

Economic analysis of COVID-19 vaccination

University of Michigan
COVID-19 Vaccination Modeling Team

***ACIP Meeting
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Study team

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Expert panelists – Pediatric Model

Matthew Daley, MD, University of Colorado School of Medicine

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Conflict of interest statement

Authors have no known conflicts of interest.

Objectives

- Original aims*:
 - Estimate annual disease burden and healthcare utilization associated with COVID-19 illness and COVID-19 booster vaccination, including cases of symptomatic illness, hospitalizations, deaths, adverse events, costs, and quality-adjusted life years
 - Project cost-effectiveness of an updated mRNA booster against COVID-19-associated illness in persons ages ≥ 18 years
- Updates for this Phase 3 model:
 - Addition of pediatric age groups: 5-11y, 12-17y
 - Updates to adult model to reflect rapidly evolving evidence base

* Earlier analyses from this model were presented to ACIP in September 2023 and February 2024: Prosser, Lisa A. (2023). Economic Analysis of Vaccination with mRNA Booster Dose against COVID-19 Among Adults; Prosser, Lisa A (2024). Economic analysis of an additional dose of COVID-19 vaccine

Phase 3 Updates

Pediatric Model - new

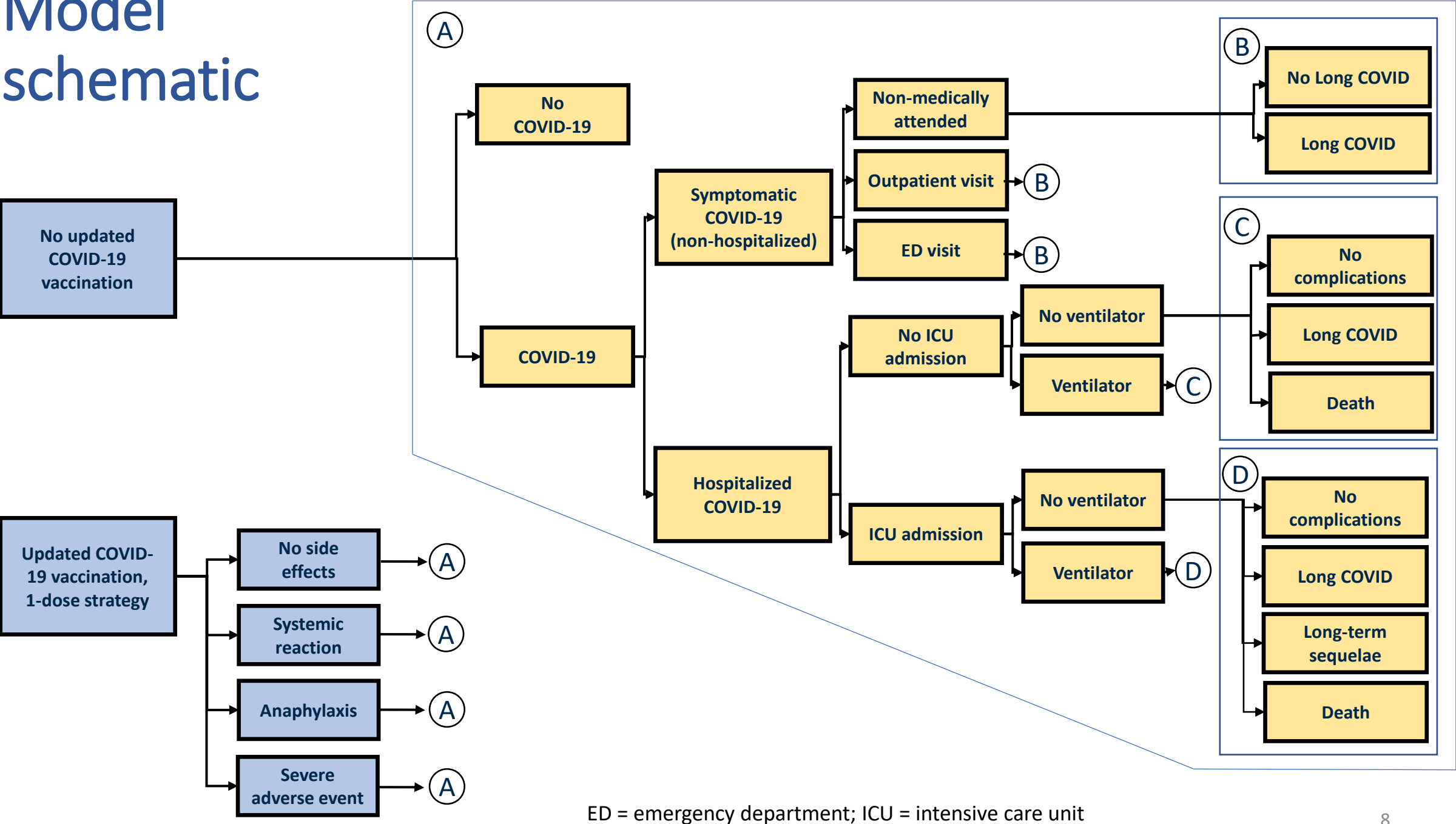
1. Epidemiologic inputs
2. Seasonality-adjusted vaccine impact
3. Cost inputs
4. Quality Adjustments

Adult Model - revised

1. Epidemiologic inputs
 - Hospitalization rates – more recent, lower
 - Probability of Long COVID - stratified by illness severity
2. Cost inputs
 - Costs & productivity losses associated with Long COVID - updated
 - Vaccine dose cost - updated to CDC list price
3. Quality adjustments
 - Symptomatic illness - updated

Methods

Model schematic



Analysis Plan

- Project health and economic outcomes stratified by intervention strategy and by age subgroups (5-11y, 12-17y, 18-49y, 50-64y, 65+y)
 - Cases
 - Hospitalizations
 - Deaths
 - Costs
 - QALYs
 - Adverse events
- Calculate incremental cost-effectiveness ratios comparing updated COVID-19 vaccination to no updated vaccination (societal perspective)
- Conduct base case and uncertainty analyses (one-way sensitivity and scenario analyses)

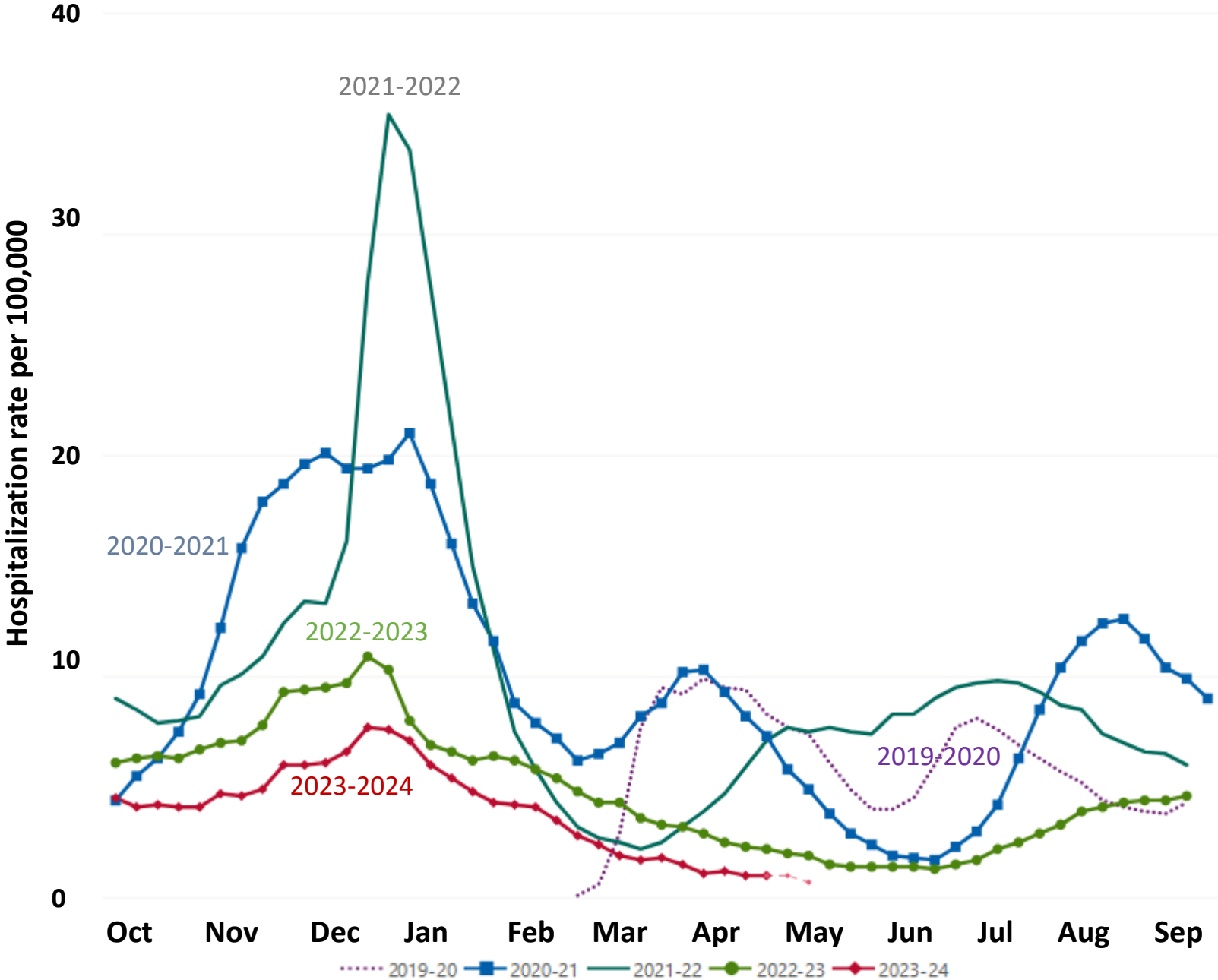
Model inputs

Probability of symptomatic illness, annualized

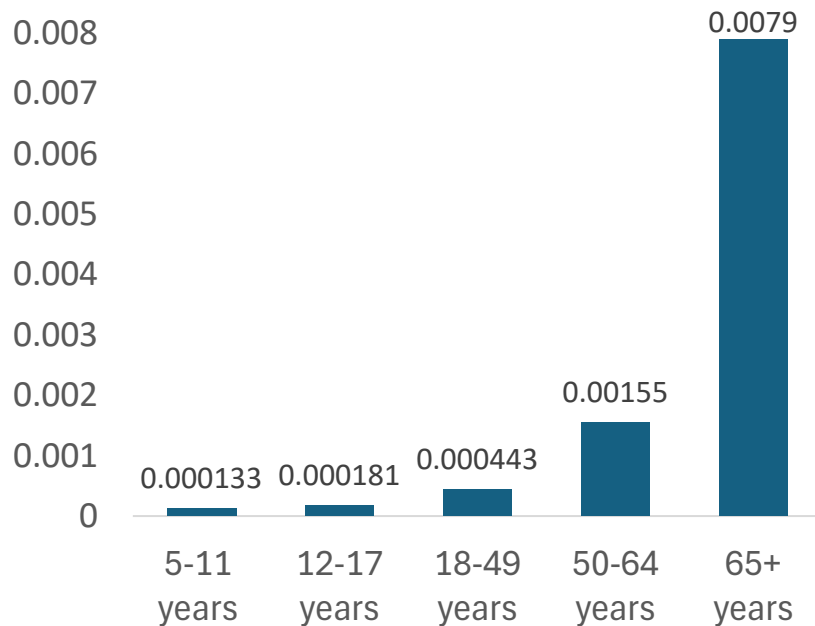
Age	Base case	Range for sensitivity analysis		Source
		Low	High	
5-11 years	0.3145	0.1790	0.4510	Assumption based on adult data*
12-17 years	0.3145	0.1790	0.4510	
18-49 years	0.3145	0.2858	0.3444	HEROES-RECOVER Dec 2022- May 2023
50-64 years	0.2841	0.2438	0.3274	
65+ years	0.3339	0.2312	0.4510	

*Base case assumed to be the same as 18-49 years with a wider range for sensitivity analysis

Weekly rates of COVID-19 associated hospitalizations by season, all ages



Probability of hospitalization, annualized



Age	Base case	Range for sensitivity analysis	
		Low	High
5-11 years	0.000133	0.000034	0.000336
12-17 years	0.000181	0.000039	0.000456
18-49 years	0.000443	0.000101	0.002040
50-64 years	0.001550	0.000413	0.004790
65+ years	0.007900	0.002450	0.020900

Source: Derived using COVID-NET data (October 2022-September 2023) adjusted by the probability of hospitalization attributable to COVID-19 by quarter. The upper limit is from COVID-NET data (October 2022-March 2023), unadjusted by the probability of hospitalization attributable to COVID-19.

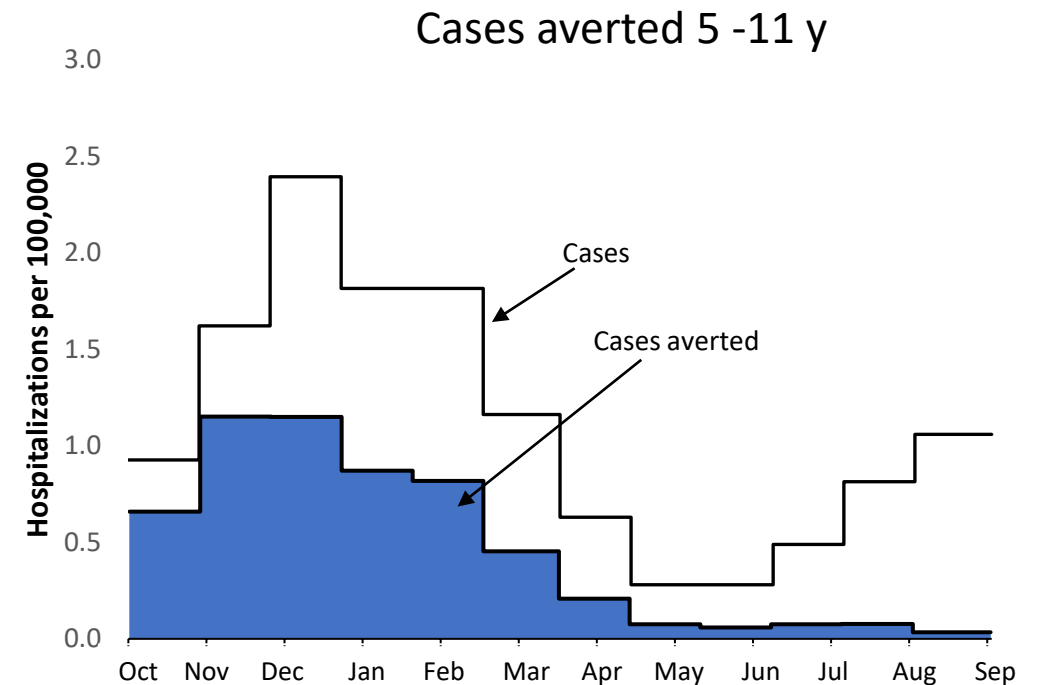
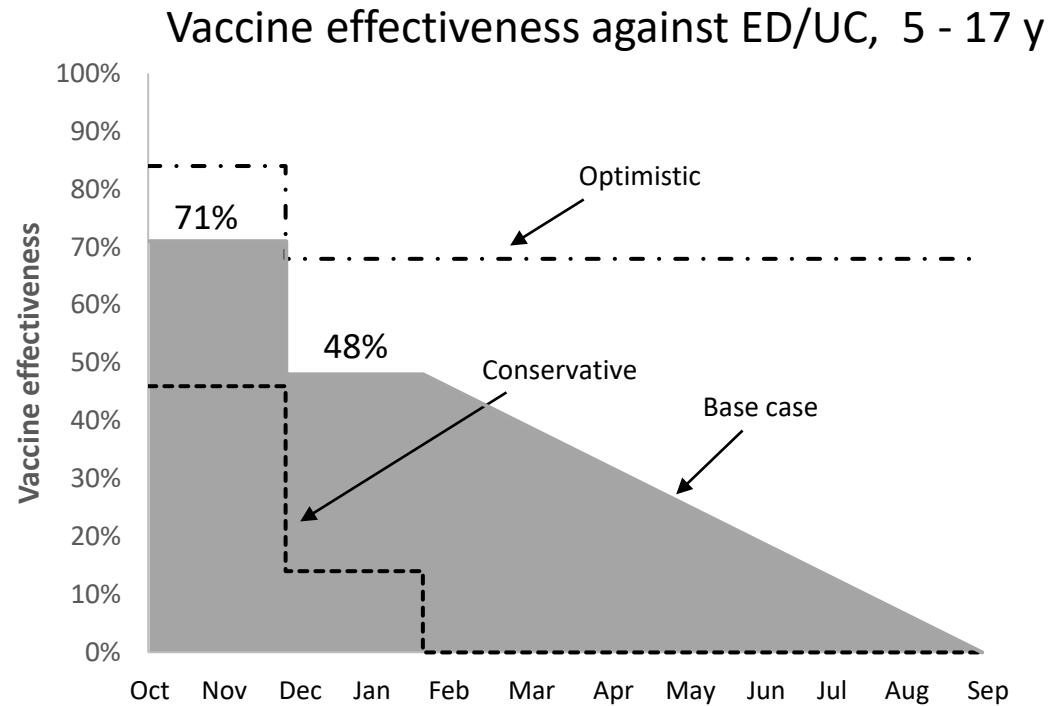
Probability and duration of Long COVID, by age

Age group	Initial illness severity	Probability of Long COVID	Range for sensitivity analysis		Median duration (months)	Source
			Low	High		
5-17 y	Symptomatic	0.002	0.002	0.003	5.8	Assumption based on adult data*
	Outpatient	0.005	0.003	0.006	7.6	
	Hospitalized	0.008	0.003	0.013	8.9	
18+ y	Symptomatic	0.011	0.009	0.013	5.8	INSPIRE, unpublished data Dec 2020 - Mar 2023. Montoy and Ford, 2023**
	Outpatient	0.023	0.017	0.029	7.6	
	Hospitalized	0.040	0.017	0.064	8.9	

* Duration assumed to be the same as 18+ y. Probabilities calibrated to national data from the National Center for Health Statistics (Vahratian 2023)

** Derived using data on extreme fatigue and cognitive difficulties from INSPIRE (Montoy and Ford 2023, INSPIRE unpublished data) calibrated to national data from the National Center for Health Statistics (Adjaye-Gbewonyo 2023)

Seasonality-adjusted vaccine impact



Age	Base case	Range for sensitivity analysis		Source
		Low	High	
5-11 years	0.423	0.133	0.711	VISION unpublished data*

*Sept 2023-May 2024

ED = emergency department; UC = urgent care

Seasonality-adjusted vaccine impact against symptomatic illness/hospitalization

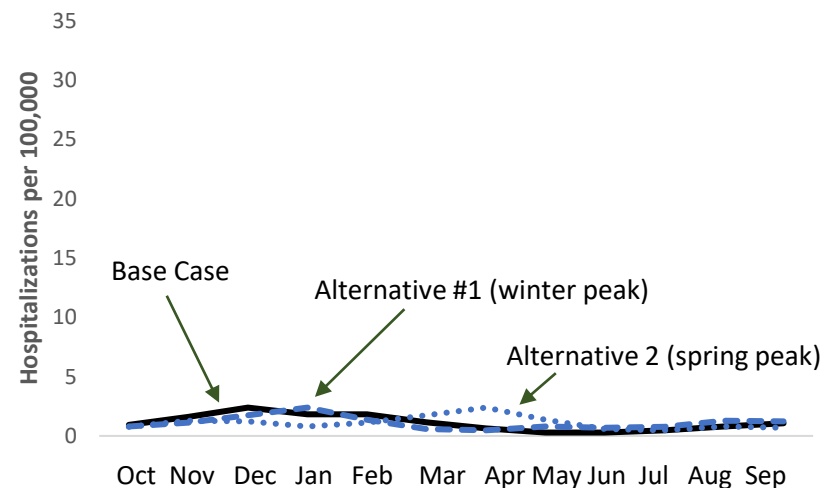
Age	Base case	Range for sensitivity analysis		Source
		Low	High	
5-11 years	0.423	0.133	0.711	VISION, Assumption*
12-17 years	0.422	0.136	0.713	
18-49 years	0.360	0.140	0.475	VISION, IVY, seasonality adjusted**
50-64 years	0.357	0.141	0.475	
65+ years	0.347	0.134	0.468	

* VISION data for Sept 2023-May 2024, adjusted VE against emergency department/urgent care visits was applied to pediatric age-group specific hospitalization rates from COVID-NET to derive seasonality-adjusted vaccine impact

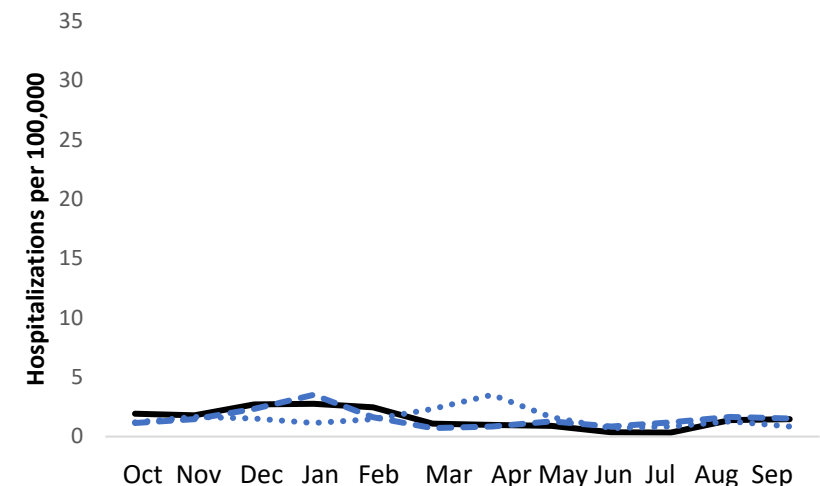
** Using data on bivalent booster data from Sep 2022-May 2023. Range includes minimum and maximum from both data sources, min: conservative approach (VE at 180 days=0) and max: optimistic approach (VE at 180 days=VE at 365 days); assumed same VE for symptomatic illness as hospitalization, seasonality adjusted

Alternative seasonality assumptions – winter, spring peaks

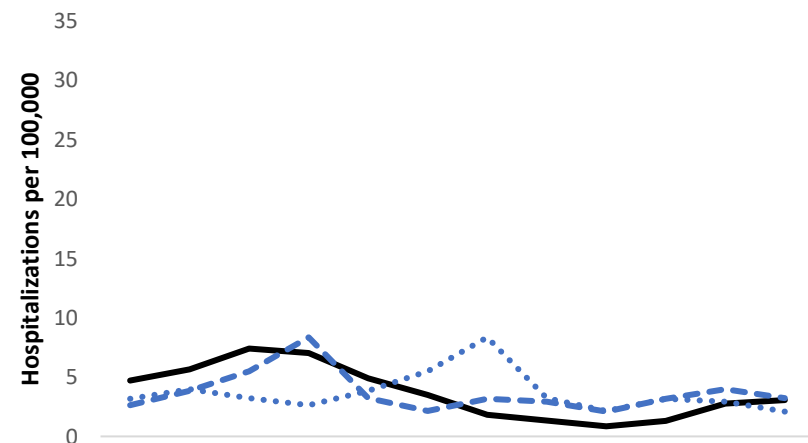
5-11 years



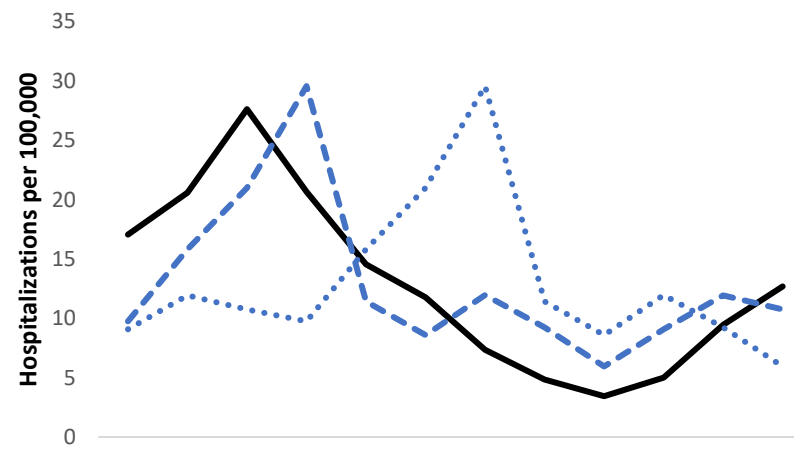
12-17 years



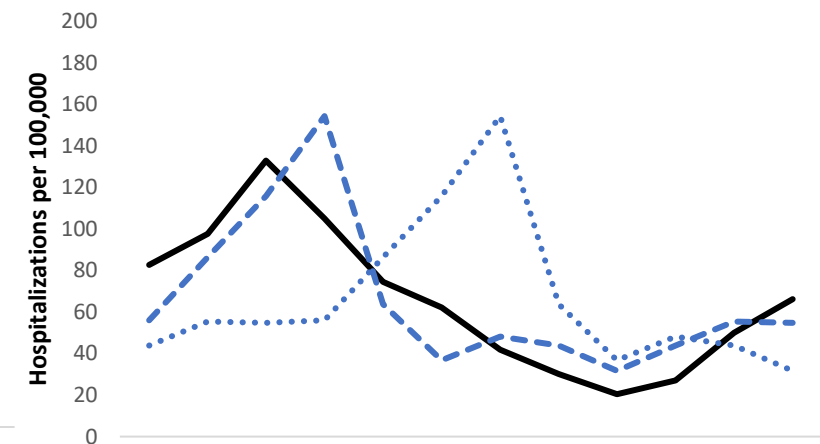
18-49 years



50-64 years



65+ years



— Base - - - Alternative seasonality scenario #1- winter peak Alternative seasonality scenario #2- spring peak

Vaccination-related costs

- Direct medical costs of vaccine dose, administration fee, and adverse events
- Time costs for recipients or caregivers; vary by setting; children ages 5-11 years most likely to be vaccinated in physician office setting

Table. Vaccine dose cost

Age	Base case	Range for sensitivity analysis		Source
		Low*	High	
5-11 years **	\$89	\$30	\$130	CDC Vaccine Price List
12-17 years**	\$102	\$30	\$130	
18+ years***	\$119	\$30	\$130	

* Lower bound reflects price of bivalent boosters as of March 2023.

** Assumes 50% CDC contract pricing and 50% private sector pricing

*** Assumes 12.8% receive vaccines through government programs (Source: CDC unpublished data)

Note: Age 12+ private sector/CDC contract prices: Moderna \$128/\$85.91; Novavax \$130/\$58; Pfizer \$115/\$97.75

Age 5-11 private sector/CDC contract prices: Moderna \$128/\$85.91; Pfizer \$77/\$65.45

Costing year: 2023

Direct medical costs (supplementary slides)

- Vaccination-related adverse events
- OTC & prescription medications for medically-attended non-hospitalized illness
- Outpatient visit (claims data)
- Emergency department visit
- Hospitalizations with and without complications (ventilator assistance, ICU stay)
- Long COVID – pediatric estimates based on adult data

OTC = over the counter medications; ICU = intensive care unit

Time costs/productivity losses* (supplementary slides)

- Vaccination receipt
- Vaccination-related adverse events
- Outpatient visit
- Emergency department visit
- Hospitalizations with and without complications (ventilator assistance, ICU stay)
- Long COVID
- Deaths

*Caregiver time costs or productivity losses for pediatric age groups

ICU = intensive care unit

QALYs lost, COVID-19 illness & hospitalization

Age	Base Case	Range for Sensitivity Analysis		QALD	Source
		Low	High		
Symptomatic illness					
5-17 years	0.0057	0.0030	0.0085	2.1 (1.1 – 3.1)	Soare 2023
18+ years	0.0046	0.0018	0.0074	1.7 (0.7 – 2.7)	
Hospitalization, no ICU stay					
5-17 years	0.0189	0.0054	0.0325	6.9 (2.0 – 11.9)	Soare 2023
18+ years	0.0174	0.0038	0.0310	6.4 (1.4 – 11.3)	
Hospitalization, with ICU stay, ventilator assistance					
5-17 years	0.0883	0.0632	0.1169	32.2 (23.1 – 42.7)	Mercon 2023
18+ years	0.0394	0.0231	0.0583	14.4 (8.5 – 21.3)	

ICU = intensive care unit; QALD = quality-adjusted life day; QALY = quality-adjusted life year

Results

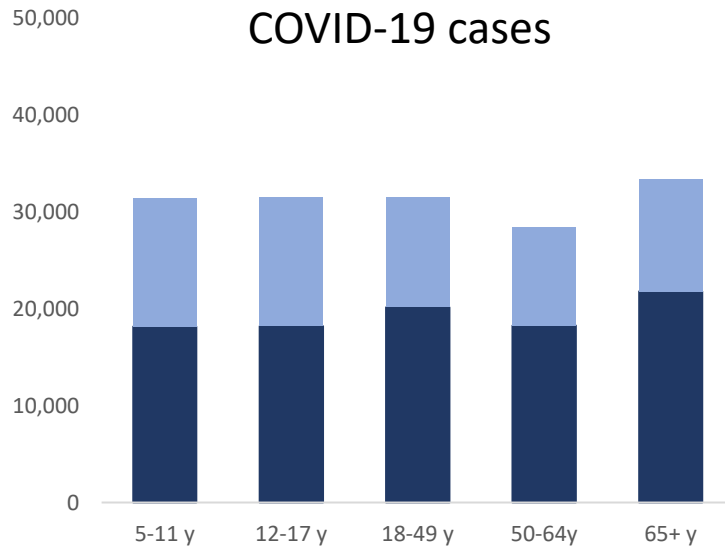
Disaggregated results, per 100,000 people, *preliminary estimates*

Age group	Strategy	Health outcomes					Health outcomes averted				
		Cases	Long COVID	Hosp	ICU	Deaths	Cases	Long COVID	Hosp	ICU	Deaths
5-11 y	No updated vax	31,450	71	13.3	2.7	0.12	-	-	-	-	-
	Updated Covid-19 vax, 1-dose	18,147	41	7.7	1.6	0.07	13,303	30	5.6	1.2	0.05
12-17 y	No updated vax	31,450	72	18.1	3.8	0.12	-	-	-	-	-
	Updated Covid-19 vax, 1-dose	18,178	41	10.5	2.2	0.07	13,272	30	7.6	1.6	0.05
18-49 y	No updated vax	31,450	413	44.3	5.8	0.59	-	-	-	-	-
	Updated Covid-19 vax, 1-dose	20,128	265	28.4	3.1	0.32	11,322	149	15.9	2.7	0.26
50-64y	No updated vax	28,410	396	155.0	29.9	4.99	-	-	-	-	-
	Updated Covid-19 vax, 1-dose	18,268	255	99.7	16.2	2.80	10,142	142	55.3	13.7	2.19
65+ y	No updated vax	33,390	501	790.0	105.9	40.06	-	-	-	-	-
	Updated Covid-19 vax, 1-dose	21,804	327	515.9	58.1	23.47	11,586	174	274.1	47.7	16.59

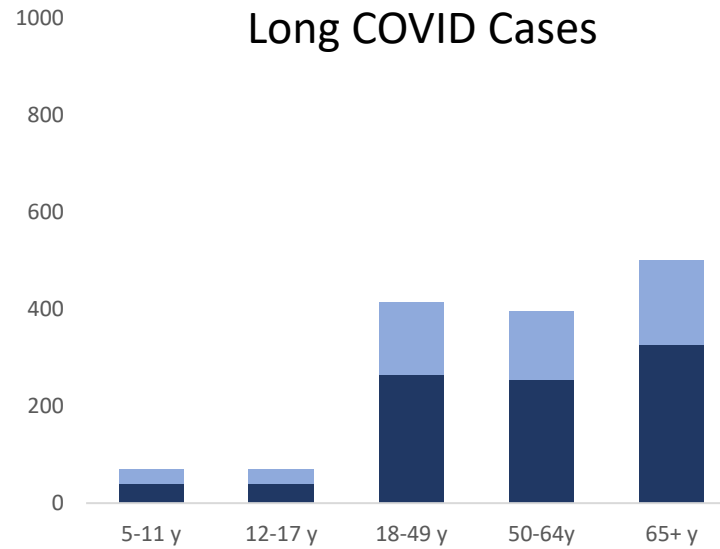
Hosp = hospitalizations; ICU = intensive care unit stays

Disaggregated results, per 100,000 people, *preliminary estimates*

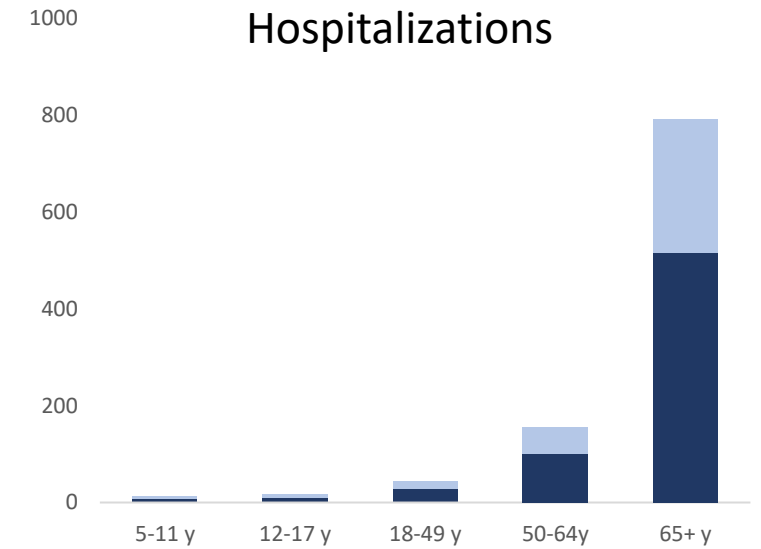
COVID-19 cases



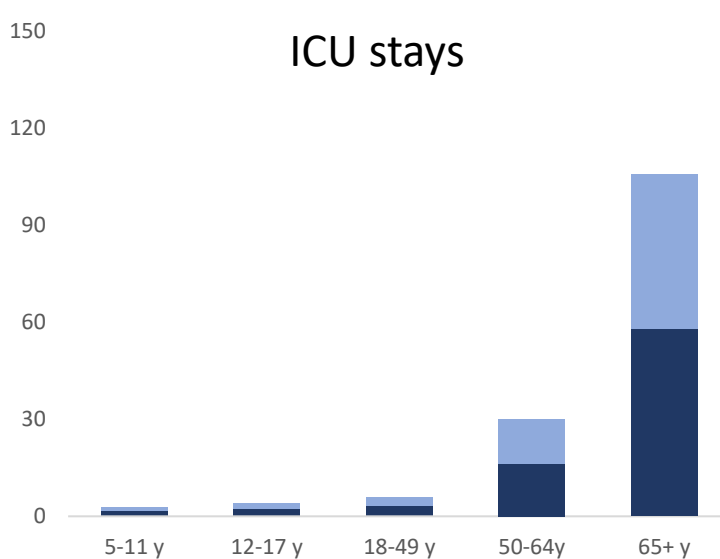
Long COVID Cases



Hospitalizations



ICU stays



Deaths



■ Health outcome when vaccinated
■ Health outcome averted

ICU = intensive care unit

Incremental cost-effectiveness ratios, societal perspective, per 1000 people, *preliminary estimates*

Age group	Strategy	Projected Costs	Incremental Costs	Projected QALYs	Incremental QALYs	\$/QALY
5-11 y	No updated vax	\$38,124	-	26,788	-	-
	Updated Covid-19 vax, 1-dose	\$188,339	\$150,215	26,789	0.7494	\$200,445
12-17 y	No updated vax	\$45,219	-	24,638	-	-
	Updated Covid-19 vax, 1-dose	\$198,613	\$153,394	24,639	0.7570	\$202,621
18-49 y	No updated vax	\$131,991	-	20,208	-	-
	Updated Covid-19 vax, 1-dose	\$261,080	\$129,089	20,209	0.6083	\$212,225
50-64y	No updated vax	\$237,902	-	12,278	-	-
	Updated Covid-19 vax, 1-dose	\$326,508	\$88,606	12,279	0.7824	\$113,248
65+ y	No updated vax	\$363,304	-	6,525	-	-
	Updated Covid-19 vax, 1-dose	\$403,428	\$40,124	6,527	1.7215	\$23,308

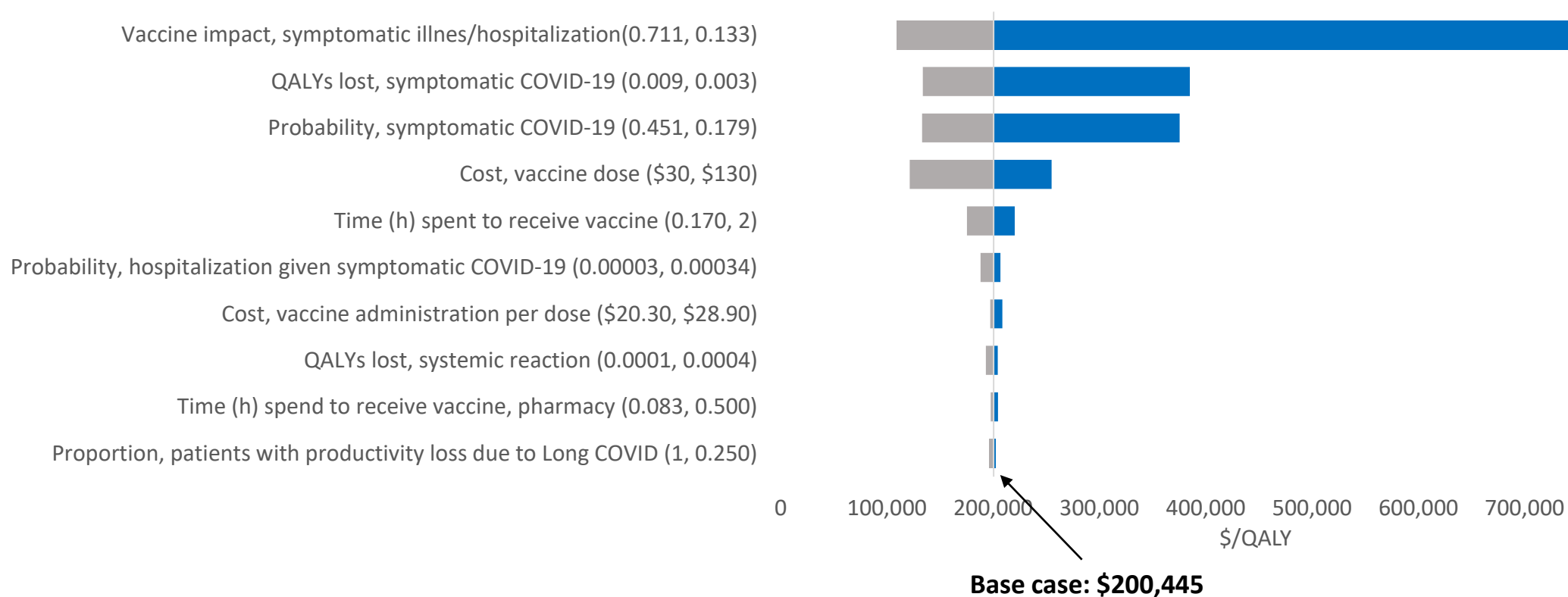
QALY = quality-adjusted life year

Incremental cost-effectiveness ratios, *preliminary estimates*

Age group	Societal perspective \$/QALY
5-11 y	\$200,445
12-17 y	\$202,621
18-49 y	\$212,225
50-64y	\$113,248
65+ y	\$23,308

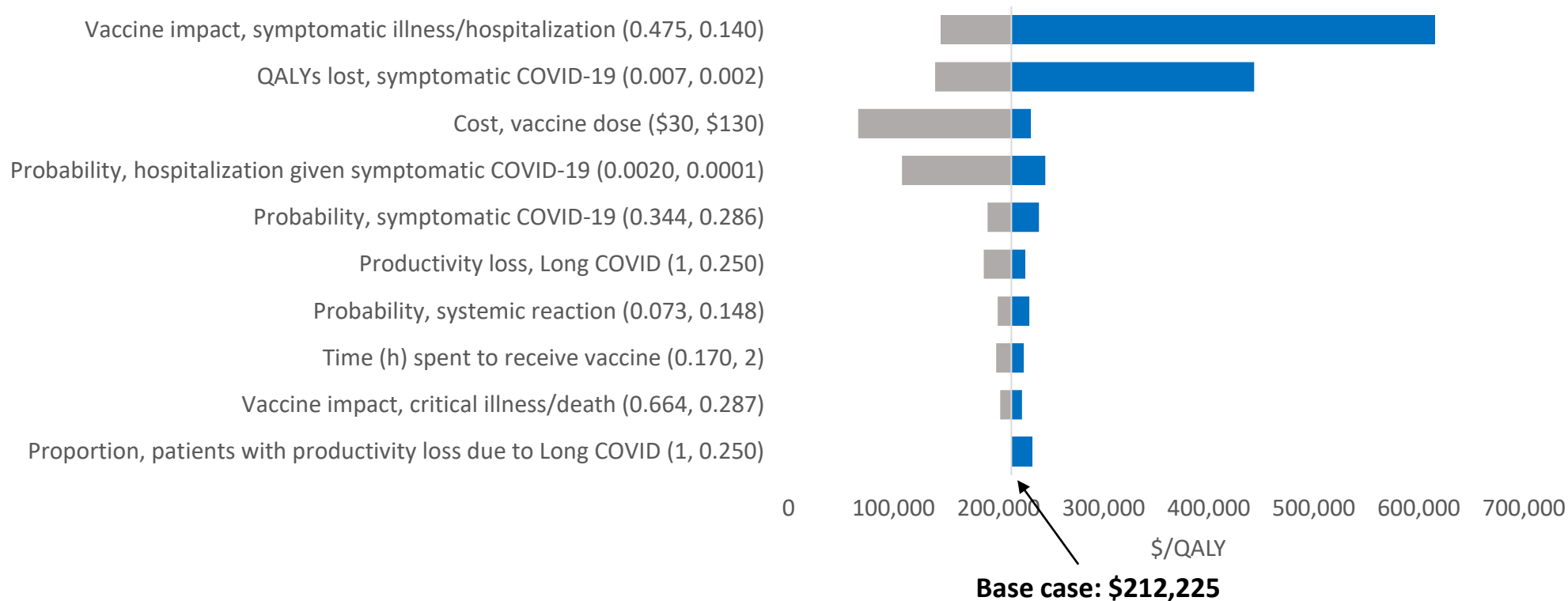
QALY = quality-adjusted life year

One way sensitivity analyses, 5-11 y *preliminary estimates*



Note: Numbers in parentheses indicate input values for sensitivity analysis
QALY = quality-adjusted life year

One way sensitivity analyses, 18-49 y *preliminary estimates*



Note: Numbers in parentheses indicate input values for sensitivity analysis
QALY = quality-adjusted life year

Scenario analysis: probability of symptomatic illness*, ICER (\$/QALY) *preliminary estimates*

Age group	Base case**	Probability of symptomatic illness				
		0.1	0.2	0.3	0.4	0.5
5-11 y	\$200,445	\$722,624	\$331,876	\$211,334	\$152,732	\$118,088
12-17 y	\$202,621	\$714,398	\$334,103	\$213,584	\$154,431	\$119,286
18-49 y	\$212,225	\$709,386	\$356,815	\$224,808	\$155,707	\$113,199
50-64 y	\$113,248	\$264,675	\$162,297	\$106,065	\$70,517	\$46,014
65+ y	\$23,308	\$48,896	\$36,178	\$26,213	\$18,195	\$11,603

*One-way sensitivity analysis of non-hospitalized symptomatic illness varied separately from hospitalization and critical illness

**Base case probability of symptomatic illness: 5-49 y: 0.3145; 50-64 y: 0.2841; 65+ y: 0.3339

ICER = incremental cost-effectiveness ratio; QALY=Quality-adjusted life year

Scenario analysis: probability of hospitalization, ICER (\$/QALY) *preliminary estimates*

Age group	Base case*	Probability of hospitalization**				
		¼ base case	½ base case	2x base case	3x base case	4x base case
5-11 y	\$200,445	\$206,836	\$204,683	\$192,231	\$184,349	\$176,779
12-17 y	\$202,621	\$210,339	\$207,740	\$192,689	\$183,146	\$173,970
18-49 y	\$212,225	\$243,483	\$232,548	\$176,831	\$147,052	\$121,649
50-64 y	\$113,248	\$214,304	\$173,146	\$41,319	Cost saving	Cost saving
65+ y	\$23,308	\$133,631	\$78,440	Cost saving	Cost saving	Cost saving

*Base case probability of hospitalization: 5-11 years: 0.000133; 12-17 years: 0.000181; 18-49 years: 0.000443; 50-64 years: 0.001550; 65+ years 0.007900

**Adjusted risk of hospitalization by underlying condition: chronic obstructive pulmonary disease: 0.9, history of stroke: 0.9, coronary artery disease: 1.3, asthma: 1.4, hypertension: 2.8, obesity: 2.9, diabetes: 3.2, chronic kidney disease: 4.0, severe obesity: 4.4. Ko et al 2021.

ICER = incremental cost-effectiveness ratio; QALY = Quality-adjusted life year

Scenario analysis: All Long COVID submodel parameters*, ICER (\$/QALY) *preliminary estimates*

Age group	Base case	Long COVID submodel parameters	
		All low	All high
5-11 y	\$200,445	\$206,021	\$188,365
12- 17 y	\$202,621	\$208,341	\$190,416
18-49 y	\$212,225	\$247,483	\$160,934
50-64 y	\$113,248	\$139,203	\$74,095
65+ y	\$23,308	\$28,118	\$15,148

*Long COVID probabilities, costs, productivity losses and quality adjustments varied simultaneously
ICER = incremental cost-effectiveness ratio; QALY = Quality-adjusted life year

Vaccine impact scenario analysis, ICER (\$/QALY), *preliminary estimates*

	Base case	Scenario 1 All lower bounds	Scenario 2 All upper bounds
5-11 y	\$200,445	\$780,660	\$108,061
12- 17 y	\$202,621	\$750,981	\$107,709
18-49 y	\$212,225	\$672,057	\$138,503
50-64 y	\$113,248	\$396,767	\$52,024
65+ y	\$23,308	\$141,215	Cost saving

QALY = quality-adjusted life year

Scenario analysis: alternative seasonality scenarios, ICER (\$/QALY), *preliminary estimates*

	Base case	Alternative seasonality scenario #1 winter peak	Alternative seasonality scenario #2 spring peak
5-11 y	\$200,445	\$229,108	\$226,324
12- 17 y	\$202,621	\$230,316	\$228,911
18-49 y	\$212,225	\$264,075	\$296,491
50-64 y	\$113,248	\$135,556	\$168,275
65+ y	\$23,308	\$27,392	\$42,660

ICER = incremental cost-effectiveness ratio; QALY = quality-adjusted life year

Scenario analysis: vaccine dose cost, ICER (\$/QALY), *preliminary estimates*

Age group	Base case*	Vaccine dose cost					
		\$30	\$50	\$70	\$90	\$110	\$130
5- 11 y	\$200,445	\$121,596	\$148,284	\$174,971	\$201,659	\$228,347	\$255,035
12- 17 y	\$202,621	\$106,933	\$133,352	\$159,770	\$186,188	\$212,607	\$239,025
18-49 y	\$212,225	\$66,351	\$99,231	\$132,112	\$164,992	\$197,873	\$230,753
50-64 y	\$113,248	Cost saving	\$25,403	\$50,965	\$76,528	\$102,090	\$127,652
65+ y	\$23,308	Cost saving	Cost saving	Cost saving	\$6,618	\$18,236	\$29,854

*Base case vaccine cost: 5-11 y: \$89.09; 12-17 y: \$102.44; 18+ y: \$118.73

ICER = incremental cost-effectiveness ratio; QALY = quality-adjusted life year

Multi-way sensitivity analysis: vaccination-related costs, ICER (\$/QALY)

preliminary estimates

Age group	Base case	Vaccination-related costs*	
		All low	All high
5-11 y	\$200,445	\$88,225	\$292,895
12- 17 y	\$202,621	\$79,777	\$271,786
18-49 y	\$212,225	\$39,518	\$267,101
50-64 y	\$113,248	Cost saving	\$155,887
65+ y	\$23,308	Cost saving	\$43,137

*Vaccination related and adverse event related costs and productivity losses varied simultaneously

ICER = incremental cost-effectiveness ratio; QALY = Quality-adjusted life year

Limitations

- Data sources vary in representativeness, generalizability
- Unpublished data used to derive key parameters in the model: vaccine impact, symptomatic illness, probabilities of hospitalization and critical illness
- VE estimates derived from a single season
- Few seasons to date to estimate seasonality
- Model does not include reduced transmission (conservative approach)
- Claims data used to estimate costs includes only supplemental insurance for 65+
- Evidence base for Long COVID is especially scarce, even more so for pediatric age groups
- Rapidly evolving evidence base; as critical illness attributable to COVID-19 illness declines, mild/moderate illness and Long COVID could become primary drivers of cost-effectiveness

Summary - *preliminary estimates*

- Vaccination averts morbidity and mortality for all age groups, but with substantial variation in impact by age
- Adult age groups
 - Phase 3 model projects somewhat less favorable results overall due to declining burden of illness
 - ICERs for 65+ age group [\$23,000/QALY] are robust to changes in parameter inputs across plausible ranges [cost saving - \$117,000/QALY]
 - ICERs for 18-49y [\$212,000/QALY] and 50-64y [\$113,000/QALY] age groups are sensitive to changes in parameter inputs

Parameter	Age	ICER range (\$/QALY)
Vaccine impact	18-49 y	\$145,000 – \$616,000
	50-64 y	\$68,000 – \$296,000
QOL impact, symptomatic illness	18-49 y	\$140,000 – \$443,000
	50-64 y	\$83,000 – \$178,000
Vaccine dose cost	18-49 y	\$66,000 – \$231,000
	50-64 y	cost saving – \$128,000
Risk of hospitalization	18-49 y	\$108,000 – \$244,000
	50-64 y	cost saving – \$211,000

Summary - *preliminary estimates (2)*

➤ Pediatric age groups

- ICERs for 5-11y [\$200,000/QALY] and 12-17y [\$203,000/QALY] age groups are very sensitive to changes in parameter inputs

Parameter	Age	ICER range (\$/QALY)
Vaccine impact	5 - 11 y	\$110,000 - \$743,000
	12 - 17 y	\$109,000 - \$720,000
QOL impact, symptomatic illness	5 - 11 y	\$134,000 - \$385,000
	12 - 17 y	\$136,000 - \$385,000
Probability, symptomatic illness	5 - 11 y	\$133,000 - \$375,000
	12 - 17 y	\$135,000 - \$377,000
Vaccine dose cost	5 - 11 y	\$107,000 - \$239,000
	12 - 17 y	\$107,000 - \$239,000

- Evidence base for pediatric age groups overall less robust
- Estimated results reflect higher degree of uncertainty compared with adult age groups