Economic analysis of COVID-19 vaccination

University of Michigan

COVID-19 Vaccination Modeling Team

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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

ED = emergency department; ICU = intensive care unit

8
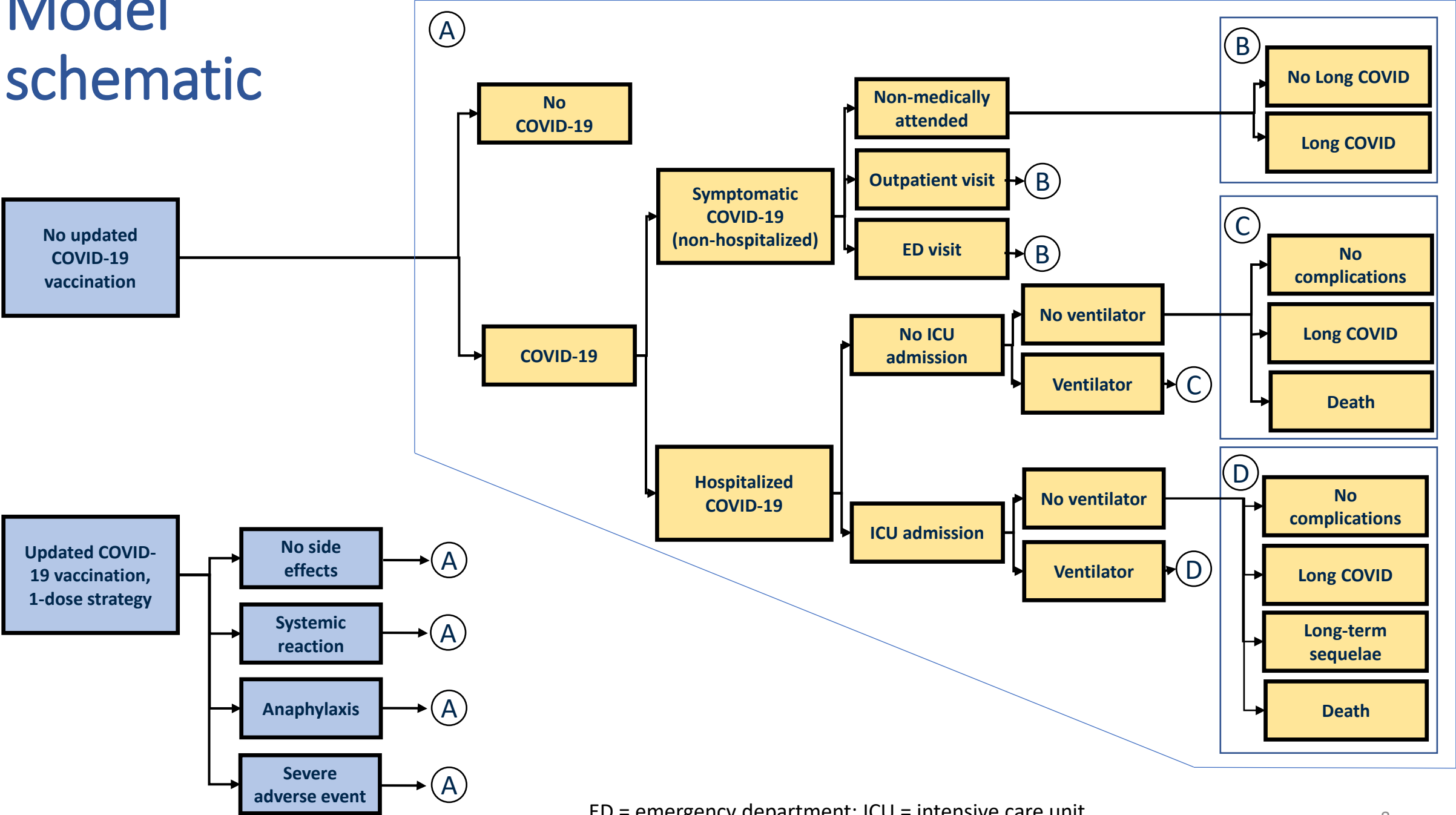
Analysis Plan

- 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

Unchanged from Phase 2

Weekly rates of COVID-19 associated hospitalizations by season, all ages
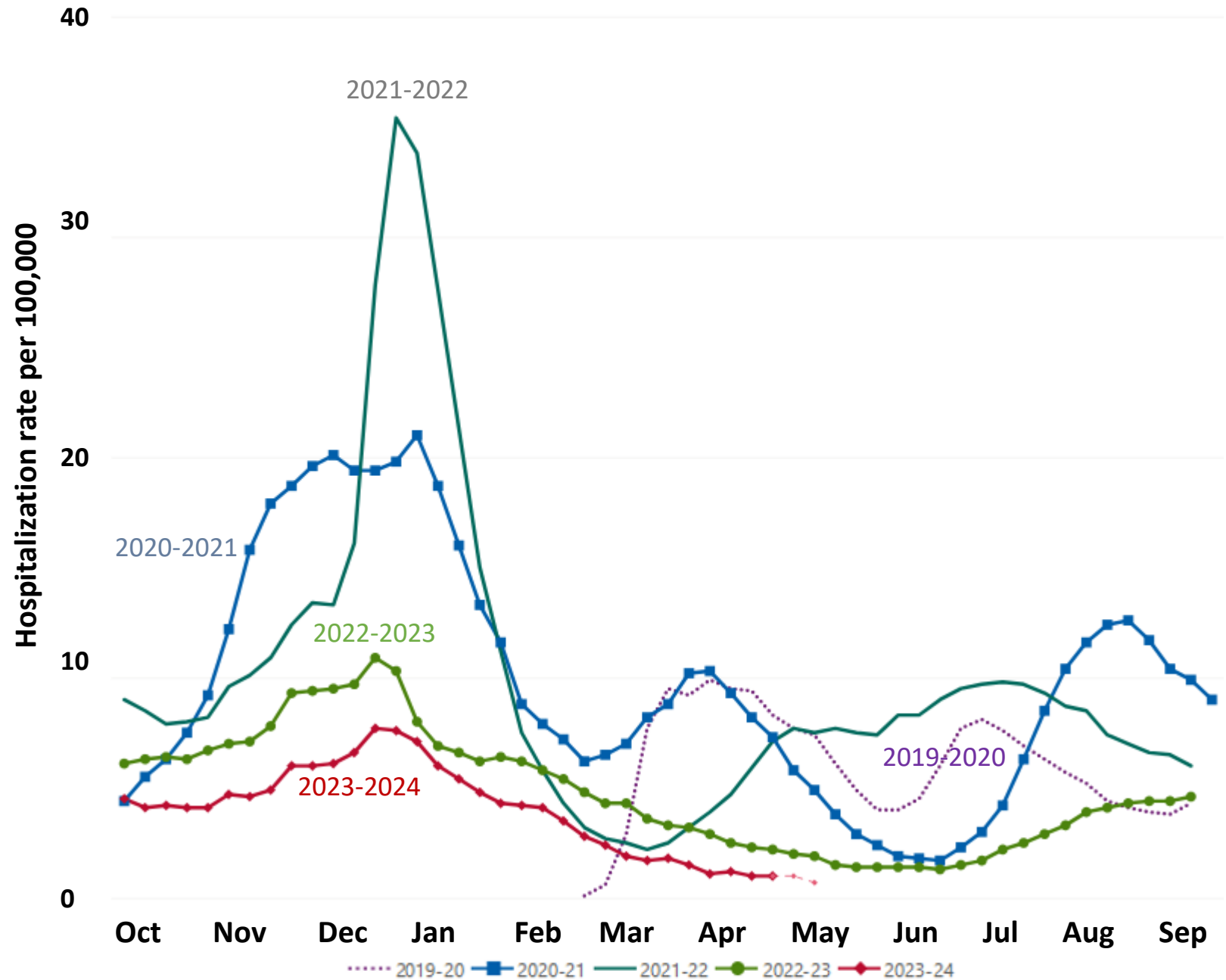
Probability of hospitalization, annualized
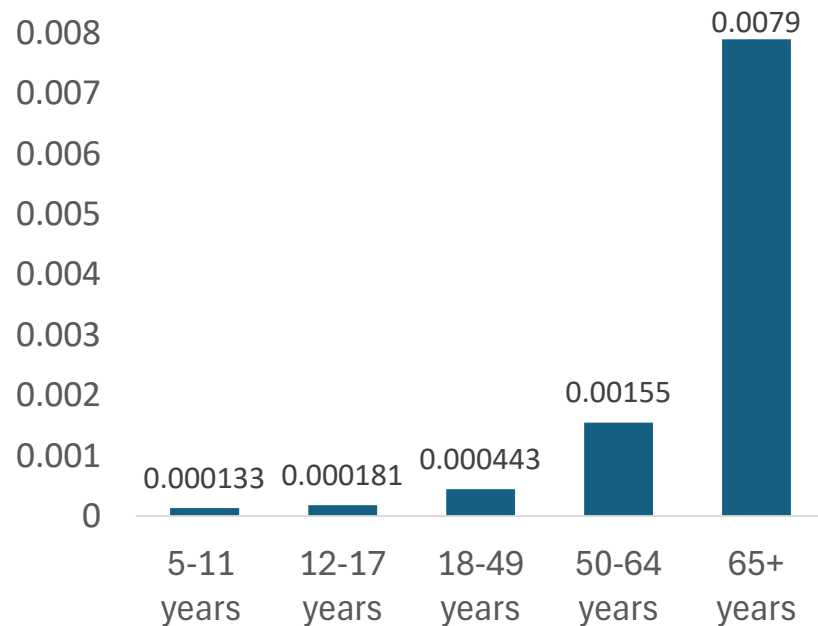
Age	Base case	Range for sensitivity analysis	
		Low	High
5-11 years	0.000133	0.000034	0.000336
12-17 years	0.000181	0.000039	0.000456
18-49 years	0.000443	0.000101	0.002040
50-64 years	0.001550	0.000413	0.004790
65+ years	0.007900	0.002450	0.020900

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
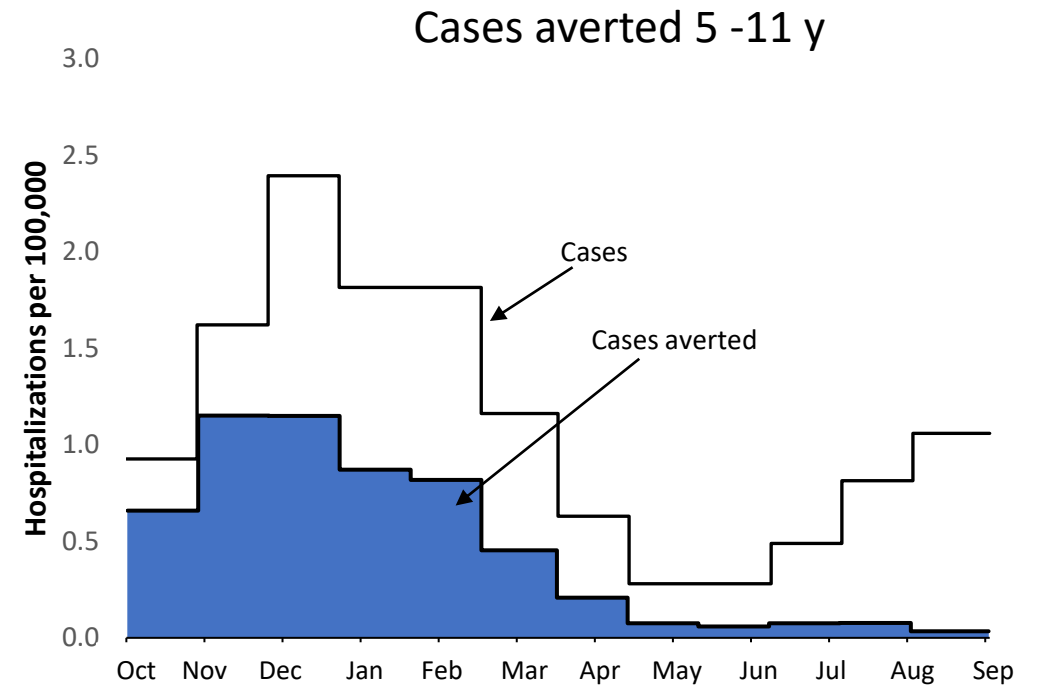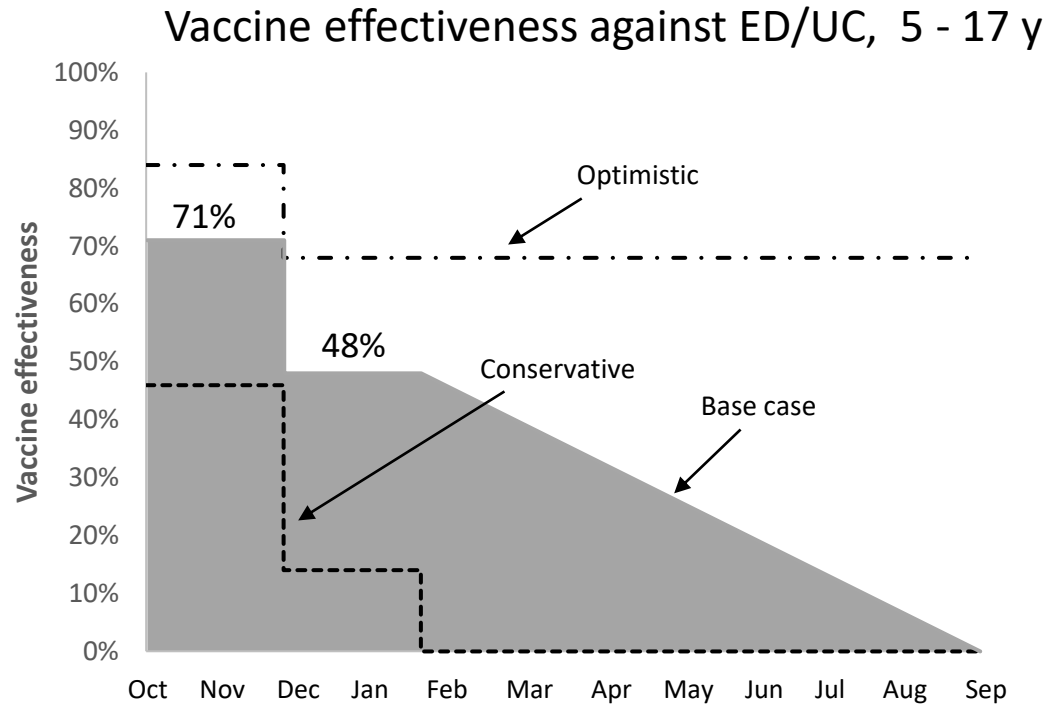
Vaccine effectiveness against ED/UC, 5 - 17 y

Cases averted 5 -11 y

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
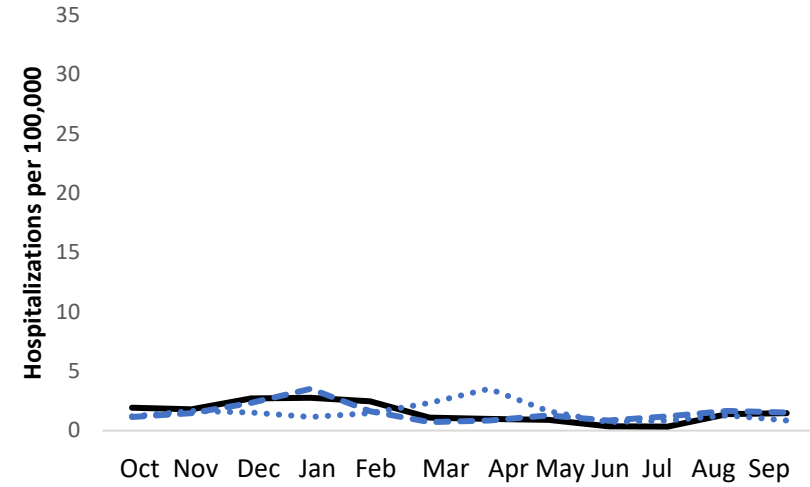
** Using data on bivalent booster data from Sep 2022-May 2023. Range includes minimum and maximum from both data sources, min: conservative approach (VE at 180 days=0) and max: optimistic approach (VE at 180 days=VE at 365 days); assumed same VE for symptomatic illness as hospitalization, seasonality adjusted
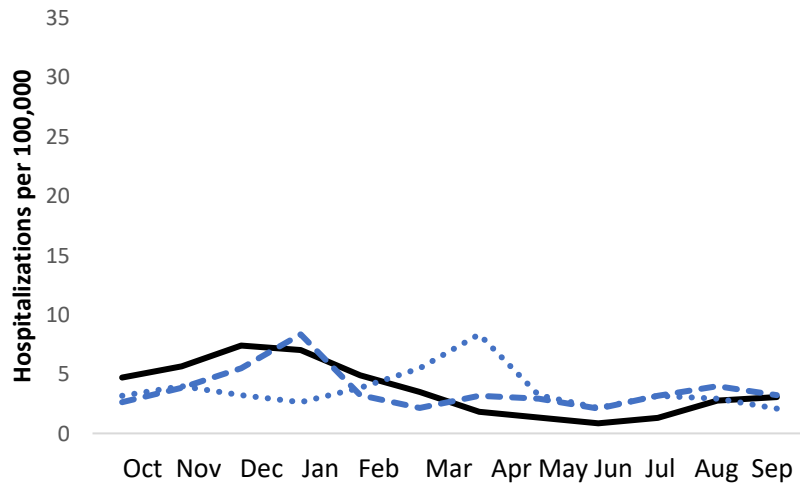
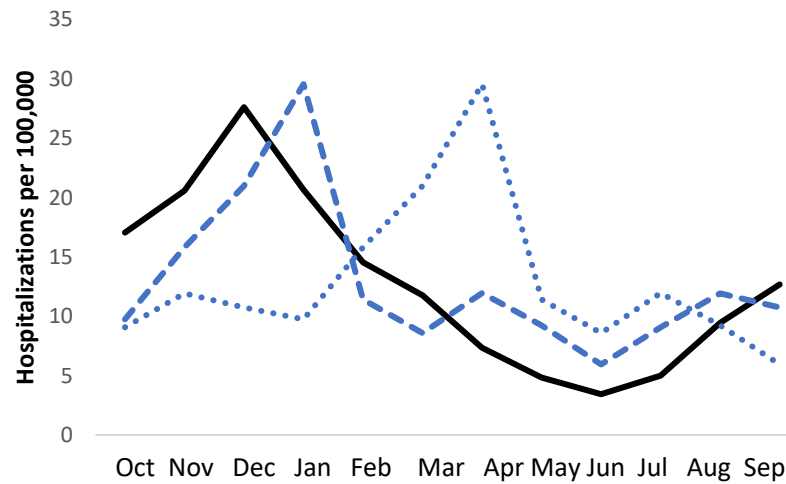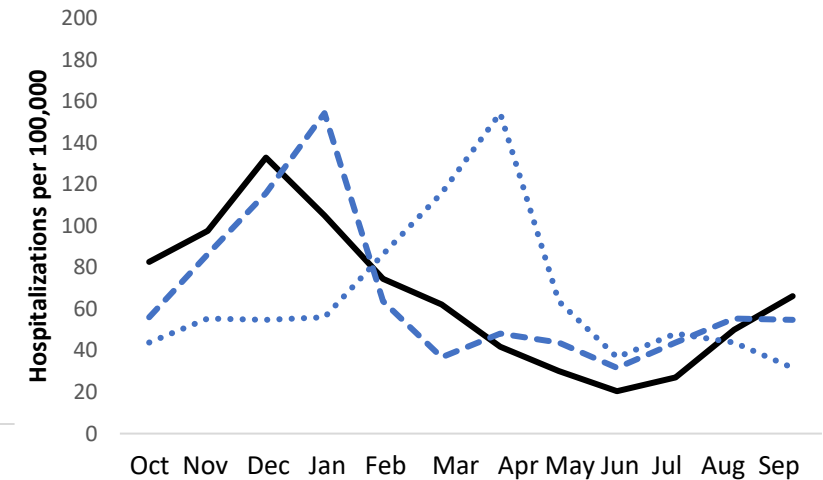# Alternative seasonality assumptions – winter, spring peaks
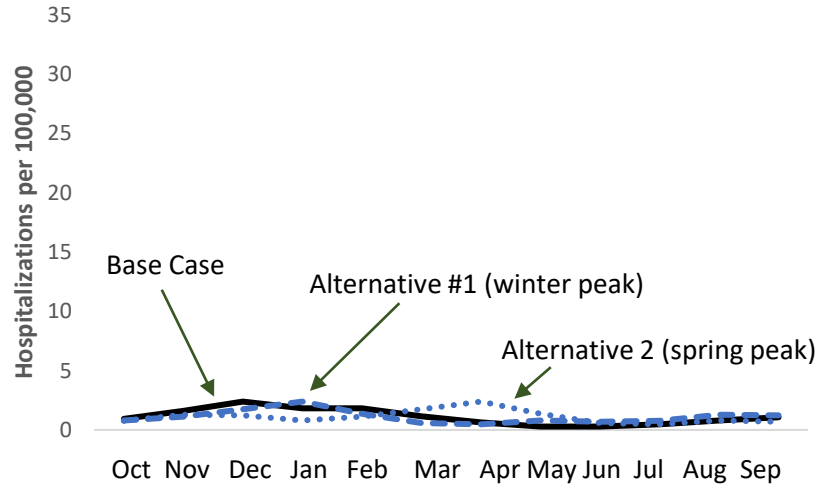
17

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*
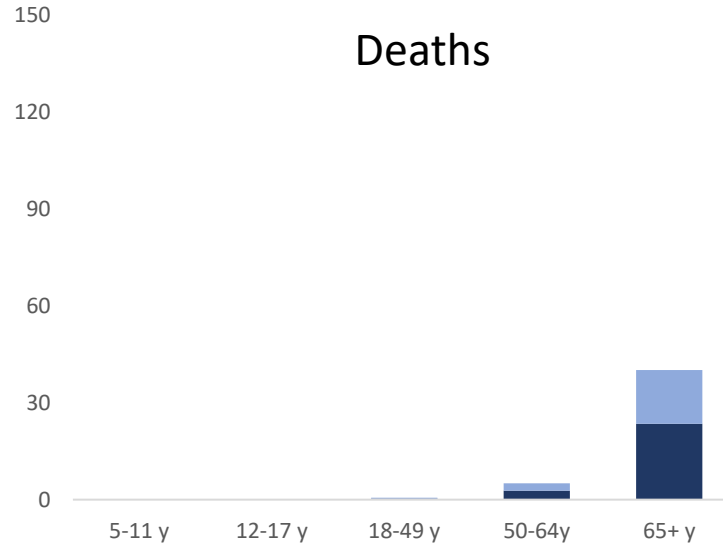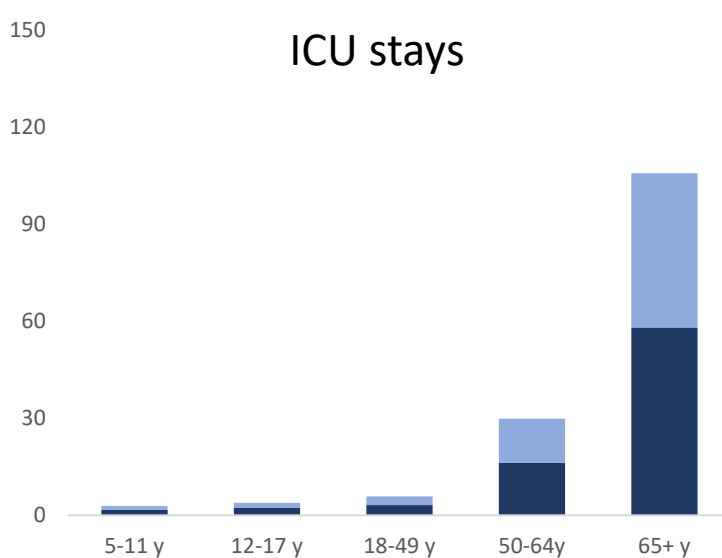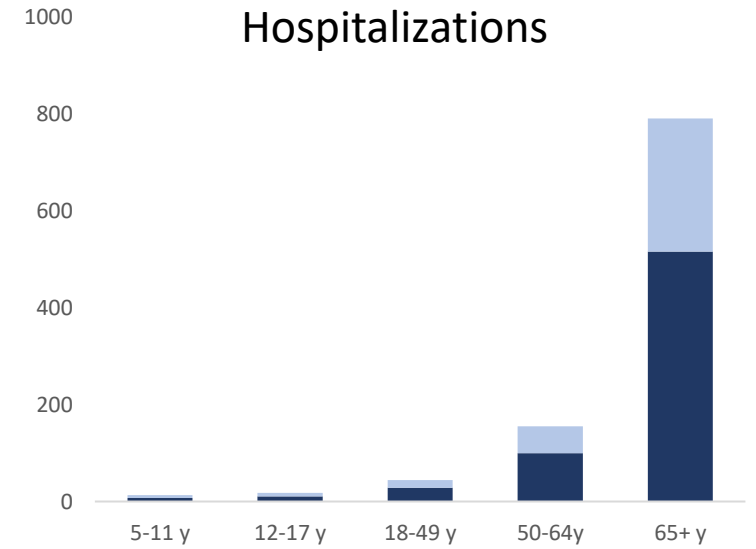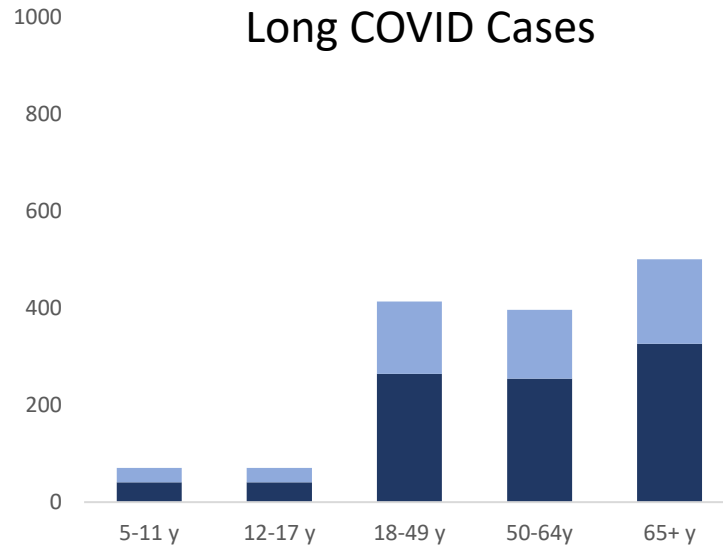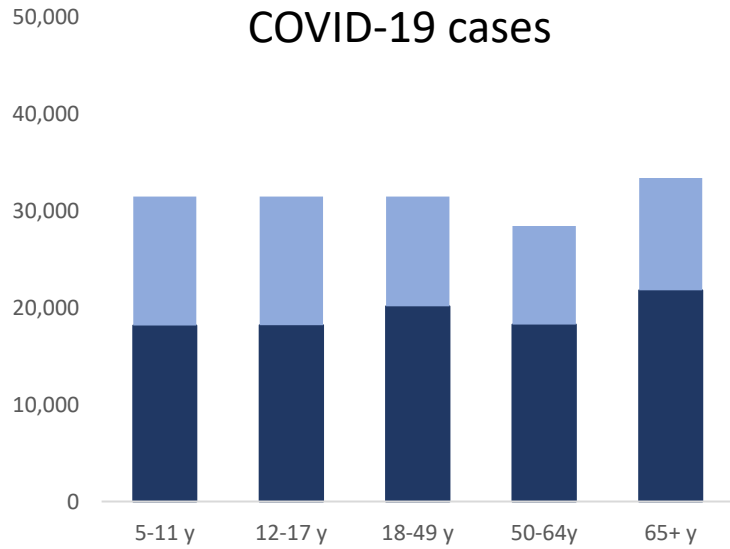
ICU = intensive care unit

24

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

Vaccine impact, symptomatic illnes/hospitalization(0.711, 0.133)

QALYs lost, symptomatic COVID-19 (0.009, 0.003)

Probability, symptomatic COVID-19 (0.451, 0.179)

Cost, vaccine dose ($30, $130)

Time (h) spent to receive vaccine (0.170, 2)

Probability, hospitalization given symptomatic COVID-19 (0.00003, 0.00034)

Cost, vaccine administration per dose ($20.30, $28.90)

QALYs lost, systemic reaction (0.0001, 0.0004)

Time (h) spend to receive vaccine, pharmacy (0.083, 0.500)

Proportion, patients with productivity loss due to Long COVID (1, 0.250)

0   100,000   200,000   300,000   400,000   500,000   600,000   700,000

$/QALY

Base case: $200,445

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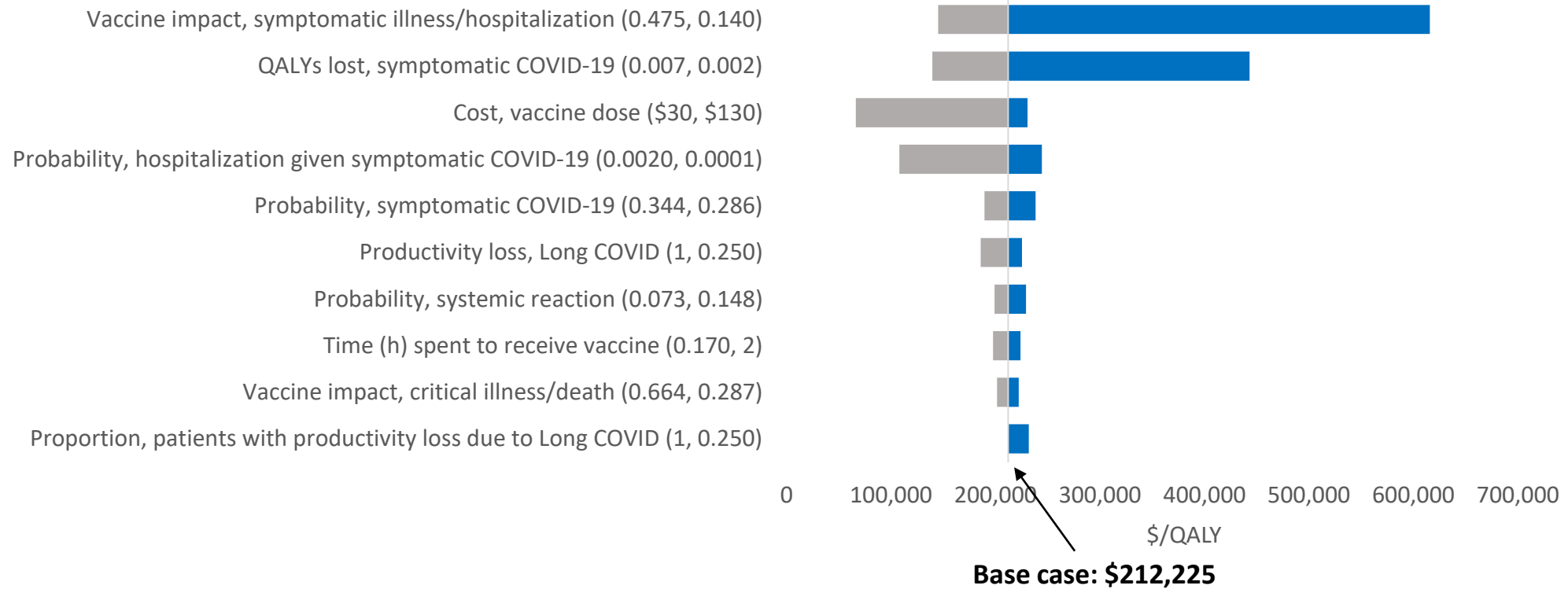QALY = quality-adjusted life year

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