. E_t = overall effectiveness in preventing transmission.

Much of the vaccine effectiveness literature reports values for E_d and E_t. Both dynamic (SIR) and static models (such as discussed here) of vaccination program impact utilize the different, but related, concepts of e_1, e_2, and e_3. Hence, it is important to clarify the relations among these concepts.

A vaccine can prevent a death either by reducing the probability of infection in the first place (e_1) OR by reducing the probability of progression to death after infection (e_2) OR both. Similarly for transmission. E_d thus depends on e_1 and e_2 and E_t depends on e_1 and e_3. Thus, two equations link these five concepts of vaccine effectiveness. To derive these equations, we need to introduce simple descriptive parameters for a pandemic:

i = probability of being infected in the course of a pandemic [some integral of i(t)], the instantaneous probability of infection as a function of time;

d = probability of dying during a pandemic [some integral of d(t)];

k = probability that an infection causes death, conditional on being infected (infection fatality rate or case fatality rate);

m = expected number of individuals that an individual will infect, conditional on being infected [some function, m(t)]; and

n = expected overall number of individuals that will be infected by a randomly chosen member of the population.

Without vaccines, the probability of dying in the course of the pandemic is, then:

$$d = ik.$$

(This assumes that surviving infection confers immunity.)

If a vaccine has effectiveness (e) against some pandemic parameter ($0 \leq e \leq 1$) then it will reduce that parameter by a factor $f=1-e$. Therefore:

$$i_v = (1-e_1)i\ ,$$

$$k_v = (1-e_2)k,$$

$$m_v = (1-e_3)m,$$

where the v subscript denotes past vaccination.

The probability of dying during the pandemic in a vaccinated world is then:

$$d_v = i_v k_v$$

$$d_v = (1-e_1)i(1-e_2)k$$

$$= (1-e_1)(1-e_2)d.$$

Since d_v is reduced from d by the factor $f=(1-e_1)(1-e_2)$, then the vaccine's overall effectiveness against death is $1-f{:}E_d = 1-(1-e_1)(1-e2)$.

Likewise, the expected number of infections that an individual will cause during a pandemic is:

$$n=im.$$

Note that while i(t) and m(t), the instantaneous rates of infection and infectiousness, may exceed 1, the values of i and m, the total numbers over the course of the pandemic, must be less than or equal to 1. Hence $n \leq 1$.

Similar to the calculation for vaccine effectiveness against overall probability of death, we have overall effectiveness of a vaccine against transmission given by:

$$E_t = 1-(1-e_1)(1-e_3).$$

Equation (1) plots overall vaccine effectiveness against death. The figure shows, for selected values of E_d, the combinations of values of e_1 and e_2 that will lead to the indicated values of E_d. The point denoted A in figure 1, for example, shows 50% overall effectiveness against death resulting from zero effectiveness against transmission and 50% effectiveness against death given infection. Point B likewise shows 50% overall effectiveness against death but with this resulting from 50% effectiveness against infection and 0 effectiveness against progression to death. Point C in the figure shows a plausible depiction of the effectiveness of intramuscular vaccines against seasonal influenza. At point C overall effectiveness against death, E_d, is somewhat less than 50% and results from a very modest effectiveness against infection and a more substantial effectiveness against progress to death given infection.

Figure A1.1 would show overall effectiveness against transmission by everywhere replacing E_d with E_t and e_2 with e_3.

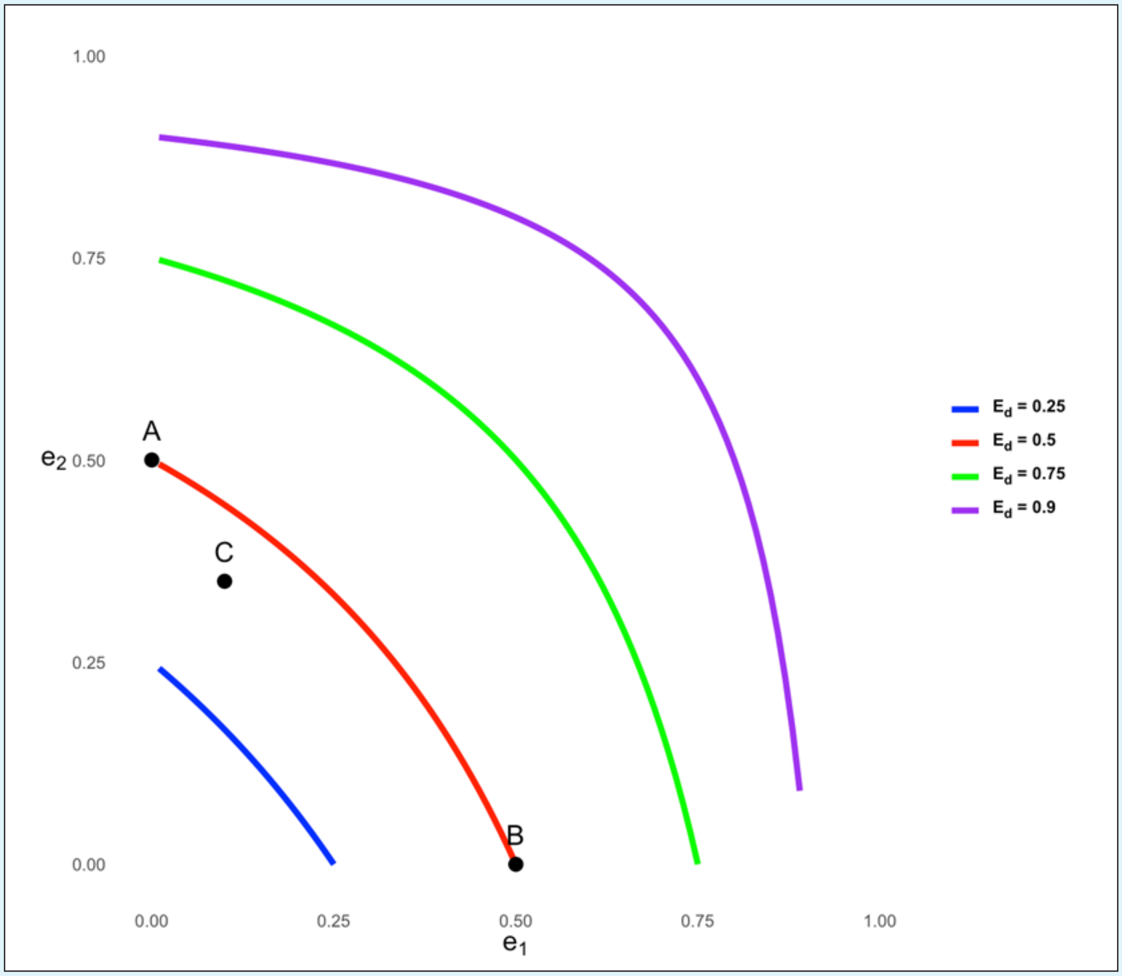
Clearly one could define vaccine effectiveness into more categories than in this appendix, e.g. by separately examining mild, moderate, and severe disease or by separating severe disease from death. Sometimes the literature on evaluations of specific vaccine effectiveness report effectiveness against mild or moderate disease. Halloran (2010) discusses nine concepts of vaccine effectiveness that deal with some of the severity gradations that are aggregated here.

For each of our three headline metrics (NNV, CDA, and BCR), we use isoquant graphs to compare results across different dimensions of analysis. These isoquant graphs also allow other analysts and national decision-makers to substitute their own parameter values if they have alternatives to ours, especially where they may have country-specific data that are more relevant than the data we were able to use from global studies and databases (see Section 3.3). Each graph includes rectangles that represent sensitivity intervals around our estimates. The width and height of each rectangle is associated with a sensitivity assessment for the key input parameters.

In the case of NNV, for example, the width of the rectangle represents variation studied in mortality rate and the height represents variation in vaccine effectiveness (for an example, see supplementary figure F1.1).

FIGURE B1.1

Overall vaccine effectiveness in preventing death, E_d



NOTE: E_d is the overall vaccine effectiveness in preventing death; e_1 is vaccine effectiveness in preventing infection; e_2 is vaccine effectiveness in preventing progression to death in an infected individual.

APPENDIX C.
DISEASE BURDEN RATES

TABLE C1.1

Mortality rates by antigen, age group, and income group

	Death rate per 10^5 population per year, 2018			
	Seasonal influenza	**Pneumococcal disease**	**RSV**	**Herpes zoster**
LICs				
20-64	3.2	6.6	.17	.13
65-74	42	59	1.4	1.2
75+	160	180	4.3	10
LMICs				
20-64	2.3	4.7	.15	.072
65-74	26	37	1.1	.64
75+	120	140	4.0	6.0
UMICs				
20-64	1.5	3.1	.14	.028
65-74	14	20	.8	.21
75+	80	91	3.8	2.2
HICs				
20-64	.89	1.5	.096	.013
65-74	8.9	8.9	.58	.10
75+	73	57	4.2	1.4

SOURCE: IHME, GBD 2021

In addition to mortality rate, we calculated results for cases and DALYs. The population rates by age and income group are presented in Table C1.2.

TABLE C1.2

Cases and DALYs by age group and income group

	Herpes zoster	
	Case rate per 10^5 population per year, 2018	**DALYs per 10^5 population per year, 2018**
LICs		
20-64	44	5.5
65-74	120	19
75+	160	67
LMICs		
20-64	48	4.5
65-74	130	15
75+	170	51
UMICs		
20-64	47	3.3
65-74	120	8.9
75+	150	24
HICs		
20-64	55	3.4
65-74	130	8.3
75+	170	21

SOURCE: IHME, GBD 2021

APPENDIX D.
VACCINE DOSE COSTS

TABLE D1.1

Vaccine dose costs

Income Group	COVID-19	Seasonal influenza	Pneumococcal	Herpes zoster	RSV
Low income	$7.00	*$1.70*	*$49*	*$100*	$89
Lower-middle income	$7.30	$2.80	*$51*	*$110*	$93
Upper-middle income	$7.80	$3.40	*$54*	*$110*	$99
High income	$17	$4.20	$120	$250	$220

SOURCE: From the MI4A vaccine purchasing database for 2024 (WHO, 2024).
NOTE: The database does not include vaccine purchases for all country income groups for all vaccines. Where there are missing data, we used COVID-19 to establish a benchmark ratio between high income group costs and costs for other income groups. We use this ratio to fill in gaps. The resulting calculations are distinguished by *italics*.

To create sensitivity intervals, we varied the dose price in HICs and UMICs by 20%. In LICs and LMICs where organizations such as GAVI have helped to significantly lower dose costs, in some cases by more than 95% (GAVI, 2010), we calculate the low end of our sensitivity range as a 90% decrease in our dose price estimate for LICs and LMICs and keep the high end as a 20% increase.

The following vaccines are selected from the MI4A database: “COVID-19”, “influenza trivalent inactivated vaccine”, “PCV20”, “RSV”, “Shingles”.

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