The Costing Model

1 Questions and suggestions

Edit suggestions

1. On sheet “6. SARS-X R&D” there are two “SARS-X Preclin PoS”, and no “Preclin Duration”. The “Preclinical / Trad Weeks” comes from Phase 1.

2. Cell C18 on sheet “11. Delivery” -> 10%
3. Stop first SSV doses at half the number of allocated doses. This changes delivery costs slightly when deliveries stop just after a change of year, due to discounting. It should not affect delivery in the impact model.
4. In “12. Cashflow & PV”, it looks like Advance Cashflows discount to 2025, and Response Cashflows to 2024. We could correct the latter to 2025, or, better still, change both to 2026.
5. Why do booster doses start again in terms of cost per dose by phase for delivery? Can I suggest the cost for delivering these doses should be the third phase cost?

Clarifications

1. 14 BPSV candidates or 8?
2. Do all BPSV start at Phase 0, or do some start at Phase 1?
3. BPSV R&D costs appear to be inflated for inflation (28%) for BPSV prep R&D but not licensure and not BPSV Phase 3. For SSV, phase costs are inflated but licensure isn’t.
4. What is the stockpile upfront cost?
5. BPSV response R&D does not appear to depend on number of candidates, probability of success, probability to occur, or inflation. Should it?
6. SSV PoS uses a beta distribution and refers to COVID data (sheet “PoS by Phase”). The formula to describe a beta distribution for probability p using data is p~Beta(a, b), where a=successes+1 and b=failures+1. So for preclinical we have p~Beta(97, 34). And in the final phase, p~Beta(28, 9), because there were 35 remaining candidates, of which 27 passed and 8 failed. Did I understand this table correctly? And is there a source for these data?

Nice to have?

1. Why was 1000000000 (1 billion) chosen as the target amount for BPSV production? This can be rationalised by setting vaccine wastage to 0.3142532. (NB: no vaccine wastage is assumed for SSV.)
2. Some values in “1. Input Dashboard” are calculated rather than given (e.g. cost for the capacity reservation, 160000000*1.08/325000000; BSPV investigational cost per dose, 12145636/1200000000; the stockpile upfront cost, 138000000/1200000000 per dose). Can we include the sources & rationale for these values?

This document describes the costing model that is used in the CEPI application.

2 Parameters

Table 1: Notation and parametric assumptions for inputs to the costing model. Parameters are used as follows: uniform distributions go from Parameter 1 to Parameter 2. Triangular distributions go from Parameter 1 to Parameter 3 with a peak at Parameter 2. Multinomial distributions have equally probable values listed individually. Exponential distributions have as a mean Parameter 1. Inverse Gaussian distributions have as a mean Parameter 1, and as a shape Parameter 2. Log normal distributions have as a mean Parameter 1, and as a standard deviation Parameter 2. PearsonV distributions have shape Parameter 1, scale Parameter 2, and location 0. PearsonVI distributions have shape Parameters 1 and 2, scale Parameter 3, and location 0. Where given, distributions are truncated at bounds.

Math notation	Description	Distribution	Parameters	Bounds	Source
$W_{0;365}^{(S)}$	SSV preclinical duration (365); weeks	Constant	14		
$W_{0;200}^{(S)}$	SSV preclinical duration (200DM); weeks	Constant	5		
$W_{0;100}^{(S)}$	SSV preclinical duration (100DM); weeks	Constant	5		
$W_{1;365}^{(S)}$	SSV phase I duration (365); weeks	Constant	0		
$W_{1;200}^{(S)}$	SSV phase I duration (200DM); weeks	Constant	0		
$W_{1;100}^{(S)}$	SSV phase I duration (100DM); weeks	Constant	0		
$W_{2;365}^{(S)}$	SSV phase II duration (365); weeks	Constant	19		
$W_{2;200}^{(S)}$	SSV phase II duration (200DM); weeks	Constant	7		
$W_{2;100}^{(S)}$	SSV phase II duration (100DM); weeks	Constant	0		
$W_{3;365}^{(S)}$	SSV phase III duration (365); weeks	Constant	16		
$W_{3;200}^{(S)}$	SSV phase III duration (200DM); weeks	Constant	15		

Math notation	Description	Distribution	Parameters	Bounds	Source
$W_{3;100}^{(S)}$	SSV phase III duration (100DM); weeks	Constant	8		
$V_{L;0}$	Cost of vaccine delivery at start up (0–10%) in LIC; USD per dose	Triangular	1, 1.5, 2		See Table 5
$V_{L;11}$	Cost of vaccine delivery during ramp up (11–30%) in LIC; USD per dose	Triangular	0.75, 1, 1.5		See Table 5
$V_{L;31}$	Cost of vaccine delivery getting to scale (31–80%) in LIC; USD per dose	Triangular	1, 2, 4		See Table 5
$V_{LM;0}$	Cost of vaccine delivery at start up (0–10%) in LMIC; USD per dose	Triangular	3, 4.5, 6		See Table 5
$V_{LM;11}$	Cost of vaccine delivery during ramp up (11–30%) in LMIC; USD per dose	Triangular	2.25, 3, 4.5		See Table 5
$V_{LM;31}$	Cost of vaccine delivery getting to scale (31–80%) in LMIC; USD per dose	Triangular	1.5, 2, 2.5		See Table 5
$V_{UM;0}$	Cost of vaccine delivery at start up (0–10%) in UMIC; USD per dose	Triangular	6, 9, 12		See Table 5
$V_{UM;11}$	Cost of vaccine delivery during ramp up (11–30%) in UMIC; USD per dose	Triangular	4.5, 6, 9		See Table 5
$V_{UM;31}$	Cost of vaccine delivery getting to scale (31–80%) in UMIC; USD per dose	Triangular	3, 4, 5		See Table 5
$V_{H;0}$	Cost of vaccine delivery at start up (0–10%) in HIC; USD per dose	Triangular	30, 40, 75		See Table 5

Math notation	Description	Distribution	Parameters	Bounds	Source
$V_{H;11}$	Cost of vaccine delivery during ramp up (11–30%) in HIC; USD per dose	Triangular	30, 40, 75		See Table 5
$V_{H;31}$	Cost of vaccine delivery getting to scale (31–80%) in HIC; USD per dose	Triangular	30, 40, 75		See Table 5
M_G	Global annual manufacturing volume; billion doses	Constant	15		Linksbridge SPC [2025]
M_C	Current annual manufacturing volume; billion doses	Constant	9		Linksbridge SPC [2025]
F	Facility transition start; weeks before vaccine approval	Constant	7		
I_R	Weeks to initial manufacturing, reserved infrastructure	Constant	12		Vaccines Europe [2023]
$I_{E,0}$	Weeks to initial manufacturing when there's no BPSV, existing and unreserved infrastructure	Constant	30		Vaccines Europe [2023]
$I_{E,1}$	Weeks to initial manufacturing when there's BPSV, existing and unreserved infrastructure	Constant	12		Vaccines Europe [2023]
I_B	Weeks to initial manufacturing, built and unreserved infrastructure	Constant	48		
C_R	Weeks to scale up to full capacity, reserved infrastructure	Constant	10		Vaccines Europe [2023]
C_E	Weeks to scale up to full capacity, existing and unreserved infrastructure	Constant	16		

Math notation	Description	Distribution	Parameters	Bounds	Source
C_B	Weeks to scale up to full capacity, built and unreserved infrastructure	Constant	16		
$P_0^{(\mathrm{BPSV})}$	Probability of success; preclinical	Multinomial	0.40, 0.41, 0.41, 0.42, 0.48, 0.57		Gouglas et al. [2018]
$P_1^{(\mathrm{BPSV})}$	Probability of success; Phase I	Multinomial	0.33, 0.40, 0.50, 0.68, 0.70, 0.72, 0.74, 0.77, 0.81, 0.90		Gouglas et al. [2018]
$P_2^{(\mathrm{BPSV})}$	Probability of success; Phase II	Multinomial	0.22, 0.31, 0.33, 0.43, 0.46, 0.54, 0.58, 0.58, 0.74, 0.79		Gouglas et al. [2018]
$P_3^{(\mathrm{BPSV})}$	Probability of success; Phase III	Uniform	0.4, 0.8		Wong et al. [2019]
X_0	COVID-19 candidates failed at preclinical	Constant	33		
X_1	COVID-19 candidates failed at Phase 1	Constant	20		
X_2	COVID-19 candidates failed at Phase 2	Constant	8		
X_3	COVID-19 candidates failed at Phase 3	Constant	8		
X_4	COVID-19 candidates successful	Constant	27		
$T_0^{(e)}$	Cost, preclinical, experienced manufacturer; USD	Exponential	24213683	1700000, 140000000	Gouglas et al. [2018]
$T_0^{(n)}$	Cost, preclinical, inexperienced manufacturer; USD	Inverse Gaussian	7882792, 13455907	1700000, 37000000	Gouglas et al. [2018]
$T_1^{(e)}$	Cost, Phase I, experienced manufacturer; USD	Inverse Gaussian	15339198, 8076755	1900000, 70000000	Gouglas et al. [2018]
$T_1^{(n)}$	Cost, Phase I, inexperienced manufacturer; USD	PearsonV	2.2774, 9799081	1000000, 30000000	Gouglas et al. [2018]

Math notation	Description	Distribution	Parameters	Bounds	Source
$T_2^{(e)}$	Cost, Phase II, experienced manufacturer; USD	Log normal	28297339, 24061641	3800000, 140000000	Gouglas et al. [2018]
$T_2^{(n)}$	Cost, Phase II, inexperienced manufacturer; USD	Inverse Gaussian	17124622, 35918793	4400000, 54000000	Gouglas et al. [2018]
$T_3^{(e)}$	Cost, Phase III, experienced manufacturer; USD	PearsonV	1.3147, 51397313	15000000, 910000000	Gouglas et al. [2018]
$T_3^{(n)}$	Cost, Phase III, inexperienced manufacturer; USD	PearsonVI	4.8928, 1.6933, 11400026	2500000, 400000000	Gouglas et al. [2018]
ω	Share of manufacturers that are inexperienced	Constant	0.875		See Table 2
L	Licensure cost, 2018; USD	Constant	287750		Gouglas et al. [2018]
$Y_0^{(B)}$	BPSV preclinical duration; years	Multinomial	1, 2		CEPI [2022]
$Y_1^{(B)}$	BPSV Phase I duration; years	Multinomial	1, 2		CEPI [2022]
$Y_2^{(B)}$	BPSV Phase II duration; years	Constant	2		CEPI [2022]
$Y_3^{(B)}$	BPSV Phase III duration; years	Multinomial	2, 3, 4		CEPI [2022]
$W_3^{(B)}$	BPSV response Phase III duration; weeks	Constant	18		
$L^{(B)}$	Licensure duration; years	Constant	2		CEPI [2022]
G	Drug substance cost; USD per dose	Constant	4.68		Kazaz [2021]
A_1	Annual BPSV reservation cost, USD per dose	Constant	0.0101213633333333		
A_2	Advanced capacity reservation fee; USD per dose per year	Constant	0.531692307692308		Pfizer [2023]
S_U	SSV procurement price, reactive capacity; USD per dose	Constant	18.9392		Linksbridge SPC [2025]

Math notation	Description	Distribution	Parameters	Bounds	Source
E	Enabling activities; million USD per year	Constant	700		CEPI [2021]
I	Inflation (2018 t0 2025)	Constant	0.28		U.S. BLS [2025]
r	Discount rate	Uniform	0.02, 0.06		Glennerster et al. [2023]
M_p	Profit margin	Constant	0.2		Kazaz [2021]
M_f	Fill/finish cost	Constant	0.1398		Kazaz [2021]
M_t	Cost to transport product	Constant	0.12		Kazaz [2021]
$N^{(0)}_{HIC}$	Population, HIC	Constant	1260028362		
$N^{(0)}_{UMIC}$	Population, UMIC	Constant	2854556263.5		
$N^{(0)}_{LMIC}$	Population, LMIC	Constant	3314048516		
$N^{(0)}_{LIC}$	Population, LIC	Constant	762656294.5		
$N^{(15)}_{HIC}$	Population aged 15 and older, HIC	Constant	1064531991.5		
$N^{(15)}_{UMIC}$	Population aged 15 and older, UMIC	Constant	2308984518		
$N^{(15)}_{LMIC}$	Population aged 15 and older, LMIC	Constant	2363976954.5		
$N^{(15)}_{LIC}$	Population aged 15 and older, LIC	Constant	450976596.5		
$N^{(65)}_{HIC}$	Population aged 65 and older, HIC	Constant	256715334		
$N^{(65)}_{UMIC}$	Population aged 65 and older, UMIC	Constant	359824402.5		
$N^{(65)}_{LMIC}$	Population aged 65 and older, LMIC	Constant	215830985.5		
$N^{(65)}_{LIC}$	Population aged 65 and older, LIC	Constant	24812768		
$Q^{(\text{SSV})}$	Probability of N or more SSV successes	Constant	0.9		Model choice
$n^{(\text{SSV})}$	Number of SSV successes	Constant	5		Model choice
$N^{(\text{BPSV})}$	Number of BPSV candidates	Constant	14		CEPI [2025]
$N^{(\text{BPSV-1})}$	Number of BPSV candidates starting at phase 1	Constant	1		
A_3	Reserved capacity for HIC, billions	Constant	0.5		

Math notation	Description	Distribution	Parameters	Bounds	Source
λ	Final vaccine coverage, proportion of population	Constant	0.8		Model choice
A_4	Size of BPSV investigational reserve, doses	Constant	100000		Model choice
δ	Fraction of BPSV expected to go to waste	Constant	0.3142532		Model choice
$Y^{(200)}$	Years of R&D to 200-day readiness	Constant	5		
$Y^{(100)}$	Years of R&D to 100-day readiness	Constant	15		
Y_{rep}	Years after which BPSV doses are to be replaced	Constant	3		
A_5	BPSV reserve upfront cost, USD per dose	Constant	0.115		
$N^{(\text{boost})}$	Number of boosters given, one per year	Constant	2		Model choice

3 Preparedness cost equation

(BPSV R&D + BPSV Stockpile + SARS-X Reserved capacity + Enabling activities) / (1 + discount rate) ^ (year – 2025)

$$D_y^{(\text{prep})} = \frac{1}{(1+r)^y}\left(D_s^{(\text{BP-adRD})} + D_{s,y}^{(\text{BP-inv})} + D_s^{(\text{S-cap})} + D_{s,y}^{text(en)}\right)$$

- $D_s^{(\text{BP-adRD})}$ is the R&D cost of BPSV prior to an outbreak; see Equation (1)
- $D_{s,y}^{(\text{BP-inv})}$ is the cost of maintaining an investigational reserve of 100,000 BPSV doses; see Equation (2)
- $D_s^{(\text{S-cap})}$ is the cost of reserved capacity for SSV; see Equation (4)
- $D_{s,y}^{text(en)}$ is the annual cost of enabling activities; see Equation (5).

3.1 BPSV advanced R&D

These values match the spreadsheet results

Table 2: Manufacturers working on BPSV and whether or not they have licensure experience

Developer	Licensure Experience
CalTech	No
SK Bio	Yes

Developer	Licensure Experience
Codiak	No
Panacea	No
NEC Onco	No
Intravacc	No
VIDO	No
IVI	No

Probabilities of success for preclinical, Phase I, Phase II, and Phase III are P_0, P_1, P_2 and P_3. Then probabilities of occurrence are:

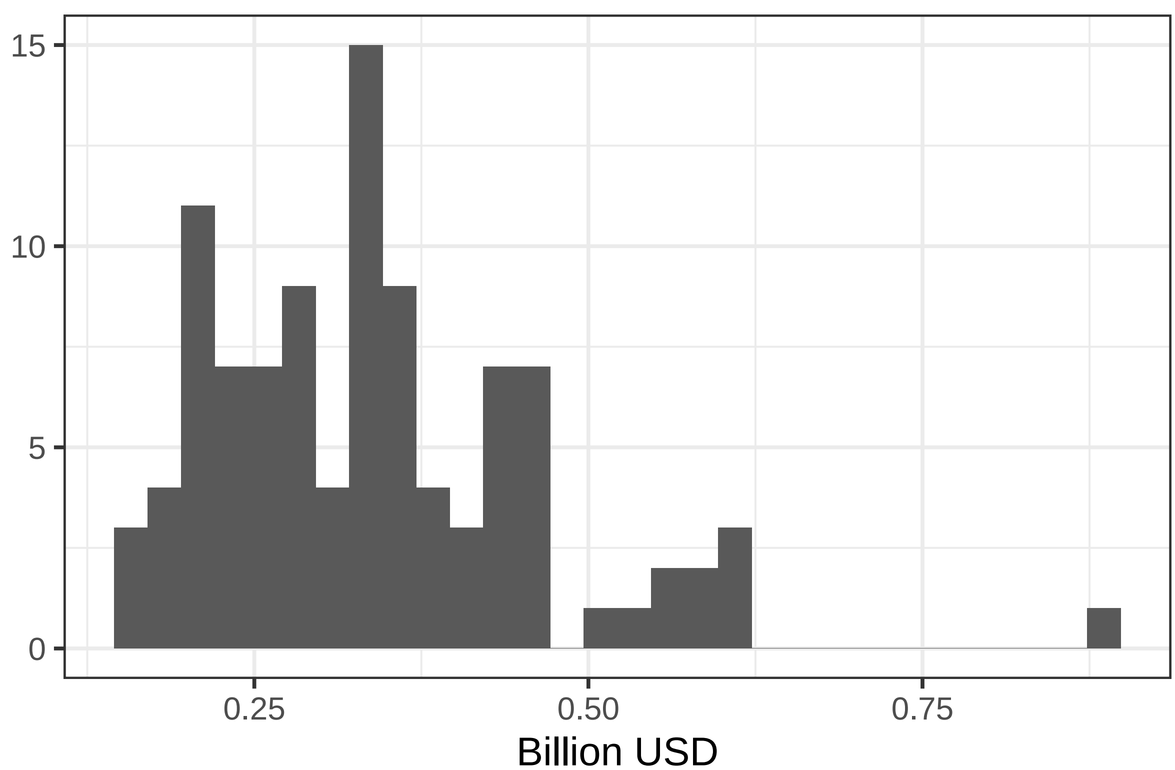
$$\hat{P}_i = \begin{cases} 1 & i = 0 \\ \prod_{j=0}^{i-1} P_j & i \in \{1,2,3\} \\ \prod_{j=0}^{3} P_j & i = L \end{cases}$$

and the cost of each phase is T_i, a weighted average of experienced and inexperienced manufacturers (with $\omega = 0.875$):

$$T_i = \omega T_i^{(n)} + (1-\omega) T_i^{(e)}.$$

Then the total weighted cost for phases 0 through 2 for $N^{(\mathrm{BPSV})} = 8$ candidates is

$$D_s^{(\text{BP-adRD})} = \begin{cases} N^{(\mathrm{BPSV})} \sum_{i=0}^{2} \hat{P}_i T_i & s \in \{1,2,3\} \\ 0 & s \notin \{1,2,3\} \end{cases} \tag{1}$$



Min. 1st Qu. Median Mean 3rd Qu. Max. 0.16 0.25 0.33 0.34 0.40 0.89

Target: 146 (103 135 177)

3.2 BPSV investigational reserve

The stockpile cost (annual) is correct, at around 162 thousand, but the total cost is slightly too high

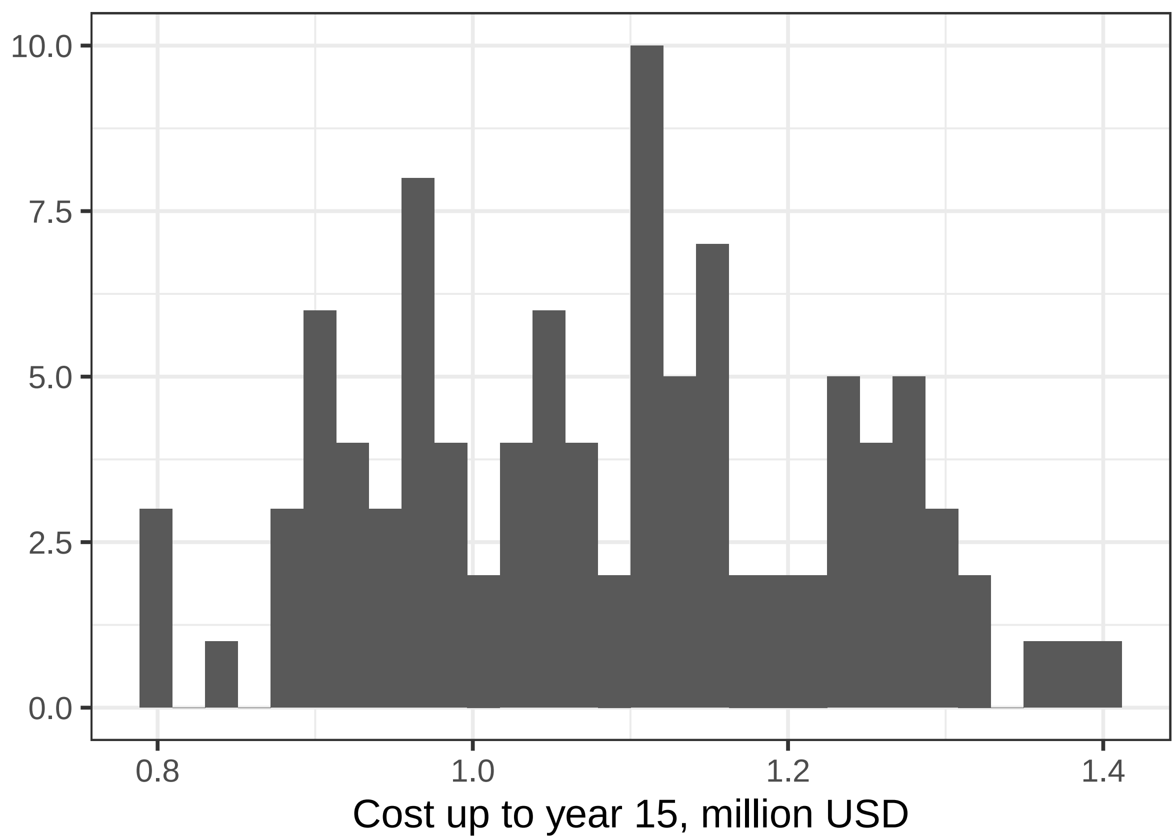
The time taken to complete development of the BPSV up to the end of phase II, from which point it is stockpiled, is:

$$Y^{(B)} = Y_0^{(B)} + Y_1^{(B)} + Y_2^{(B)}.$$

The cost of goods supplied is $G = 4.68$. Then the cost of drug substance is $G(1 - M_f)(1 + M_p) = 4.83$ USD per dose. The reserve is replenished every $Y_{rep} = 3$ years. Then the annual cost to maintain the reserve of $A_4 = 100,000$ doses is

$$D_{s,y}^{(\text{BP-inv})} = \begin{cases} \frac{A_4}{Y_{rep}} G(1 - M_f)(1 + M_p) + A_1 & s \in \{1, 2, 3\} \ \& \ y > Y^{(B)} \\ 0 & s \notin \{1, 2, 3\} \ \| \ y \leq Y^{(B)} \end{cases} \tag{2}$$

where $A_1 = 0$ USD is the annual reservation cost.



Min. 1st Qu. Median Mean 3rd Qu. Max. 0.80 0.97 1.09 1.09 1.19 1.40

Target: 1 (0.9 1 1.1)

3.3 SSV capacity reservation

This matches the spreadsheet results.

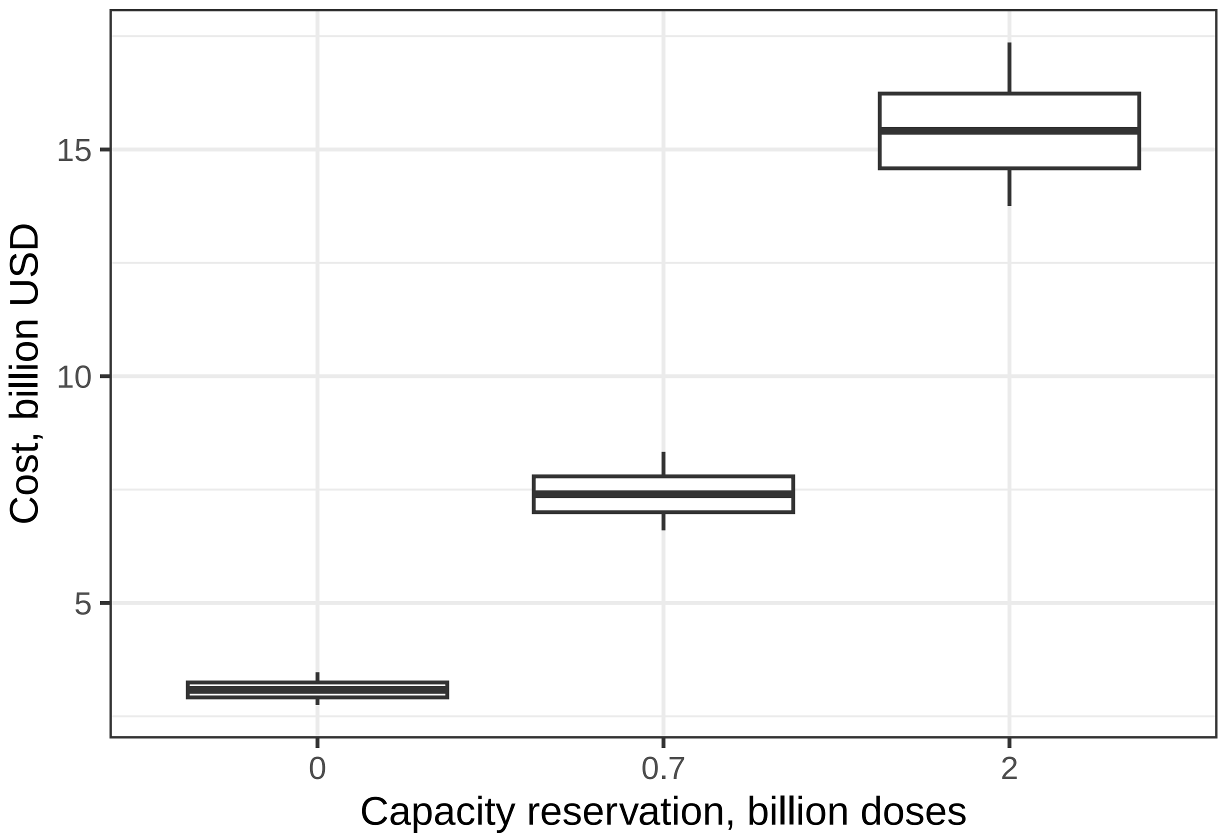
The cost per dose reservation per year is $A_2 = 0.5316923$ USD. Reservation sizes, in billions, depend on scenarios, including the $A_3 = 0.5$ billion doses reserved for HIC, as follows:

$$M_{R,s} = \begin{cases} A_3 & s \in \{0, 1, 6, 9, 12\} \\ A_3 + 0.7 & s \in \{2, 4, 7, 10\} \\ A_3 + 2 & s \in \{3, 5, 8, 11\} \end{cases} \tag{3}$$

Then the total cost per year is

$$D_s^{(\text{S-cap})} = M_{R,s} A_2 \tag{4}$$

The annual costs in billion USD are 0.2658462, 0.6380308, and 1.3292308, respectively.



0 Min. 1st Qu. Median Mean 3rd Qu. Max. 2.75 2.92 3.08 3.09 3.25 3.47

0.7 Min. 1st Qu. Median Mean 3rd Qu. Max. 6.60 7.00 7.40 7.41 7.79 8.33

2 Min. 1st Qu. Median Mean 3rd Qu. Max. 13.75 14.58 15.41 15.43 16.23 17.36

Targets: 3,086 (2,897 3,074 3,269)

7,407 (6,954 7,378 7,845)

15,431 (14,487 15,370 16,344)

3.4 Enabling activities

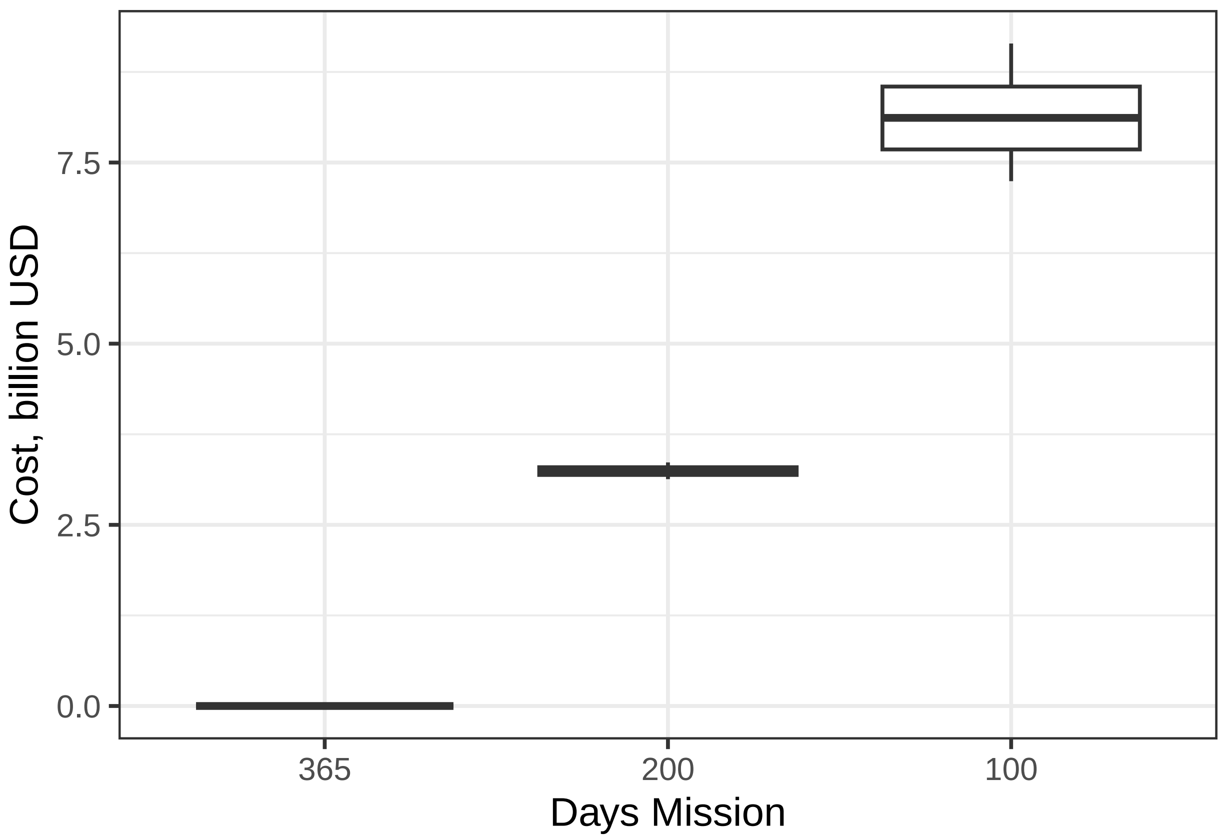
This matches the spreadsheet results

Denote the "Days Mission" by ζ, so that $\zeta \in \{365, 200, 100\}$. Then annual costs, $E = 700$ million, accumulate depending on the year and the mission:

$$D^{(\text{en})}_{s,y} = \begin{cases} E & \zeta(s) = 200 \ \& \ y \leq 5 \mid \zeta(s) = 100 \ \& \ y \leq 15 \\ 0 & \zeta(s) = 365 \mid y > 15 \mid \zeta(s) = 200 \ \& \ y \ > \ 5 \end{cases} \tag{5}$$

For our scenarios, we have

$$\zeta(s) = \begin{cases} 365 & s \in \{0, 1, 2, 3, 4, 5, 12\} \\ 200 & s \in \{6, 7, 8\} \\ 100 & s \in \{9, 10, 11\} \end{cases} \tag{6}$$



365 Min. 1st Qu. Median Mean 3rd Qu. Max. 0 0 0 0 0 0

200 Min. 1st Qu. Median Mean 3rd Qu. Max. 3.13 3.19 3.24 3.24 3.30 3.36

100 Min. 1st Qu. Median Mean 3rd Qu. Max. 7.24 7.68 8.12 8.13 8.55 9.14

Targets:

3,242 (3,182 3,241 3,302)

8,126 (7,629 8,094 8,607)

4 Response cost equation

(BPSV R&D + SARS-X R&D + BPSV Procurement + SARS-X Procurement + BPSV Delivery + SARS-X Delivery) / (1 + discount rate) ^ (year − 2025)

$$D_y^{(\text{res})} = \frac{1}{(1+r)^y}\left(D_s^{(\text{BP-resRD})} + D_s^{(\text{S-RD})} + D_s^{(\text{BP-proc})} + D_s^{(\text{S-proc})} + D_s^{(\text{BP-del})} + D^{(\text{S-del})}\right)$$

- $D_s^{(\text{BP-resRD})}$ is the R&D cost of BPSV after an outbreak; see Equation (9)
- $D_s^{(\text{S-RD})}$ is the R&D cost for SSV; see Equation (7)
- $D_s^{(\text{BP-proc})}$ is the cost of procuring BPSV; see Equation (11)
- $D_s^{(\text{S-proc})}$ is the cost of procuring SSV; see Equation (10)
- $D_s^{(\text{BP-del})}$ is the cost of delivering BPSV; see Equation (13)
- $D^{(\text{S-del})}$ is the cost of delivering SSV; see Equation (12)

4.1 Risk-adjusted R&D cost per candidate calculation

4.1.1 SSV

These don't match the spreadsheet results. Values too low.

Trial costs are adjusted for the duration of the trial, which depend on the R&D investment, denoted $\zeta \in \{365, 200, 100\}$:

$$T_{\zeta,i}^{(e)} = \frac{W_{i;\zeta}^{(S)}}{52Y_i^{(B)}}T_i^{(e)}.$$

Then the total cost is

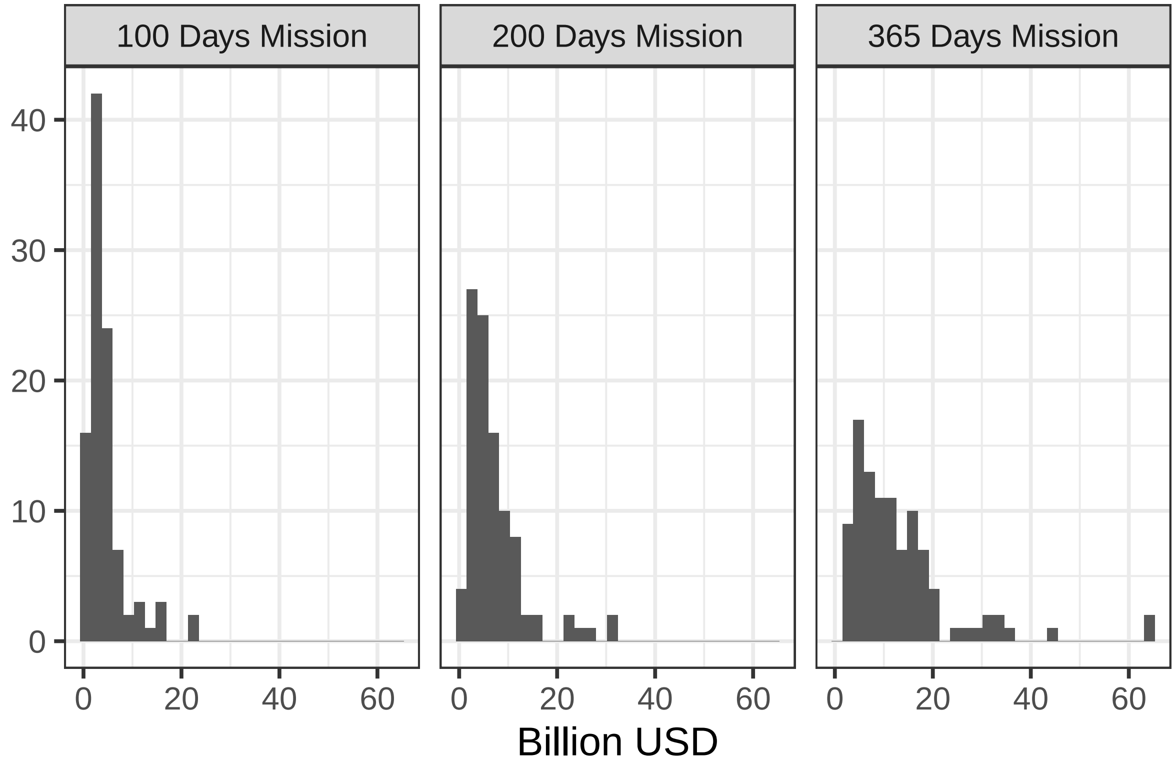
$$D_s^{(\text{S-RD})} = N^{(\text{SSV})}\left(\sum_{i=0}^{3}\hat{P}_i T_{\zeta(s),i}^{(e)} + (1+I)\hat{P}_L L\right) \tag{7}$$

where I is inflation from 2018 to 2025.

We multiply by the number of candidates, $N^{(\text{SSV})}$, to get the total cost from the weighted average per candidate, where

$$N^{(\text{SSV})} = n^{(\text{SSV})} + F_{NegBin}^{-1}\left(Q^{(\text{SSV})}; n^{(\text{SSV})}, P_3^{(\text{SSV})}\right) \tag{8}$$

is chosen to secure $n^{(\text{SSV})} = 5$ successful candidates with probability $Q^{(\text{SSV})} = 90\%$.



4.2

DM	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
365	0.04	0.12	0.2	0.24	0.3	0.97

200 0.03 0.06 0.11 0.13 0.16 0.88

4.3 100 0.01 0.04 0.07 0.08 0.1 0.47

Targets:

284 (105 170 283)

195 (61 97 164)

118 (35 61 108)

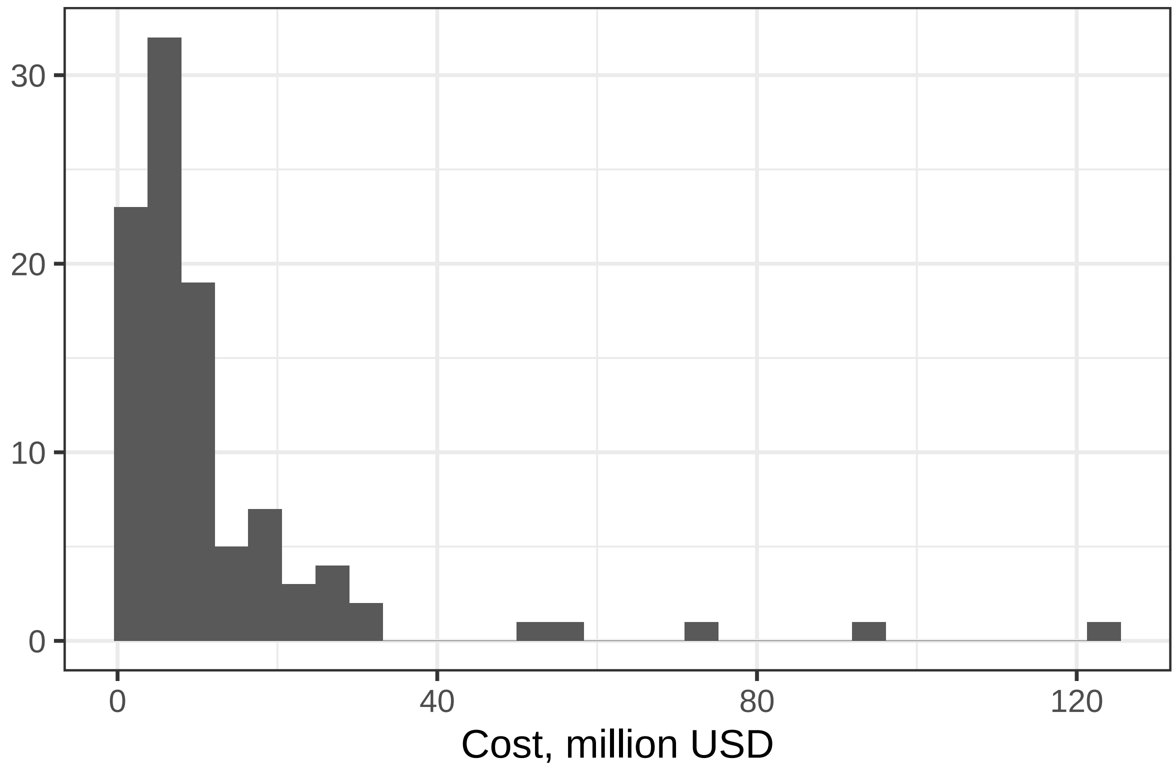
4.3.1 BPSV

This is a little higher than the spreadsheet results

I have basically assumed the same as SSV except for the numbers given (8 candidates and 18 weeks)

The BPSV has $N^{(\mathrm{BPSV})} = 8$ candidates. Those that have passed through Phases 0 to 2 prior to the outbreak go through Phase 3 during the response. The duration is $W_3^{(B)} = 18$ weeks. Thus we write the BPSV R&D response cost

$$D_s^{(\text{BP-resRD})} = \begin{cases} N^{(\text{BPSV})}\hat{P}_3 \left(\frac{W_3^{(B)}}{52Y_3^{(B)}} T_3^{(e)} + (1+I)P_3L \right) & s \in \{1,2,3\} \\ 0 & s \notin \{1,2,3\} \end{cases} \tag{9}$$



Min. 1st Qu. Median Mean 3rd Qu. Max. 1.0 2.2 3.7 7.4 7.0 89.7

Target: 14 (3 5 10)

4.4 Procurement cost calculation

The cost per dose comes from the cost of goods supplied ($G = 4.68$) adjusted for profits ($M_p = 0.2$) and the transportation cost ($M_t = 0.12$).

$S_R = G(1 + M_p)(1 + M_t)$ evaluates to 6.29.

This cost is used both for SSV doses manufactured using reserved capacity, and all newly manufactured BPSV doses.

4.4.1 SSV

These values are close, but not identical, to the spreadsheet results if I adjust for the total demand

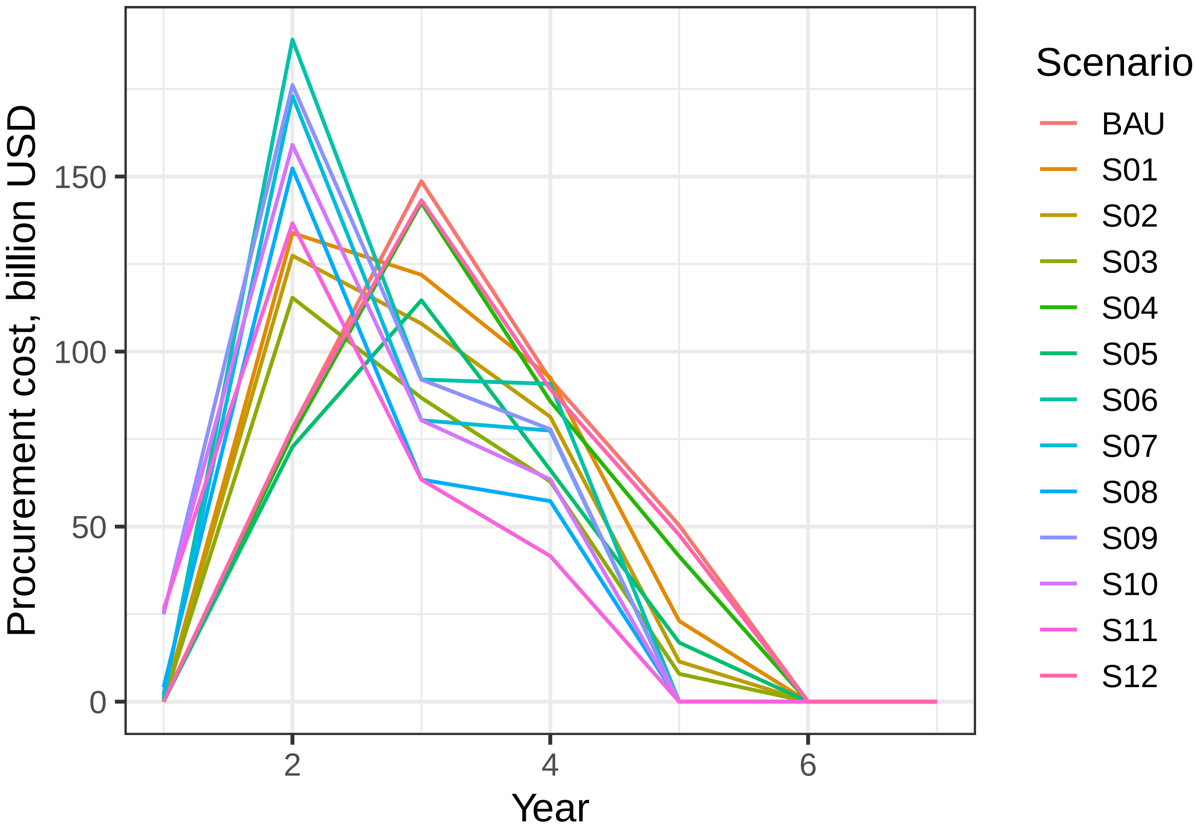
If we write annual demand in billions as $A_{SSV,s,y}$, then we would have costs, in billion USD, of:

$$D_{s,y}^{(\text{S-proc})} = \min\{A_{SSV,s,y}, M_C\} \cdot S_R + \max\{A_{SSV,s,y} - M_C, 0\} \cdot S_U \tag{10}$$

Here, $S_R = 6.29$ is the cost per reserved dose and $S_U = 18.9392$ the cost per unreserved dose in USD.

The total number of doses produced in week w in scenario s is $Z_{T,s,w}$ (see Equation (18)). The total in a one-year period is

$$A_{SSV,s,y} = \sum_{w \in y} Z_{T,s,w}.$$



4.5

Scenario	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
BAU	136	163	192	194	222	268

S01 139 166 195 197 226 272

S02 124 147 173 175 200 240

S03 103 123 144 146 167 200

S04 128 153 180 182 209 252

S05 101 120 141 143 164 197

S06 142 169 198 200 228 274

S07 127 151 177 179 204 245

S08 106 126 148 149 170 204

S09 143 169 198 200 228 274

S10 127 150 175 177 202 242

S11 104 123 144 145 166 198

4.6 S12 132 158 186 188 216 261

Table: Costs summed and discounted from year 16 to year 20, billion USD

Targets:

184,127 (151,271 180,171 214,966) 187,255 (154,376 183,358 218,147) 165,976 (136,961 162,544 193,238) 138,384 (114,281 135,548 161,043) 167,519 (137,713 163,938 195,495) 135,910 (111,925 133,050 158,444) 189,820 (157,000 185,976 220,684) 169,549 (140,293 166,133 197,067) 141,440 (117,134 138,613 164,309) 189,878 (157,295 186,091 220,526) 168,378 (139,564 165,035 195,494) 137,984 (114,513 135,278 160,078) 178,766 (146,883 174,927 208,686)

4.6.1 BPSV

This is pretty close

$$D_s^{\text{(BP-proc)}} = \begin{cases} A_{BPSV,s} \cdot S_R + A_4(M_f + M_t)(1 + M_p)G & s \in \{1,2,3\} \\ 0 & s \notin \{1,2,3\} \end{cases} \tag{11}$$

For a world population aged 65 and over of 0.9 billion, an uptake of 80% (accounting for wastage of 0.3142532), and a cost per dose of $S_R = 6.29$ USD (the same as for SSV via reserved capacity), the procurement cost for BPSV is 6.68 billion USD.

Although 1.0625 billion doses are manufactured, as manufacturing stops once one billion doses have been made.

Min. 1st Qu. Median Mean 3rd Qu. Max. 2.82 3.27 3.74 3.76 4.22 4.93

Target: 3,628 (3,062 3,568 4,165)

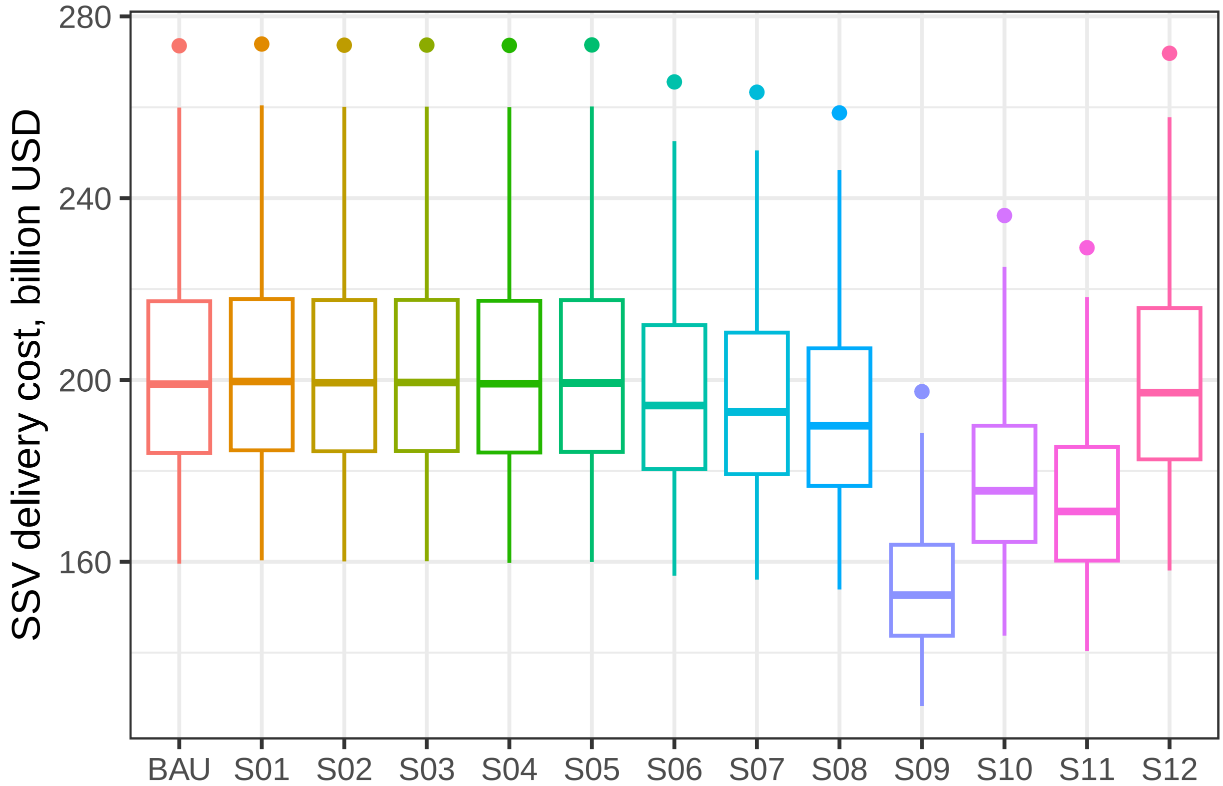
4.7 Delivery Cost Equation

4.7.1 SSV

These values are ballpark correct but too concentrated

For populations aged 15 and above $N_i^{(15)}$ in income group $i \in$ {LIC, LMIC, UMIC, HIC}, we have delivery cost:

$$D^{\text{(S-del)}} = \begin{cases} \sum_i \lambda N_i^{(15)} V_{i;0} & \lambda \leq \frac{1}{10} \\ \sum_i \left(\frac{1}{10} V_{i;0} + \left(\lambda - \frac{1}{10}\right) V_{i;11}\right) N_i^{(15)} & \frac{1}{10} < \lambda \leq \frac{3}{10} \\ \sum_i \left(\frac{1}{10} V_{i;0} + \frac{2}{10} V_{i;11} + \left(\lambda - \frac{3}{10}\right) V_{i;31}\right) N_i^{(15)} & \lambda > \frac{3}{10} \end{cases} \tag{12}$$



BAU Min. :159.6 1st Qu.:183.9 Median :199.1 Mean :201.1
S01 Min. :160.3 1st Qu.:184.5 Median :199.7 Mean :201.7
S02 Min. :160.1 1st Qu.:184.3 Median :199.4 Mean :201.5
S03 Min. :160.1 1st Qu.:184.3 Median :199.4 Mean :201.5
S04 Min. :159.7 1st Qu.:184.0 Median :199.2 Mean :201.3
S05 Min. :159.9 1st Qu.:184.2 Median :199.4 Mean :201.4
S06 Min. :156.9 1st Qu.:180.4 Median :194.4 Mean :196.6
S07 Min. :156.1 1st Qu.:179.3 Median :193.0 Mean :195.3
S08 Min. :153.9 1st Qu.:176.7 Median :189.9 Mean :192.3
S09 Min. :128.2 1st Qu.:143.7 Median :152.7 Mean :153.5
S10 Min. :143.7 1st Qu.:164.3 Median :175.6 Mean :177.5
S11 Min. :140.3 1st Qu.:160.3 Median :171.1 Mean :172.7
S12 Min. :158.1 1st Qu.:182.5 Median :197.2 Mean :199.3

```
BAU 3rd Qu.:217.3   Max.   :273.5
S01 3rd Qu.:217.8   Max.   :273.9
S02 3rd Qu.:217.6   Max.   :273.7
S03 3rd Qu.:217.6   Max.   :273.7
S04 3rd Qu.:217.4   Max.   :273.6
S05 3rd Qu.:217.6   Max.   :273.7
S06 3rd Qu.:212.1   Max.   :265.6
S07 3rd Qu.:210.4   Max.   :263.3
S08 3rd Qu.:206.9   Max.   :258.8
S09 3rd Qu.:163.8   Max.   :197.4
S10 3rd Qu.:189.9   Max.   :236.2
S11 3rd Qu.:185.2   Max.   :229.1
S12 3rd Qu.:215.8   Max.   :271.9
```

Targets:

114,526 (90,654 110,005 134,444) 114,771 (91,321 111,130 134,341) 114,769 (91,620 110,604 133,752) 114,811 (91,647 110,815 133,856) 114,527 (91,170 110,664 133,720) 114,615 (91,074 110,653 133,836) 115,095 (91,858 111,205 134,355) 115,634 (92,514 111,639 134,375) 116,385 (93,116 112,183 135,664) 117,196 (93,427 113,114 136,861) 116,913 (93,536 112,957 136,414) 118,141 (94,682 114,649 137,100) 113,540 (89,745 109,012 132,595)

4.7.2 BPSV

These values match the spreadsheet results. (NB: more doses are purchased and delivered than there are eligible people in the population)

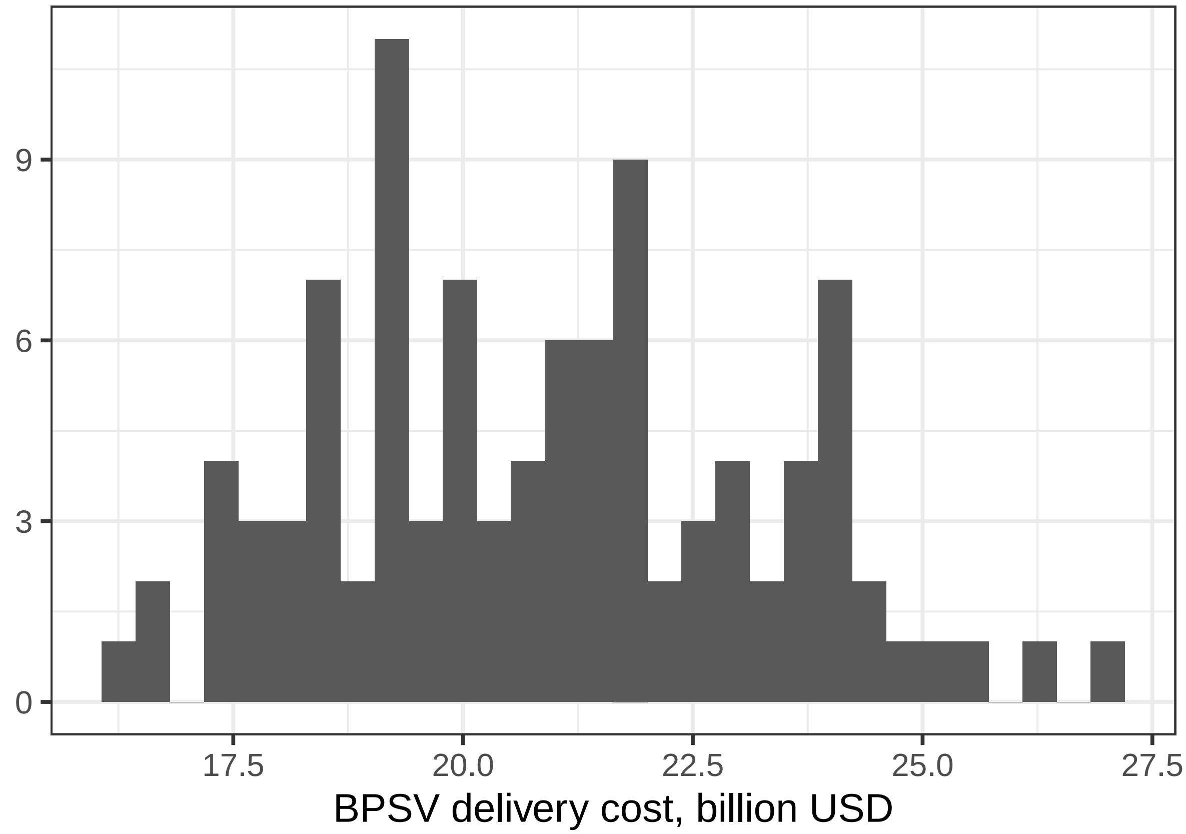
For the BPSV, which goes only to people aged 65 or older, with populations $N_i^{(65)}$, coverage is reached earlier in the process, so the cost is weighted more heavily towards start up and ramp up:

$$D_s^{(\text{BP-del})} = \begin{cases} \sum_i D_{\text{BPSV},i} & s \in \{1,2,3\} \\ 0 & s \notin \{1,2,3\} \end{cases} \tag{13}$$

$$D_{\text{BPSV},i} = \begin{cases} N_i^{(65)} V_{i;0} & N_i^{(65)} \leq \frac{1}{10} N_i^{(15)} \\ \frac{N_i^{(15)}}{10} V_{i;0} + \left(N_i^{(65)} - \frac{N_i^{(15)}}{10} \right) V_{i;11} & \frac{1}{10} N_i^{(15)} < N_i^{(65)} \leq \frac{3}{10} N_i^{(15)} \\ \frac{N_i^{(15)}}{10} V_{i;0} + \frac{2}{10} N_i^{(15)} V_{i;11} + \left(N_i^{(65)} - \frac{3}{10} N_i^{(15)} \right) V_{i;31} & N_i^{(65)} > \frac{3}{10} N_i^{(15)} \end{cases} \tag{14}$$

The logic of this is as follows:

- The increments in cost correspond to numbers of eligible people in the whole population, namely those aged 15 and above.
- If the number of people eligible for the BPSV is less than 10% of the population aged 15 and over, then all doses cost the “start up” amount.
- If the number of people eligible for the BPSV is more than 10% and less than 30% of the 15+ population, then cost of the first doses, a number equal to 10% of the 15+ population, is the “start up” amount. All remaining doses cost the “ramp up” amount.
- If the number of people eligible for the BPSV is more than 30% of the 15+ population, then the cost of the first doses, a number equal to 10% of the 15+ population, is the “start up” amount. The cost of the second tranche of doses, a number equal to 20% of the 15+ population, is the “ramp up” amount. All remaining doses cost the “getting to scale” amount.



Min. 1st Qu. Median Mean 3rd Qu. Max. 8.09 9.88 11.49 11.77 13.57 16.87

Target: 11,206 (9,037 10,865 13,054)

Table 5: Literature review of global and country-specific delivery costs

Country	Country status	Study type	Financial Cost per dose (USD)	Source
WHO, Gavi, and UNICEF AMC Estimate	AMC	Top down	1.66	Griffiths et al. [2021]
UNICEF Global Estimate	All	Model	0.73	Oyatoye [2023]
DRC	LIC	Bottom up	1.91	Moi et al. [2024]
Malawi	LIC	Bottom up	4.55	Ruisch et al. [2025]
Mozambique	LIC	Bottom up	0.5	Namalela et al. [2025]
Uganda	LIC	Bottom up	0.79	Tumusiime et al. [2024]
Bangladesh	LMIC	Bottom up	0.29	Yesmin et al. [2024]
Cote d'Ivoire	LMIC	Bottom up	0.67	Vaughan et al. [2023]
Nigeria	LMIC	Bottom up	0.84	Noh et al. [2024]
Philippines	LMIC	Bottom up	2.16	Banks et al. [2023]

Country	Country status	Study type	Financial Cost per dose (USD)	Source
Vietnam	LMIC	Bottom up	1.73	Nguyen et al. [2024]
Ghana	LMIC	CVIC tool	2.2–2.3	Nonvignon et al. [2022]
Lao PDR	LMIC	CVIC tool	0.79–0.81	Yeung et al. [2023]
Kenya	LMIC	Top down	3.29–4.28	Orangi et al. [2022]
Botswana	UMIC	Mixed	19	Vaughan et al. [2025]
South Africa	UMIC	Top down	3.84	Edoka et al. [2024]

Table 6: Cost differences: investments vs. BAU, for different types of investment.

timing	category	type	Cost vs. BAU
One-off	R&D	200 days to SSV	$3.5\ (3.5, 3.5)$
One-off	R&D	100 days to SSV	$10\ (10, 10)$
One-off	R&D	BPSV	$0.35\ (0.26, 0.44)$
Per year	Manufacturing	BPSV	$0.16\ (0.16, 0.16)$
Per year	Manufacturing	0.7 billion capacity	$0.37\ (0.37, 0.37)$
Per year	Manufacturing	2 billion capacity	$1.1\ (1.1, 1.1)$
Per pandemic	R&D	200 days to SSV	$-0.14\ (-0.25, -0.086)$
Per pandemic	R&D	100 days to SSV	$-0.23\ (-0.36, -0.15)$
Per pandemic	R&D	BPSV	$0.0073\ (0.004, 0.013)$
Per pandemic	Manufacturing	0.7 billion capacity	$-23\ (-23, -23)$
Per pandemic	Manufacturing	2 billion capacity	$-99\ (-99, -99)$
Per pandemic	Manufacturing	BPSV	$6.7\ (6.7, 6.7)$
Per pandemic	Delivery	BPSV	$21\ (19, 23)$
Per pandemic	Delivery	0.7 billion capacity	$0.14\ (0.12, 0.17)$
Per pandemic	Delivery	2 billion capacity	$0.31\ (0.26, 0.38)$
Per pandemic	Delivery	Equality + Delivery	$-1.8\ (-2.2, -1.5)$

5 SSV delivery

Table 7: Manufacturing response timeline assumptions

Category	Reserved capacity	Private response (existing capacity)	Private response (built capacity)
Annual manufacturing volume	By scenario (0.5–2.5B)	2.5B minus reserved volume	6B
Facility transition start	7 weeks before vaccine approval	7 weeks before vaccine approval	7 weeks before vaccine approval
Weeks to initial manufacturing	12	12 (BPSV) or 30 (no BPSV)	48
Scale-up weeks to full capacity	10	16	16

Table 8: Vaccine Production Timeline when there is no BPSV. When BPSV is also modelled, Existing Private Capacity scales from 0 to 100 in weeks 12–21.

Weeks from transition start	Reserved Capacity (%)	Existing Private Capacity (%)	Response Private Capacity (%)
0–11			
12–21	Scales from 0 to 100		
22–29	100		
30–45	100	Scales from 0 to 100	
46–47	100	100	
48–63	100	100	Scales from 0 to 100
64+	100	100	100

5.1 Timing

Facility transition occurs $F = 7$ weeks before vaccine approval, which in turn depends on R&D investments. We have three levels in our scenarios, corresponding to a 100 Days Mission, 200 days, and 365 days. The total weeks taken for vaccine approval can be written as follows:

$$W_j^{(S)} = \sum_{i=0}^{3} W_{i;j}^{(S)}$$

for $j \in \{365, 200, 100\}$. These work out as 52, 29, and 14 weeks, respectively. Thus "week 0" for manufacturing occurs 45, 22, and 7 weeks, respectively, after the new pathogen has been sequenced. We denote this variable $w_s^{(0)}$.

5.2 Production

The total global manufacturing volume is $M_G = 15$ billion doses. The amount that is reserved, in billion doses, including the HIC-specific reservation of $A_3 = 0.5$ billion doses, depends on the scenarios as follows:

$$M_{R,s} = \begin{cases} A_3 & s \in \{0, 1, 6, 9, 12\} \\ A_3 + 0.7 & s \in \{2, 4, 7, 10\} \\ A_3 + 2 & s \in \{3, 5, 8, 11\} \end{cases} \tag{15}$$

where $s = 0$ denotes the BAU scenario. By definition, $M_{E,s} = M_C - M_{R,s}$, and $M_B = M_G - M_C$.

Then the number of doses, in billions, that are made from capacity $x \in \{R, E, B\}$ in week w of scenario s is:

$$Z_{x,s,w} = \begin{cases} 0 & w - w_s^{(0)} \leq I_x \\ \frac{1}{52} \frac{w - w_s^{(0)} - I_x}{C_x} M_{x,s} & w - w_s^{(0)} \in (I_x, I_x + C_x] \\ \frac{1}{52} M_{x,s} & w - w_s^{(0)} > I_x + C_x \end{cases} \tag{16}$$

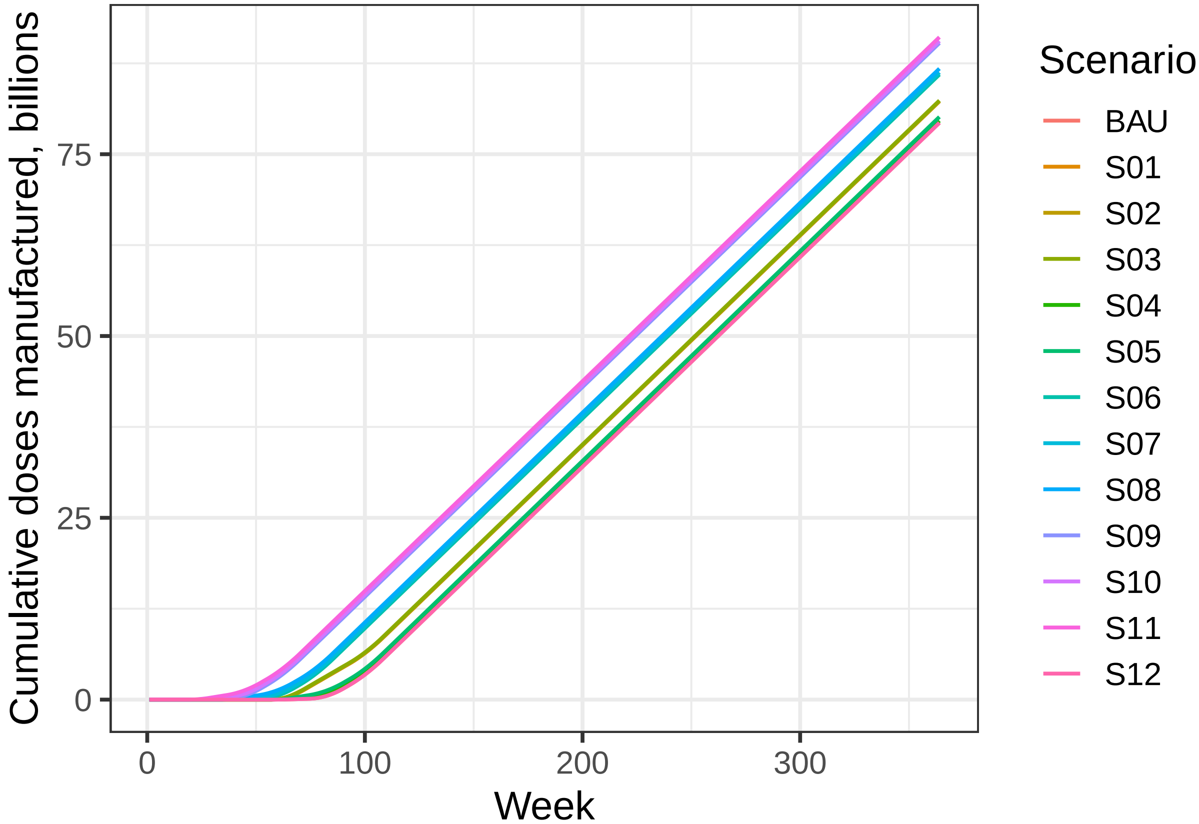
where $I_R = 12$ is the number of weeks to initial manufacturing for reserved capacity, $C_R = 10$ is the number of weeks to scale up to full capacity; $I_B = 48$ is the number of weeks to initial manufacturing for built and unreserved capacity, $C_B = 16$ is the number of weeks to scale up to full capacity, and

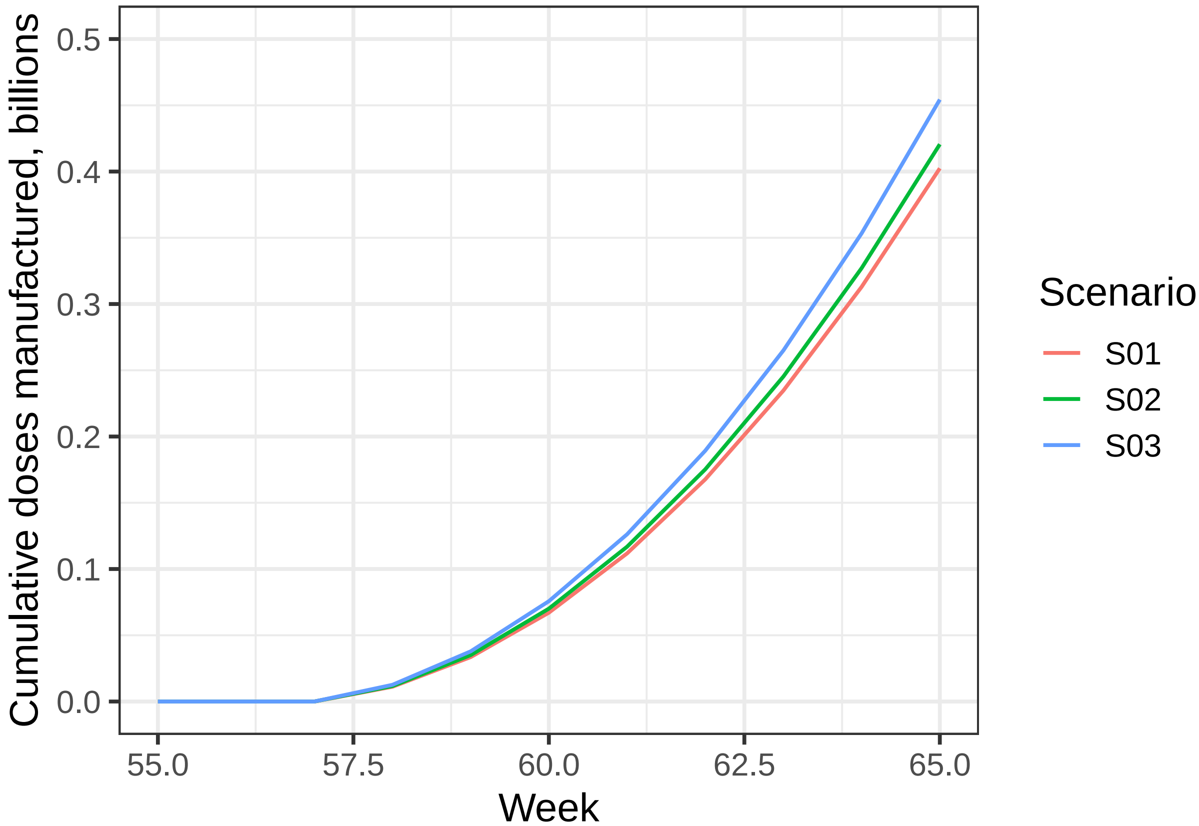
$$I_E = \begin{cases} I_{E,1} & s \in \{1, 2, 3\} \\ I_{E,0} & s \notin \{1, 2, 3\} \end{cases} \tag{17}$$

where $I_{E,0} = 30$ and $I_{E,1} = 12$ are the number of weeks to initial manufacturing for existing and unreserved capacity, $C_E = 16$ is the number of weeks to scale up to full capacity.

Then the total number of doses produced in week w is

$$Z_{T,s,w} = Z_{R,s,w} + Z_{E,s,w} + Z_{B,s,w}. \tag{18}$$





In Figure ??, the following scenarios have identical supply (because they have the same capacity reservations and R&D investments): BAU & S01 & S12; S02 & S04; and S03 & S05.

5.3 Allocation

Denote the weekly allocated doses at week w from capacity x to income level i $k_{s,x,i,w}$, and the cumulative number $K_{s,i,w}$, such that

$$K_{s,i,w} = \sum_{x\in\{R,E,B\}} \sum_{j=0}^{w} k_{s,x,i,j}.$$

We write

$$X_i = \frac{2 \cdot \lambda \cdot N_i^{(15)}}{1-\delta}$$

as the maximum demand for income group i, representing two doses each for $\lambda = 80\%$ of the population assuming vaccine wastage of $\delta = 0.3142532$.

$$k_{s,R,i,w} = \begin{cases} Z_{R,s,w} & K_{s,\text{HIC},w} < A_3 \ \& \ i = \text{HIC} \\ 0 & K_{s,\text{HIC},w} < A_3 \ \& \ i \neq \text{HIC} \\ \frac{N_i}{N_{HIC}+N_{UMIC}+N_{LLMIC}} Z_{R,s,w} & A_3 < K_{s,\text{HIC},w} < X_{\text{HIC}} \\ \frac{N_i}{N_{UMIC}+N_{LLMIC}} Z_{R,s,w} & K_{s,\text{HIC},w} \geq X_{\text{HIC}} \ \& \ K_{s,\text{UMIC},w} < X_{\text{HIC}} \ \& \ i \neq \text{HIC} \\ Z_{R,s,w} & K_{s,\text{UMIC},w} \geq X_{\text{UMIC}} \ \& \ i = \text{LLMIC} \end{cases} \tag{19}$$

The logic of this reads as follows:

- The first $A_3 = 0.5$ billion doses from reserved capacity go exclusively to HIC
- None go to UMIC and LLMIC
- When HIC coverage is between 500 million and its total demand, reserved capacity doses are allocated according to population
- Once HIC reach their total demand, doses from reserved capacity are split proportional to population between UMIC and LLMIC
- Once UMIC reach their total demand, all doses from reserved capacity go to LLMIC

For $x \in \{E, B\}$,

$$k_{s,x,i,w} = \begin{cases} Z_{x,s,w} & K_{s,\mathrm{HIC},w} < X_{\mathrm{HIC}} \;\&\; i = \mathrm{HIC} \\ 0 & K_{s,\mathrm{HIC},w} < X_{\mathrm{HIC}} \;\&\; i \neq \mathrm{HIC} \\ Z_{x,s,w} & K_{s,\mathrm{HIC},w} \geq X_{\mathrm{HIC}} \;\&\; K_{s,\mathrm{UMIC},w} < X_{\mathrm{UMIC}} \;\&\; i = \mathrm{UMIC} \\ 0 & K_{s,\mathrm{HIC},w} \geq X_{\mathrm{HIC}} \;\&\; K_{s,\mathrm{UMIC},w} < X_{\mathrm{UMIC}} \;\&\; i \neq \mathrm{UMIC} \\ Z_{x,s,w} & K_{s,\mathrm{UMIC},w} \geq X_{\mathrm{UMIC}} \;\&\; i = \mathrm{LLMIC} \\ 0 & K_{s,\mathrm{UMIC},w} \geq X_{\mathrm{UMIC}} \;\&\; i \neq \mathrm{LLMIC} \end{cases} \tag{20}$$

The logic of this reads as follows:

- Until HIC demand is reached, all doses from unreserved capacity go to HIC
- None go to UMIC and LLMIC
- Once HIC demand has been met and until UMIC demand is reached, all doses from unreserved capacity go to UMIC
- None go to HIC and LLMIC
- Once HIC and UMIC demand have been met, all remaining doses from unreserved capacity go to LLMIC
- None go to UMIC and HIC

5.4 Delivery

These values do not look correct

6 BPSV delivery

6.1 Timing

The duration of the Phase III trial is $W_3^{(B)} = 18$ weeks. The time to manufacturing transition is $I_R = 12$ weeks, and the time to manufacturing scale-up $C_R = 10$ weeks; these are the same as the reserved-capacity times for SSV.

Facility transition occurs in week 1. Thus manufacturing begins in week $1 + I_R = 13$ and dose distribution begins in week $1 + W_3^{(B)} = 19$.

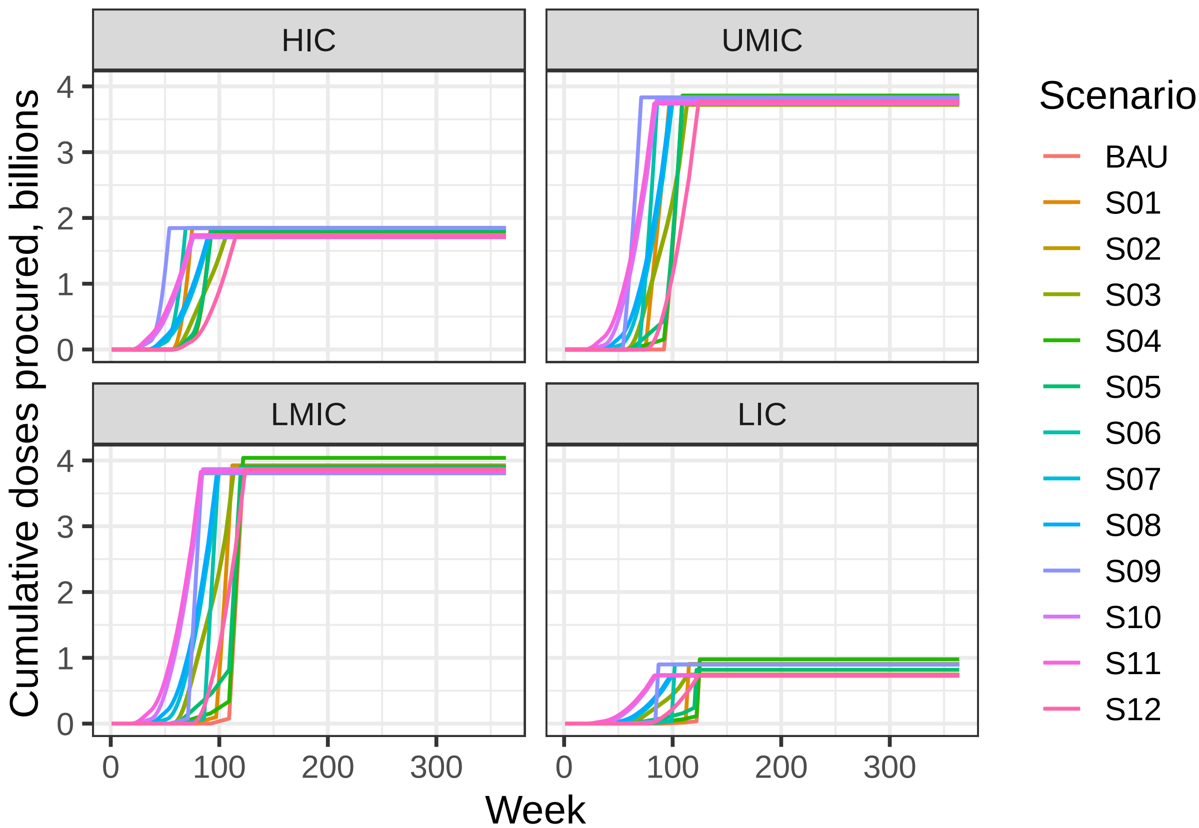


Figure 1: Doses procured by country income level

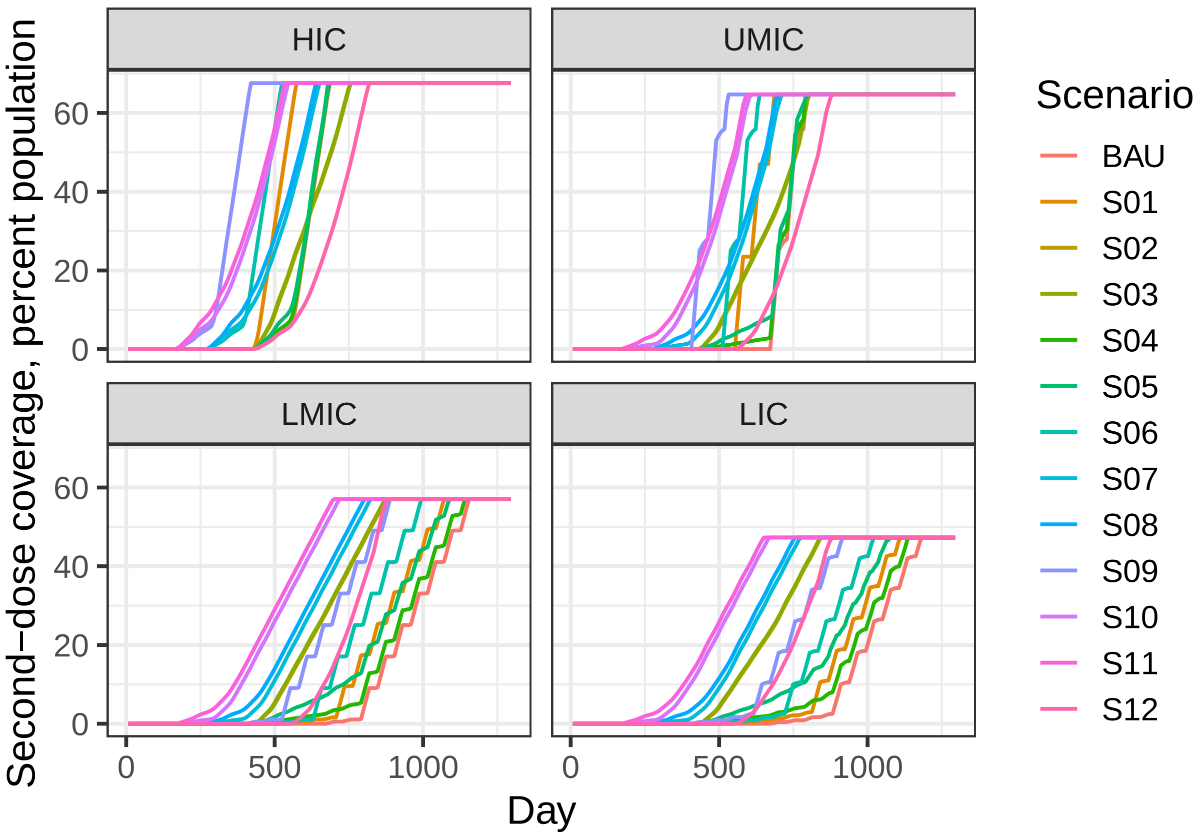


Figure 2: Cumulative vaccine coverage (second SSV dose) by country income level

6.2 Production

The number of doses, in billions, that are made in week w is:

$$Z_w = \begin{cases} 0 & w < I_R \\ \frac{1}{52}\frac{w-I_x+1}{C_x}M_{x,s} & w \in [I_R, I_R + C_R) \\ \frac{1}{52}M_{x,s} & w - 1 \geq I_R + C_xR \end{cases} \tag{21}$$

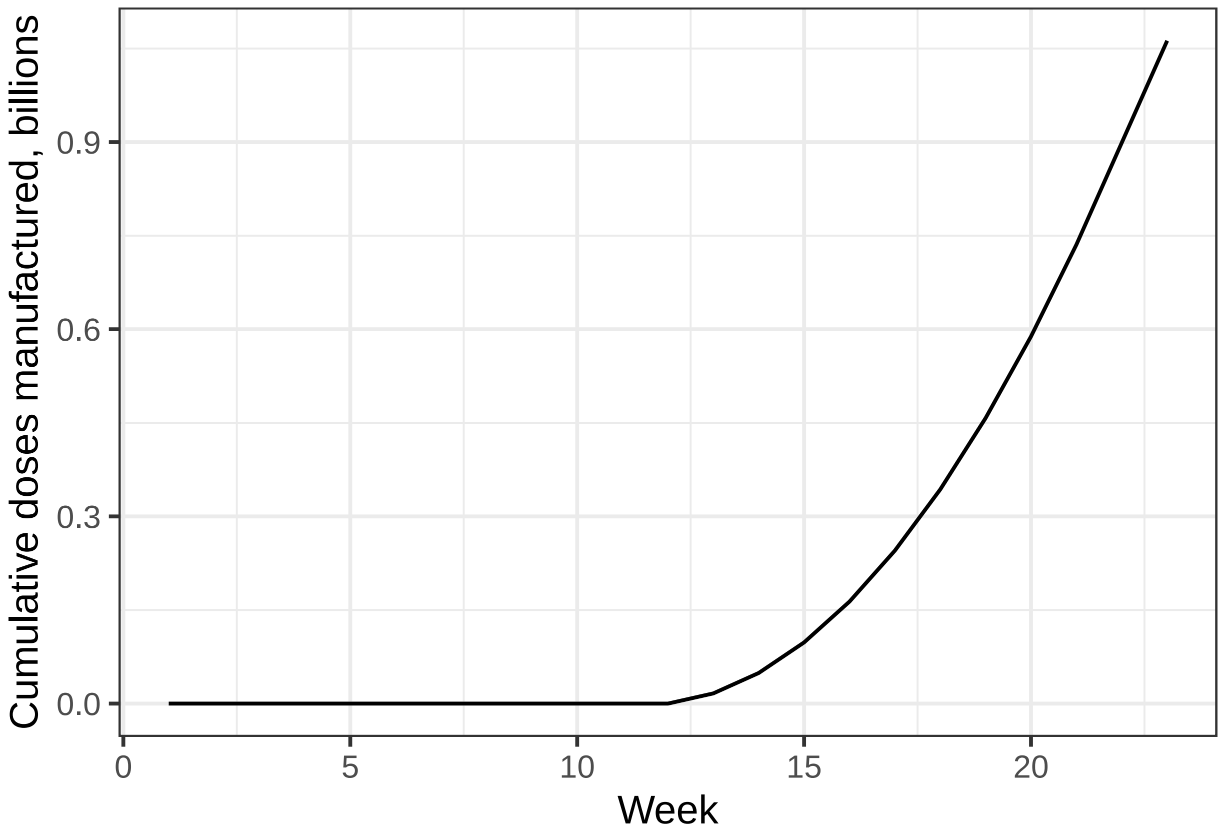


Figure 3: BPSV doses made available from manufacturing per scenario. Weeks are in reference to the sequencing of the pathogen.

6.3 Allocation

Doses are all allocated in proportion to the eligible population.

6.4 Delivery

These values do not look correct

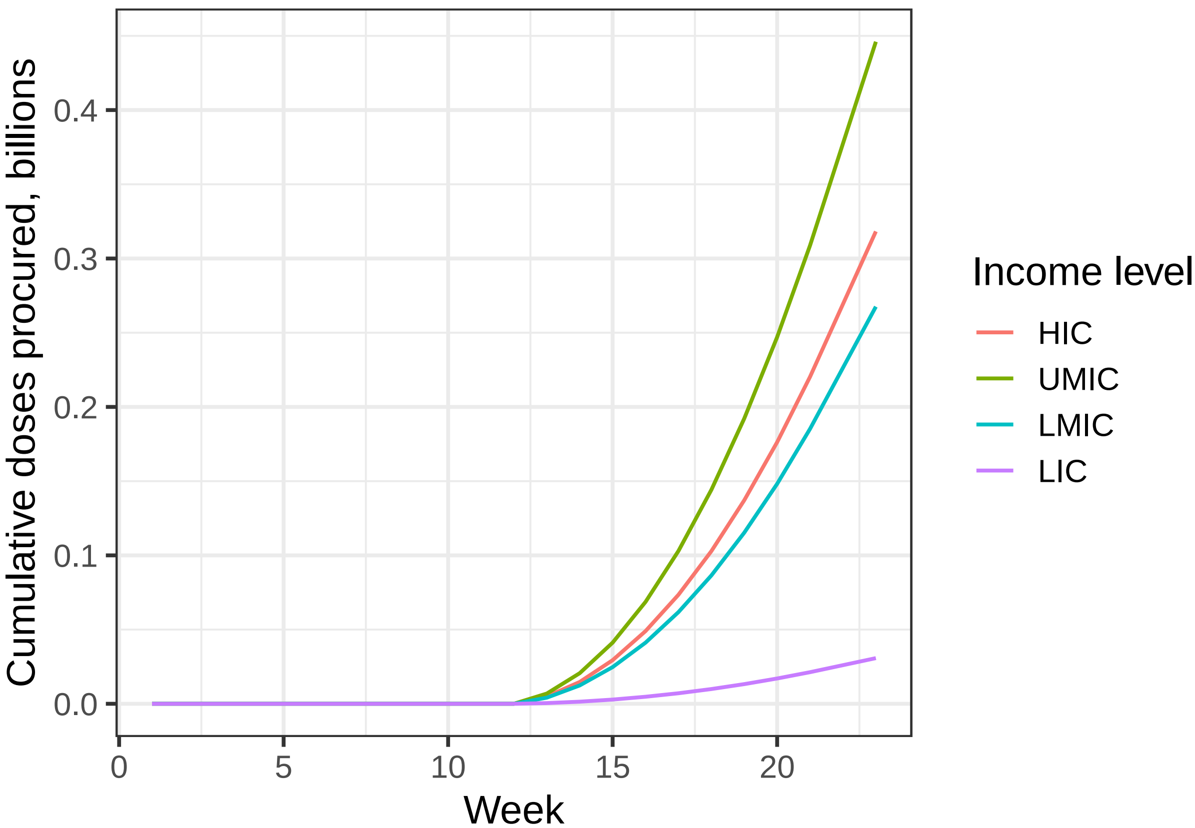


Figure 4: BPSV doses procured by country income level

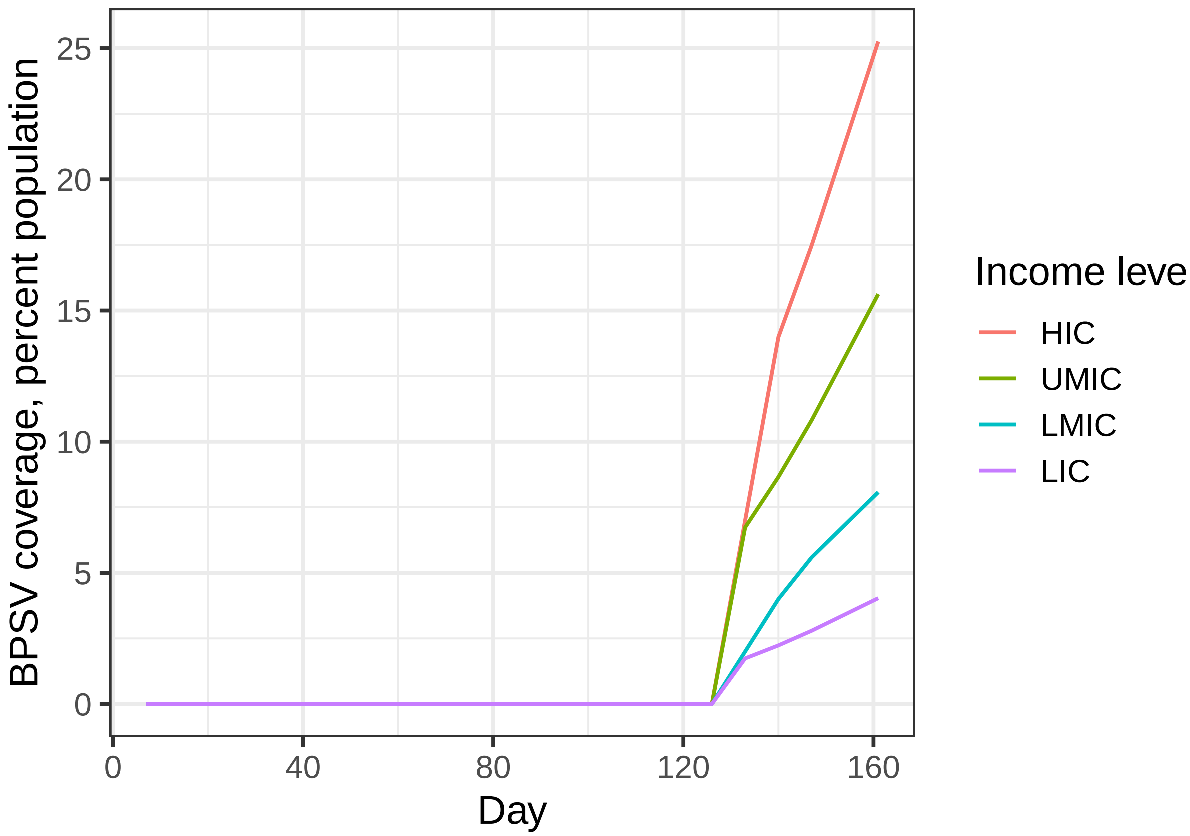
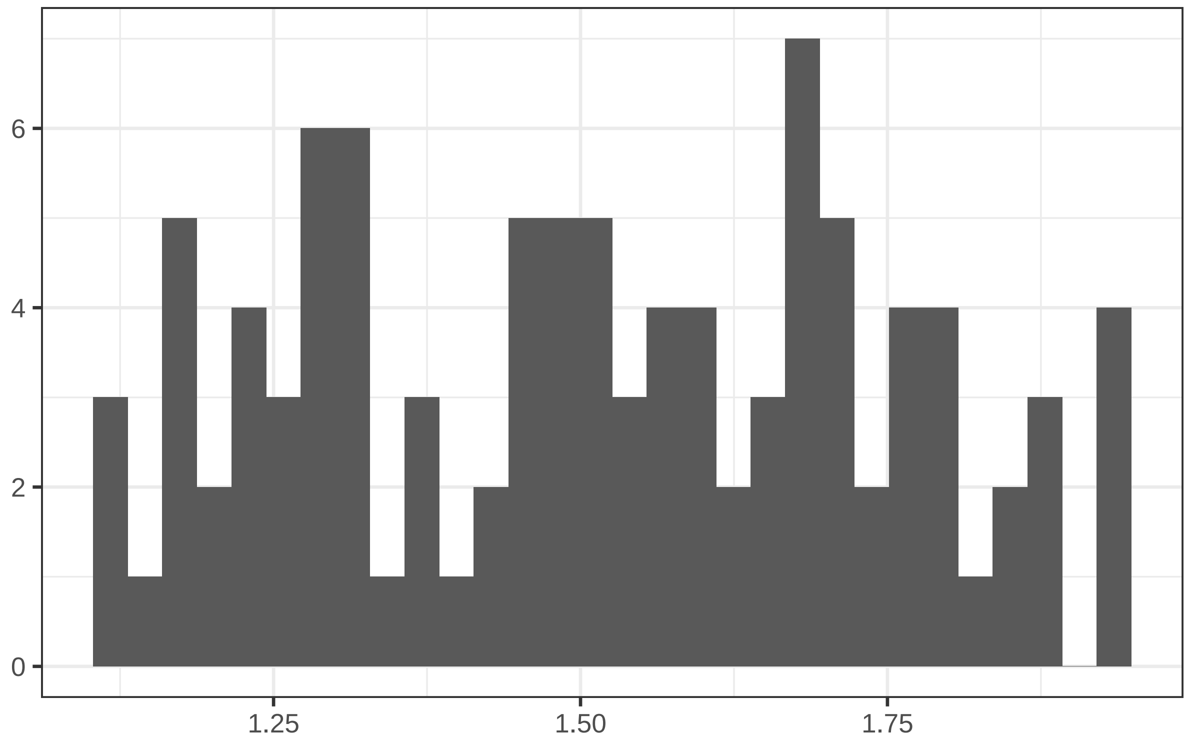


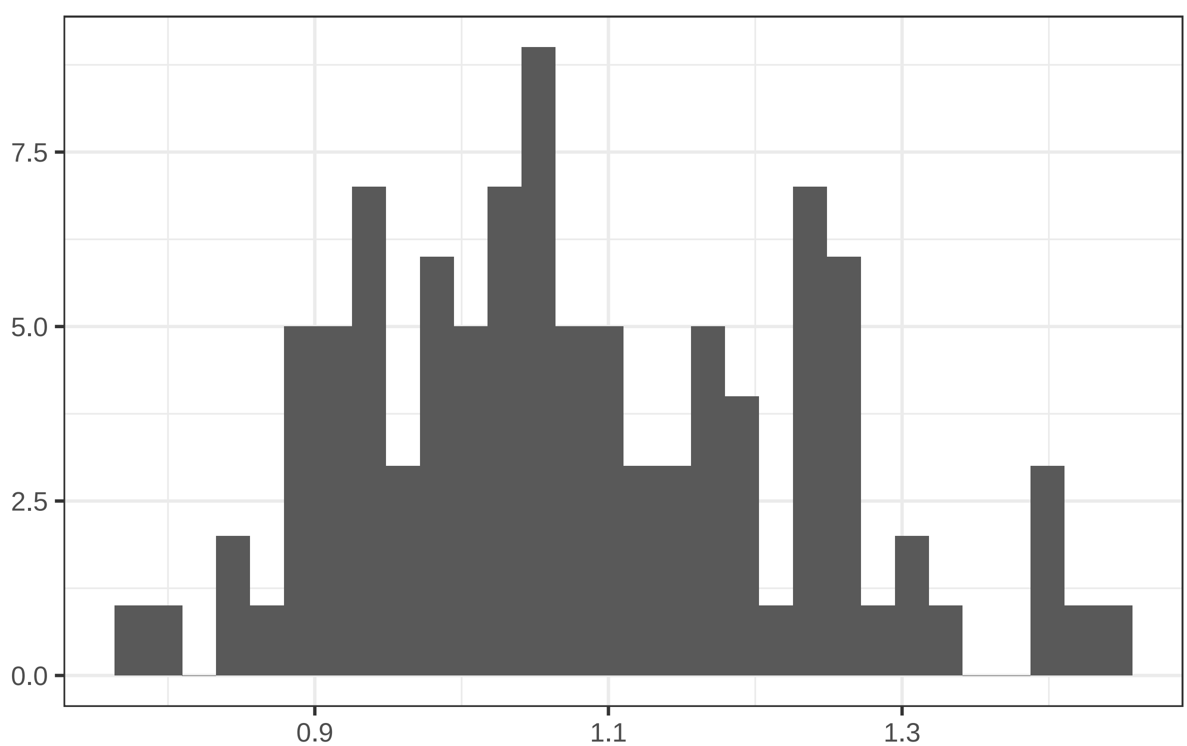
Figure 5: BPSV vaccine coverage by country income level

7 Parameter samples

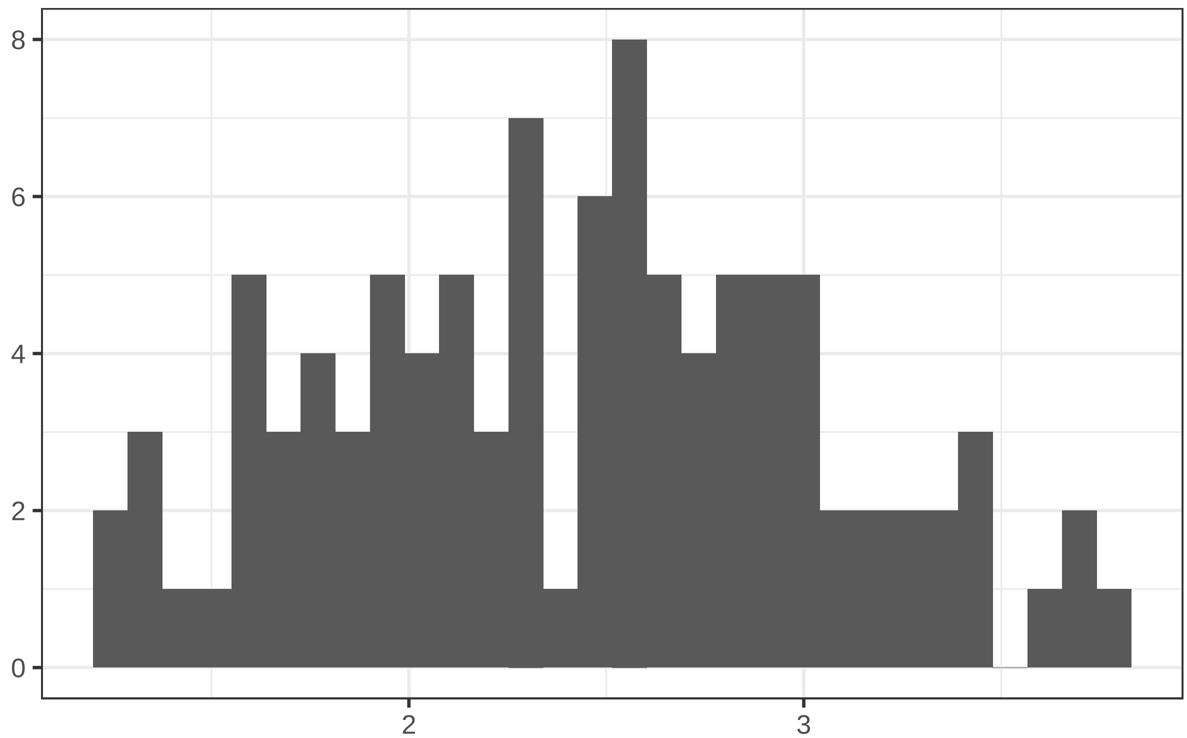
Cost of vaccine delivery at start up (0−10\%) in LIC; USD per



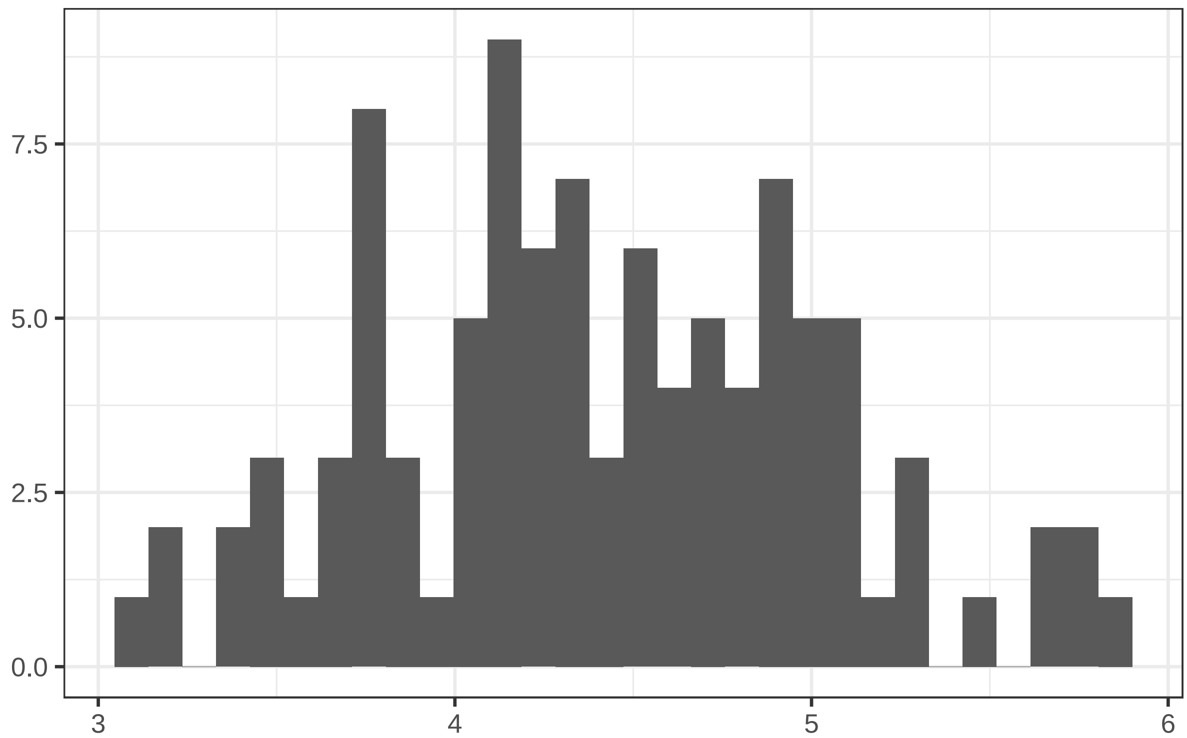
Cost of vaccine delivery during ramp up (11−30\%) in LIC; U

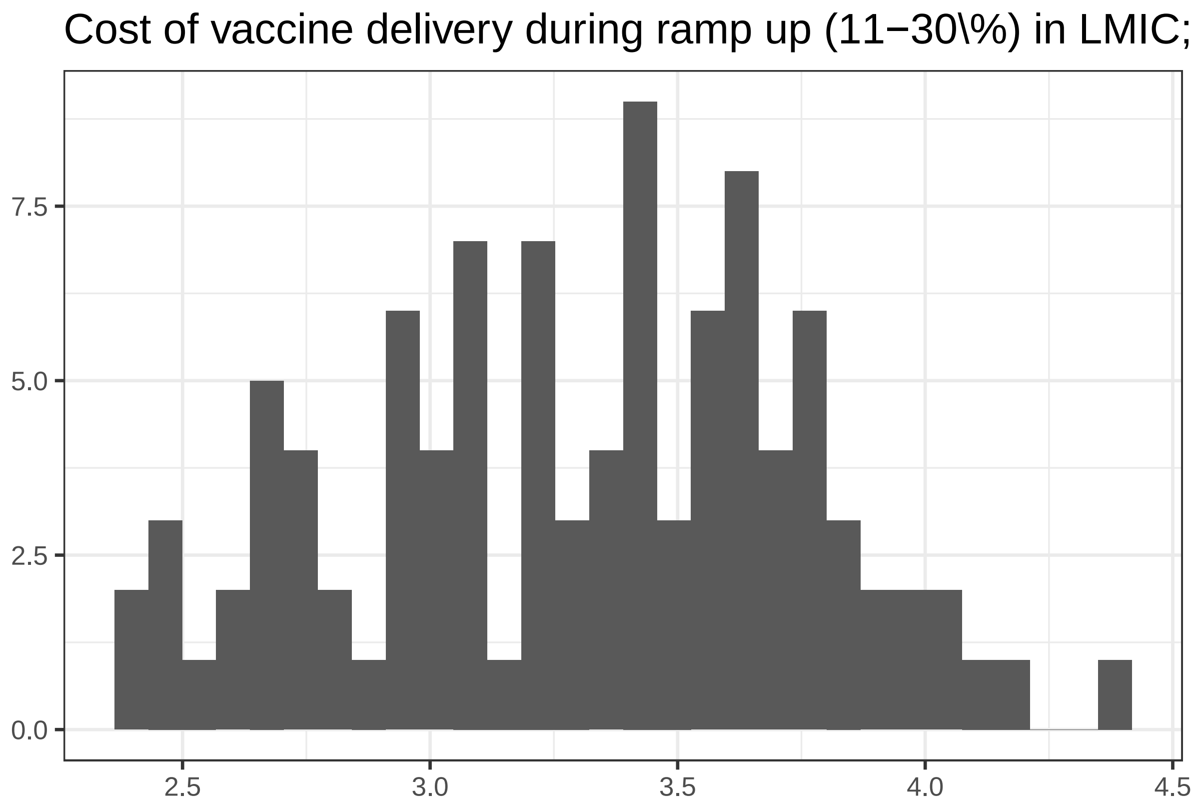


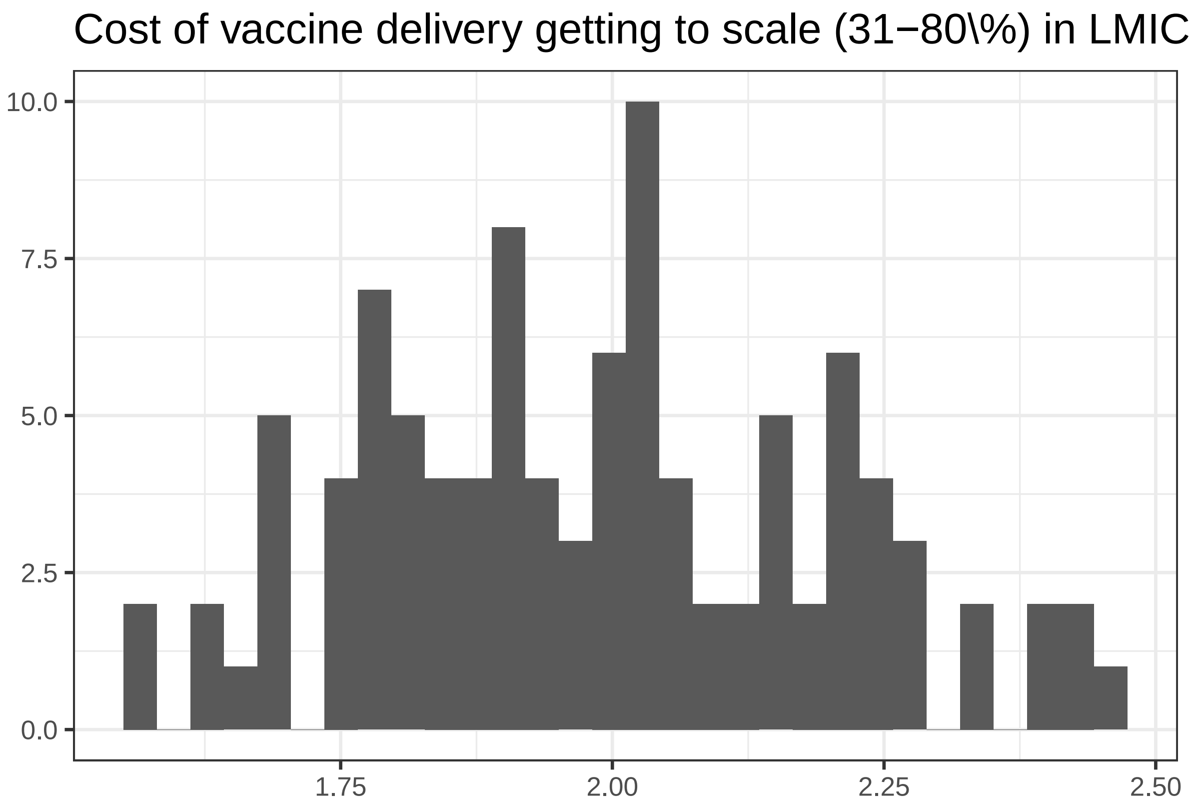
Cost of vaccine delivery getting to scale (31−80\%) in LIC; US



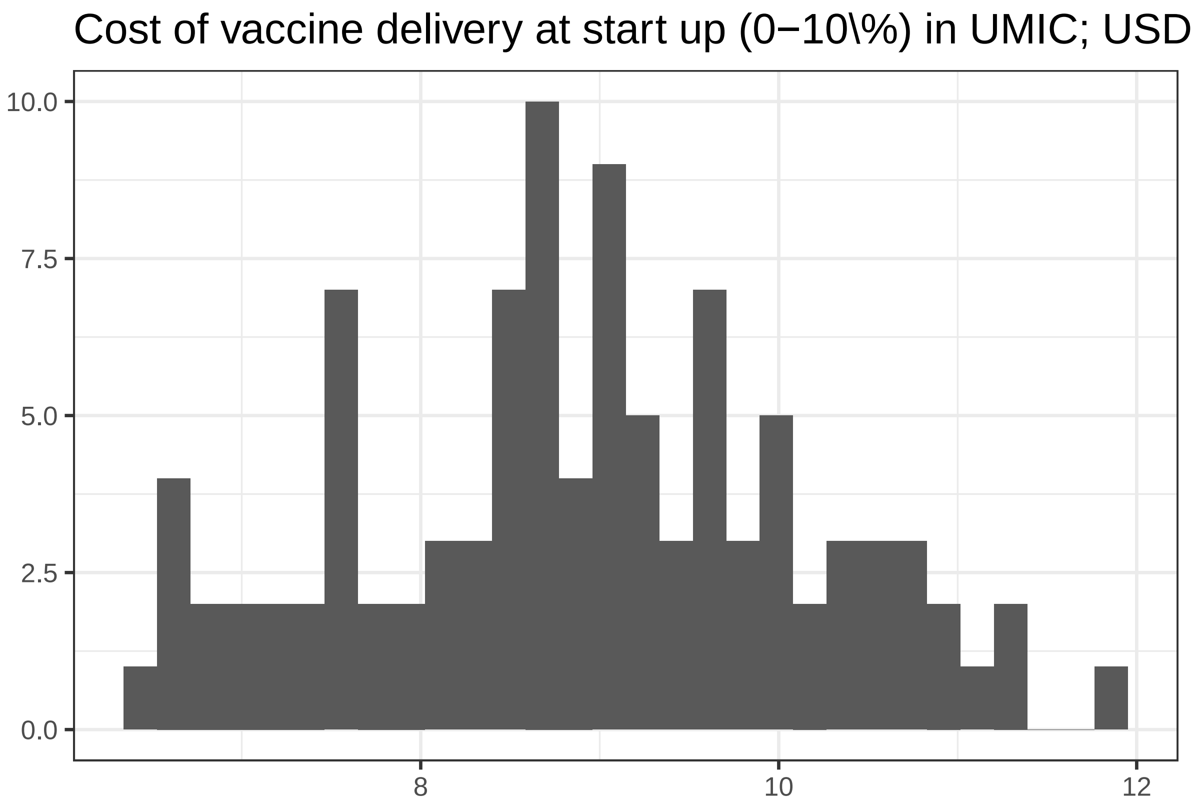
Cost of vaccine delivery at start up (0−10\%) in LMIC; USD p



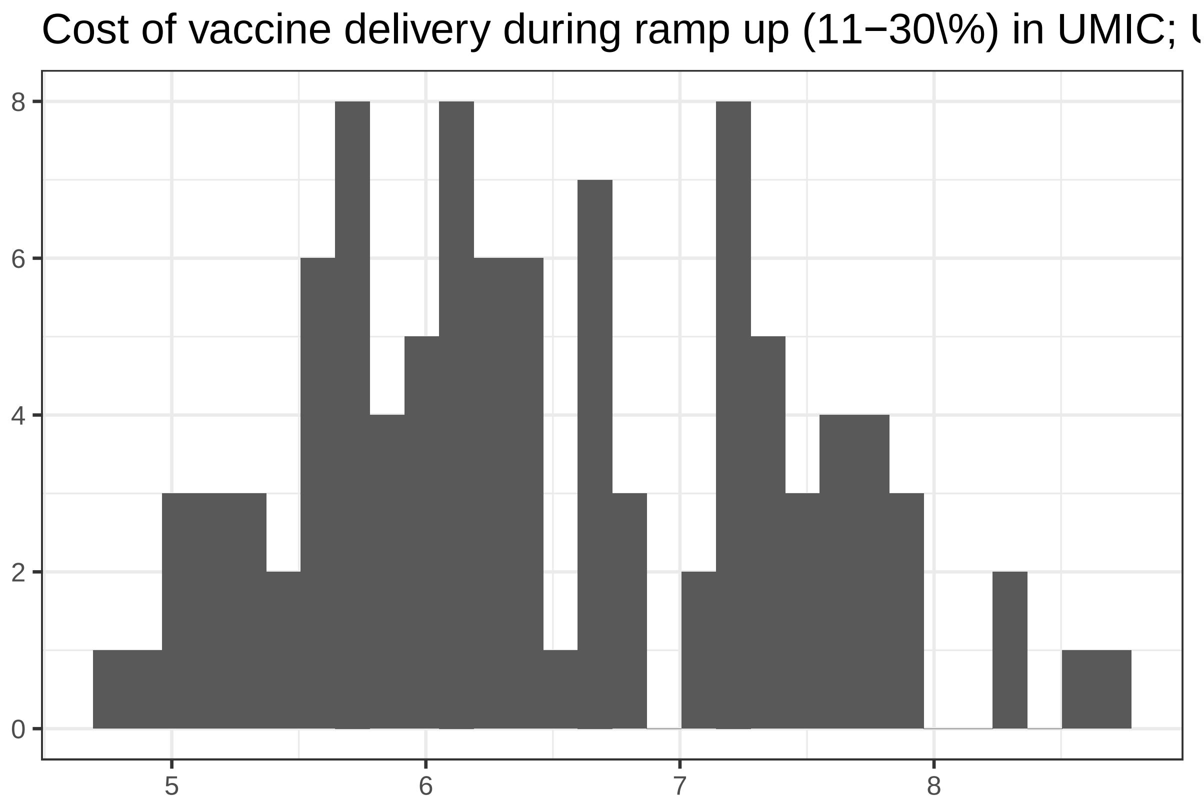

Cost of vaccine delivery during ramp up (11−30\%) in LMIC;
7.5
5.0
2.5
0.0
2.5
3.0
3.5
4.0
4.5



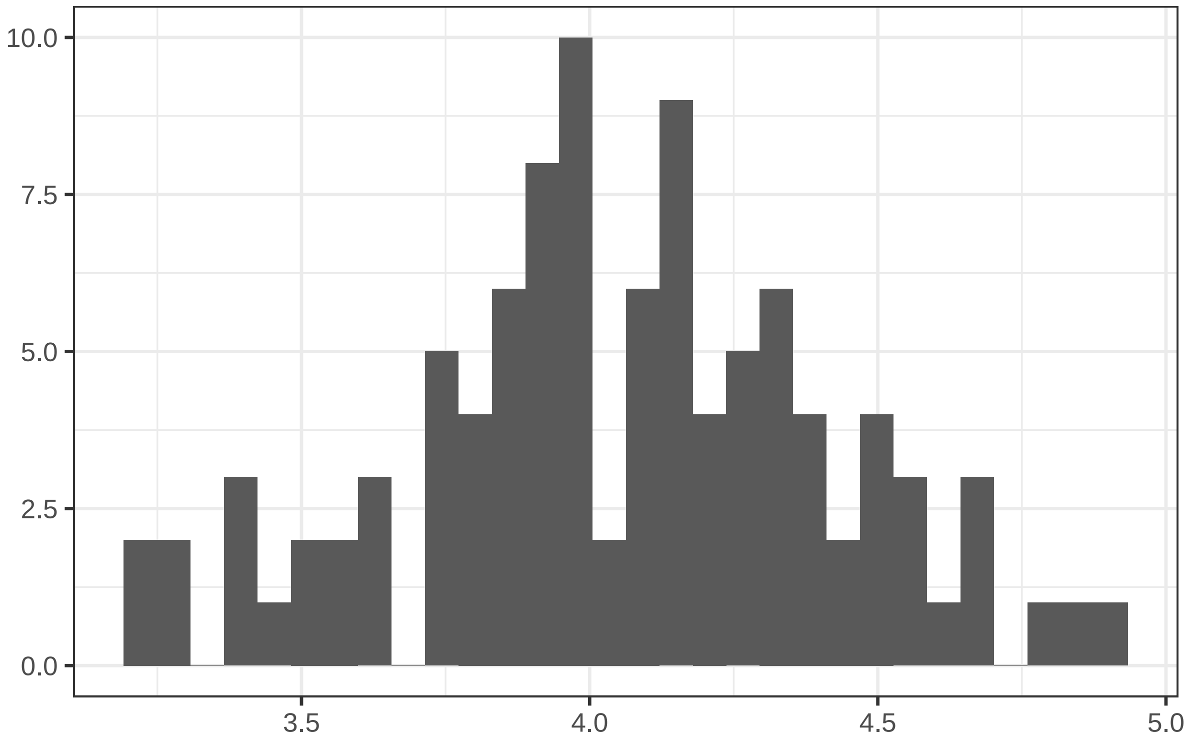
Cost of vaccine delivery getting to scale (31−80\%) in LMICs
10.0
7.5
5.0
2.5
0.0
1.75
2.00
2.25
2.50

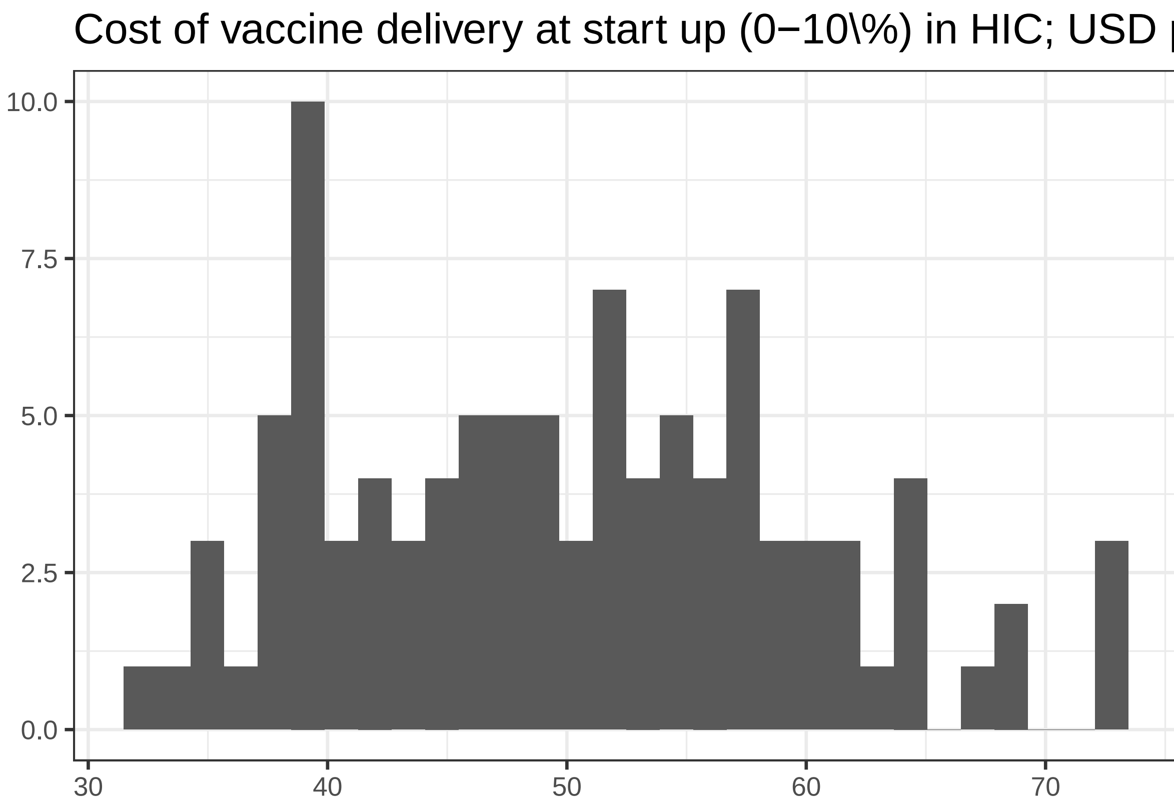


Cost of vaccine delivery at start up (0−10\%) in UMIC; USD
10.0
7.5
5.0
2.5
0.0
8
10
12

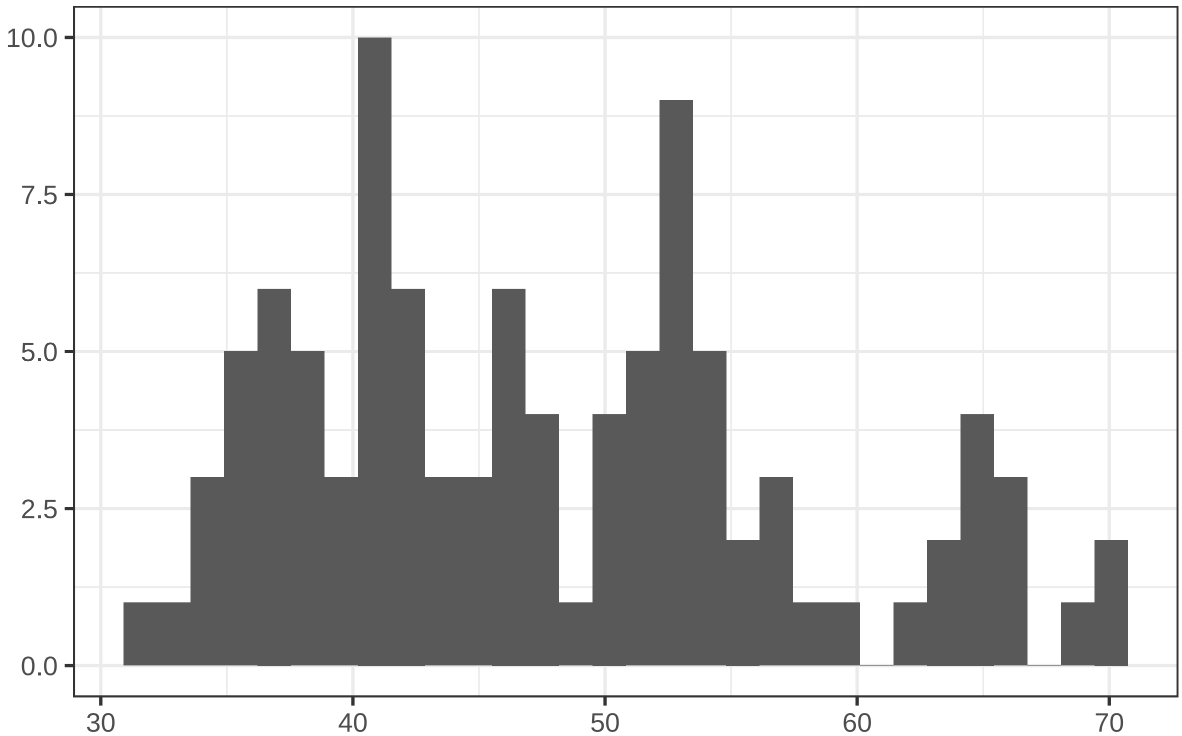

Cost of vaccine delivery during ramp up (11−30\%) in UMIC; U
8
6
4
2
0
5
6
7
8

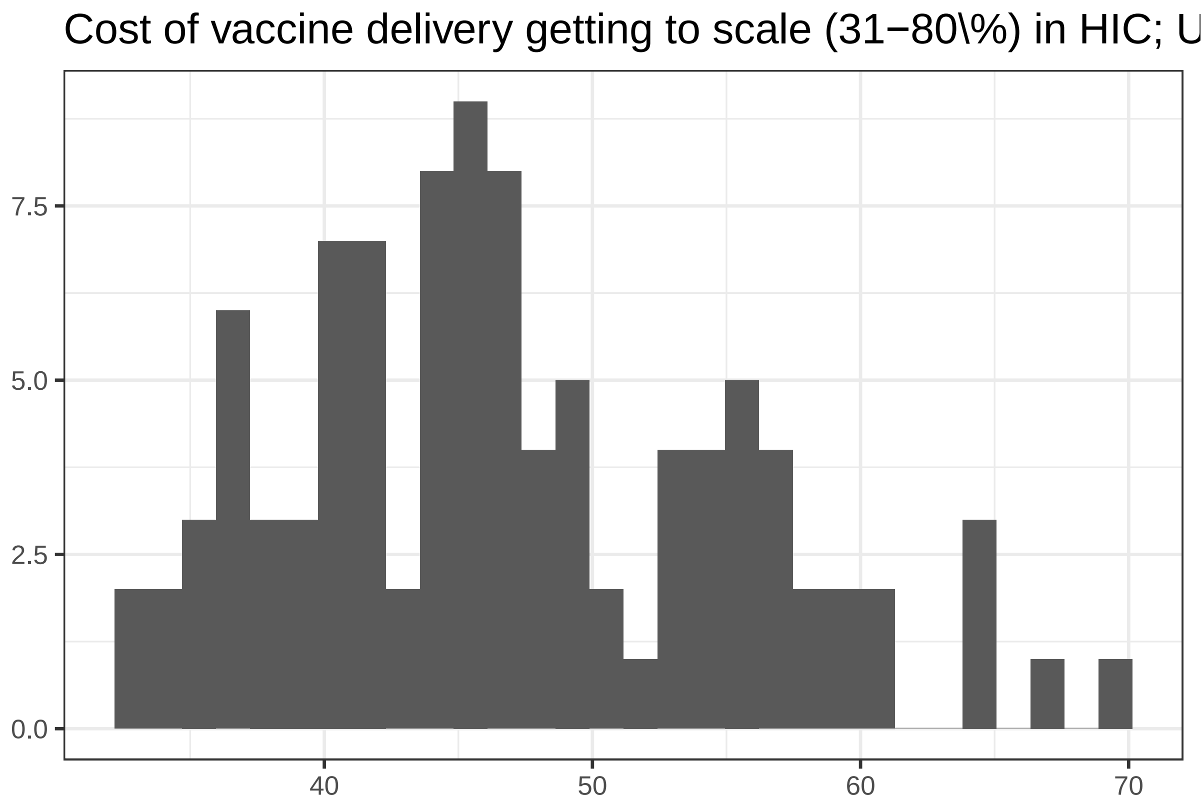
Cost of vaccine delivery getting to scale (31−80\%) in UMIC

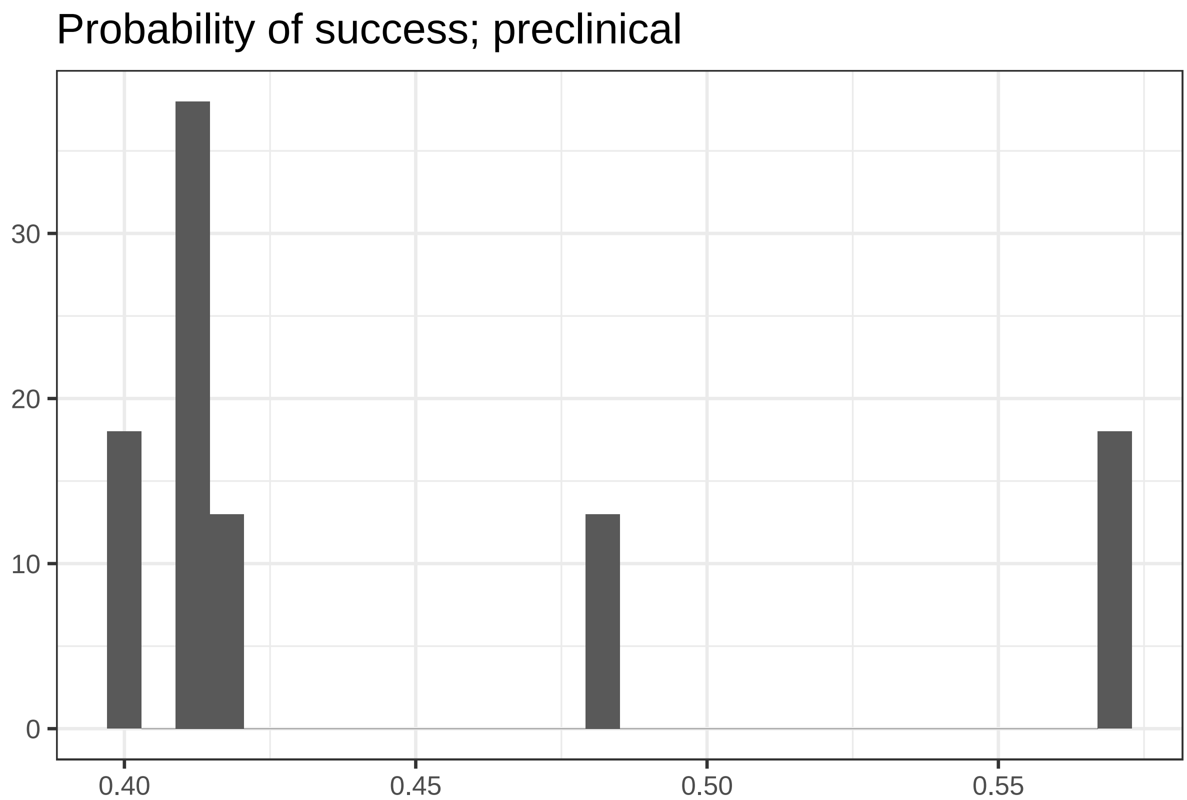


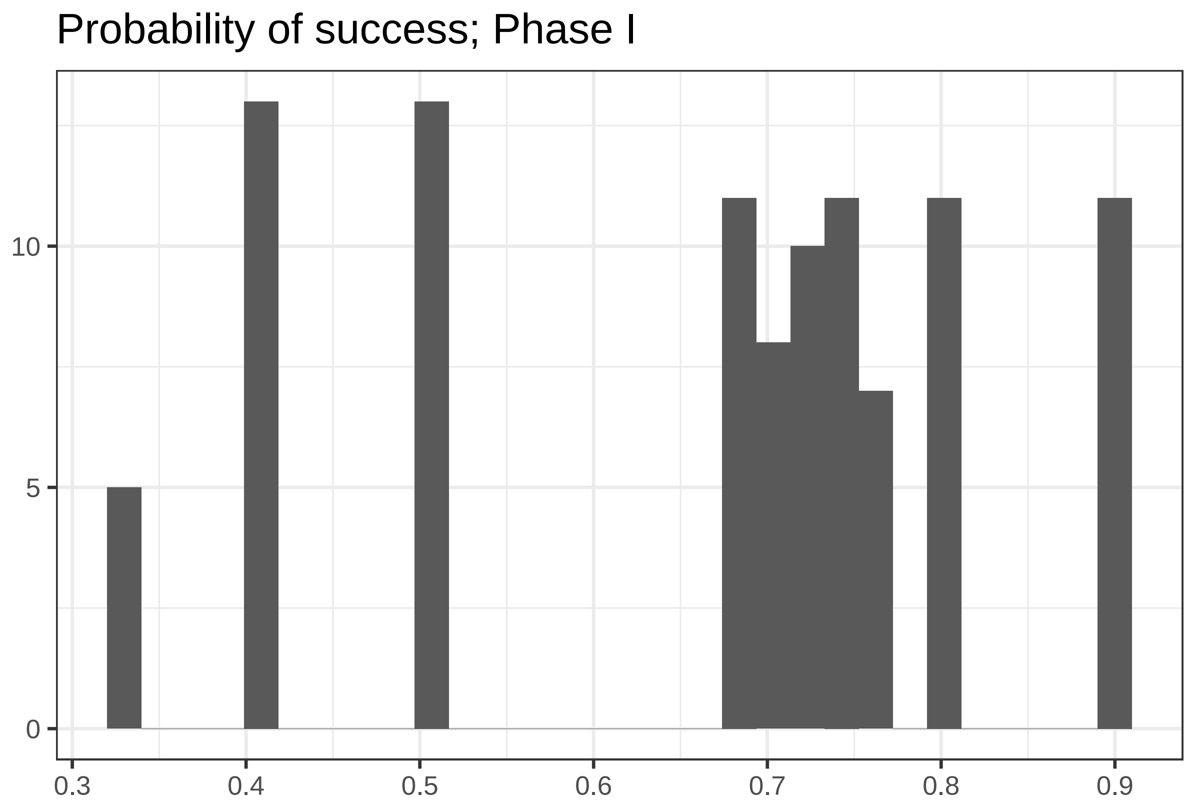

Cost of vaccine delivery at start up (0−10\%) in HIC; USD p
10.0
7.5
5.0
2.5
0.0
30
40
50
60
70

Cost of vaccine delivery during ramp up (11−30\%) in HIC; U

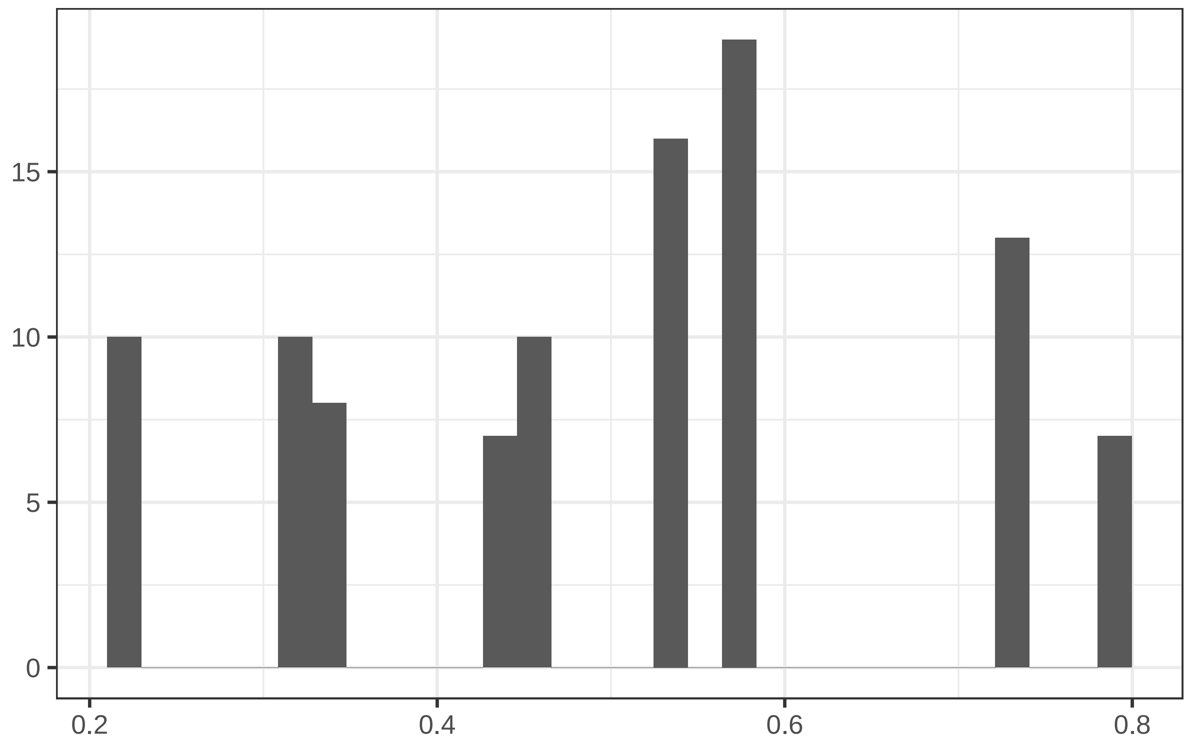


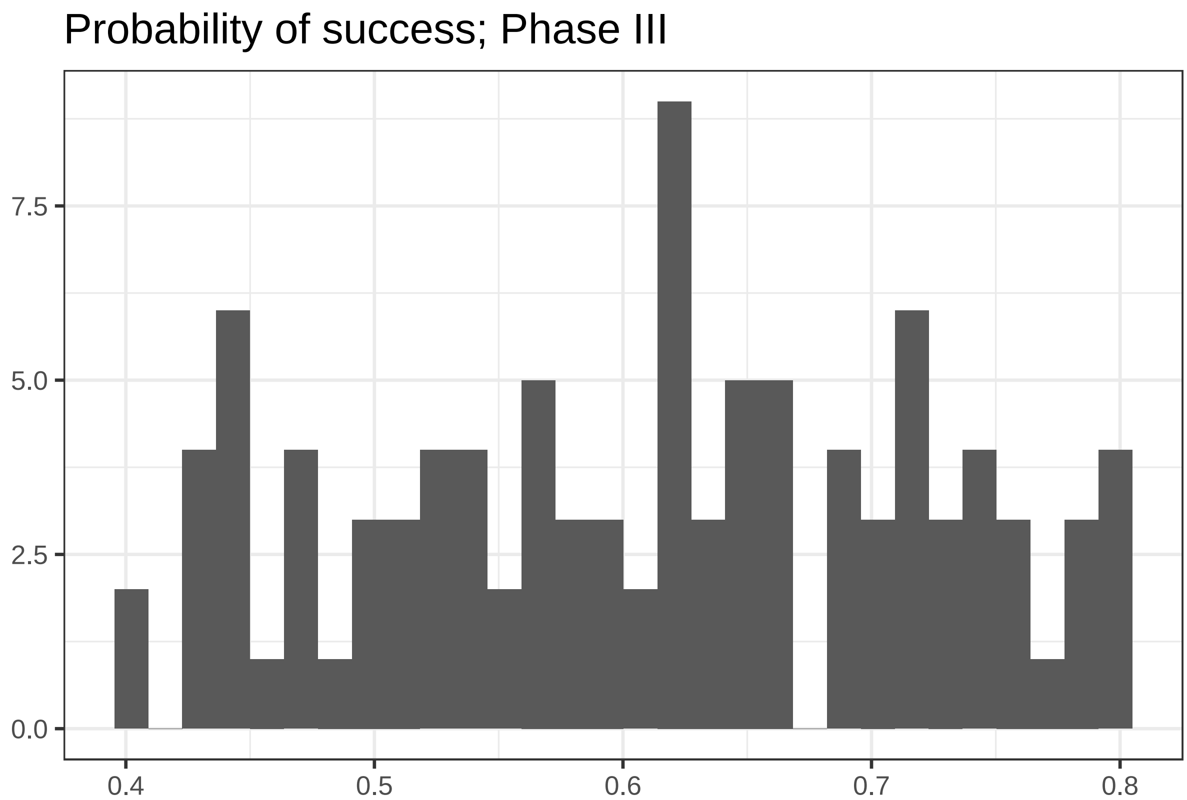

Cost of vaccine delivery getting to scale (31−80\%) in HIC; U
7.5
5.0
2.5
0.0
40
50
60
70


Probability of success; preclinical
30
20
10
0
0.40
0.45
0.50
0.55

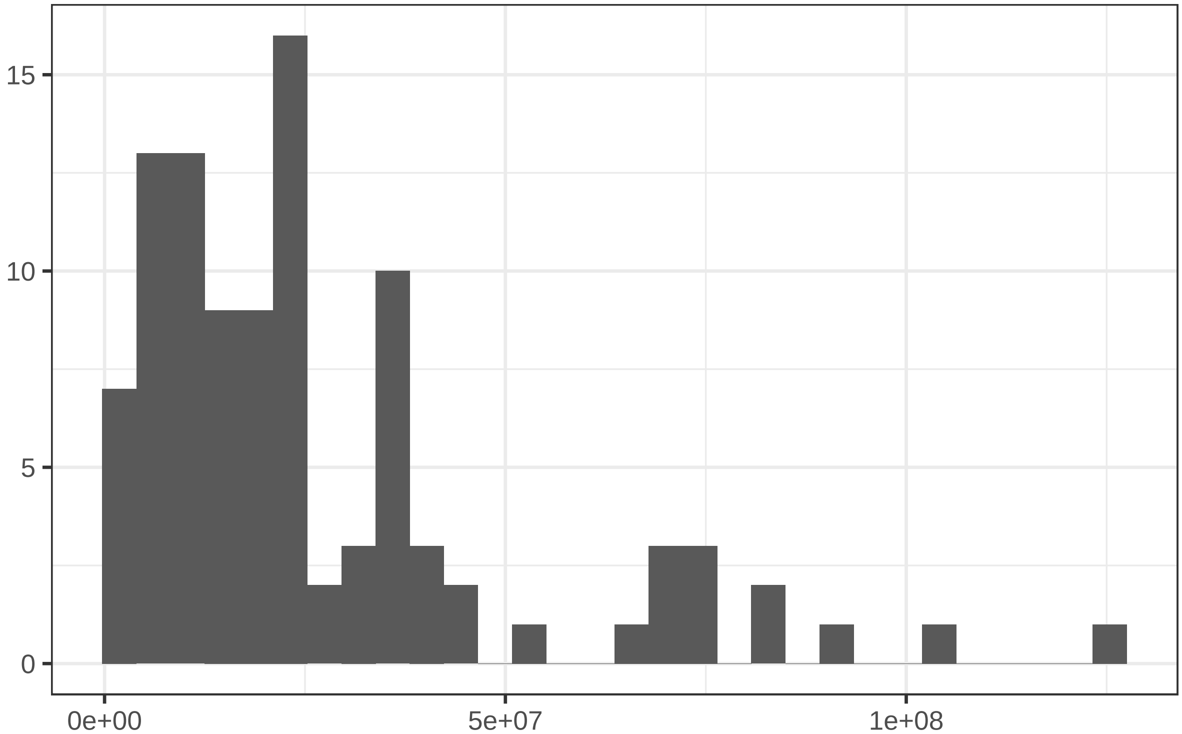

Probability of success; Phase I
10
5
0
0.3
0.4
0.5
0.6
0.7
0.8
0.9

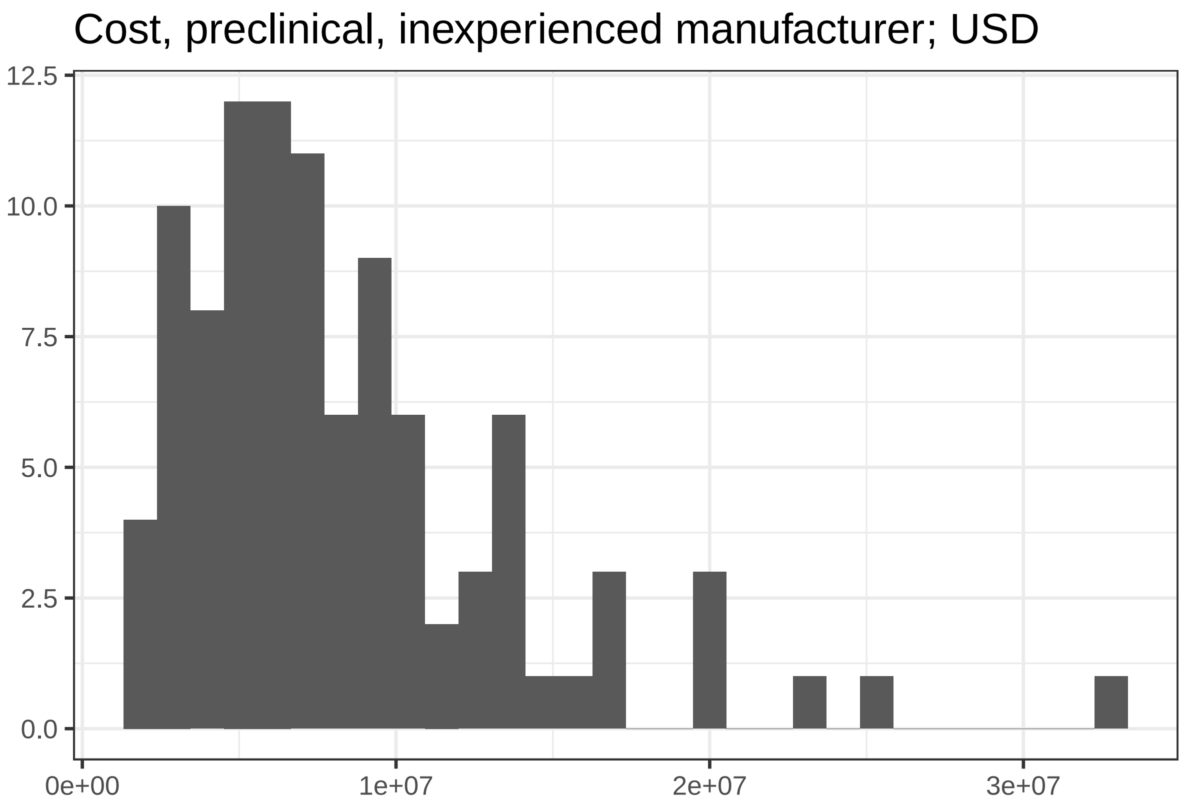
Probability of success; Phase II



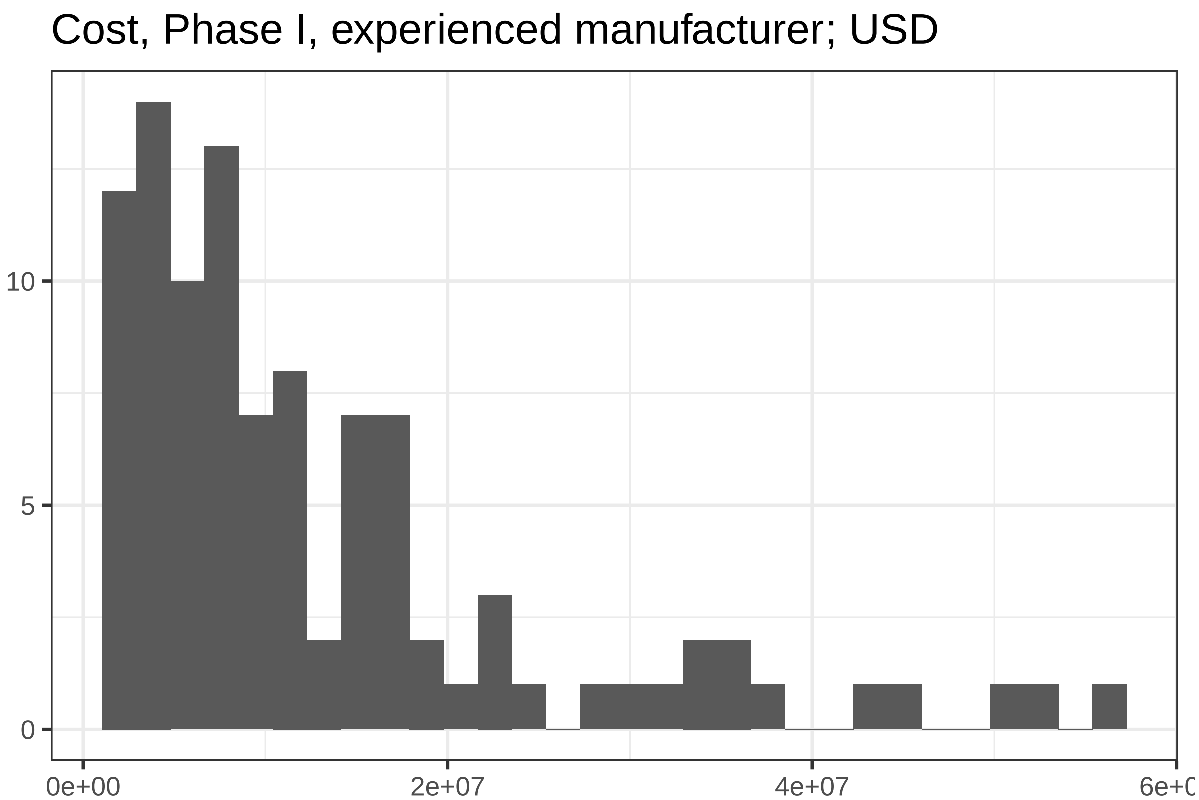

Probability of success; Phase III
7.5
5.0
2.5
0.0
0.4
0.5
0.6
0.7
0.8

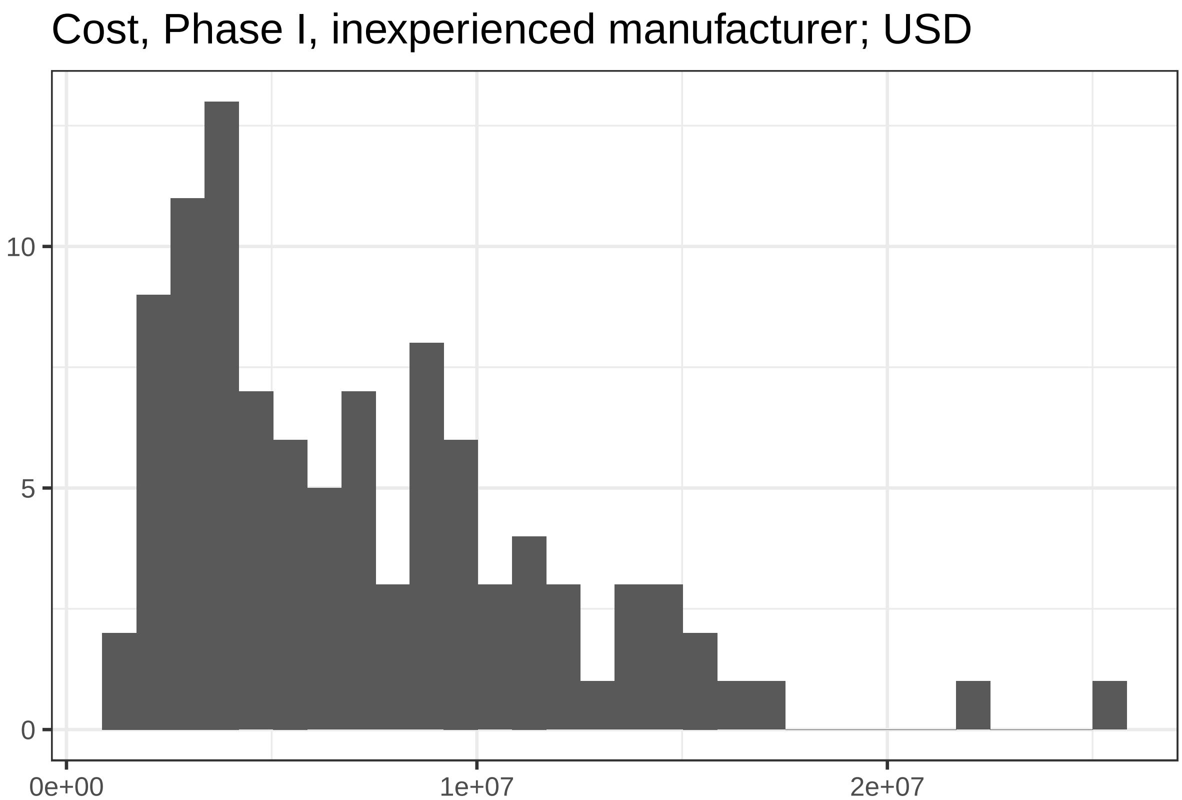
Cost, preclinical, experienced manufacturer; USD

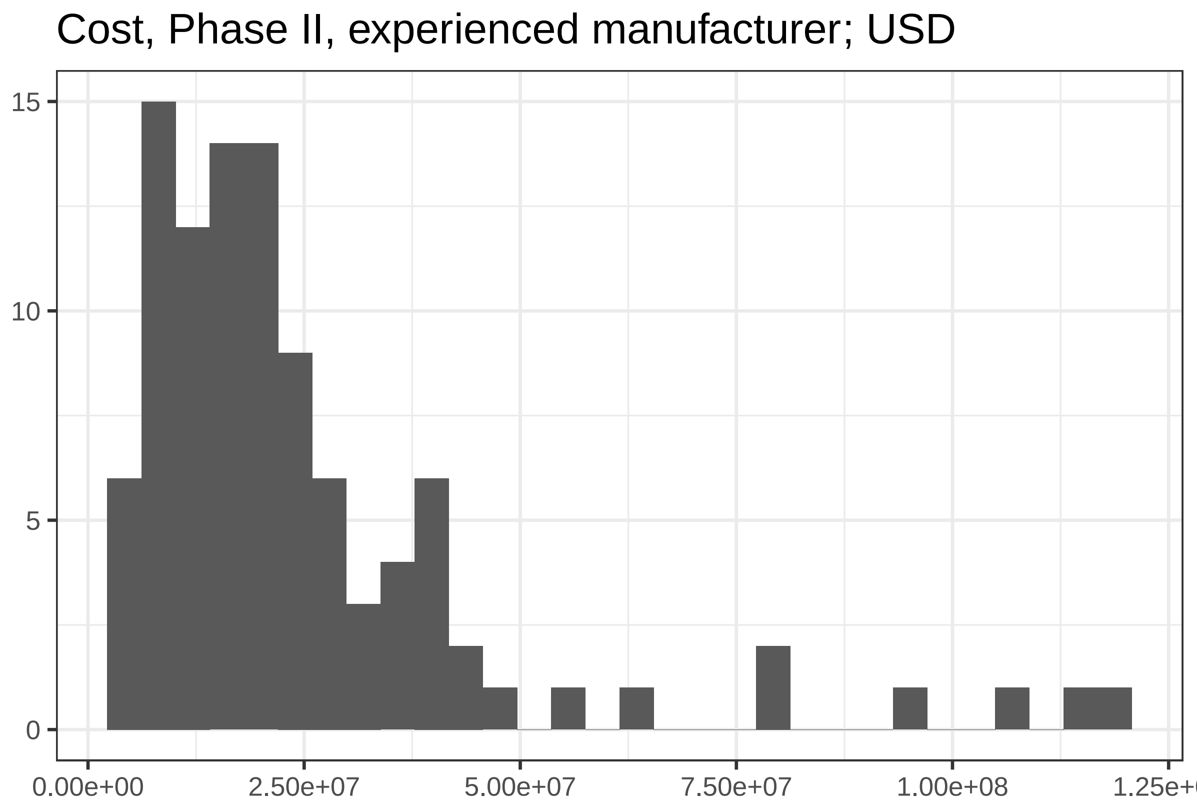




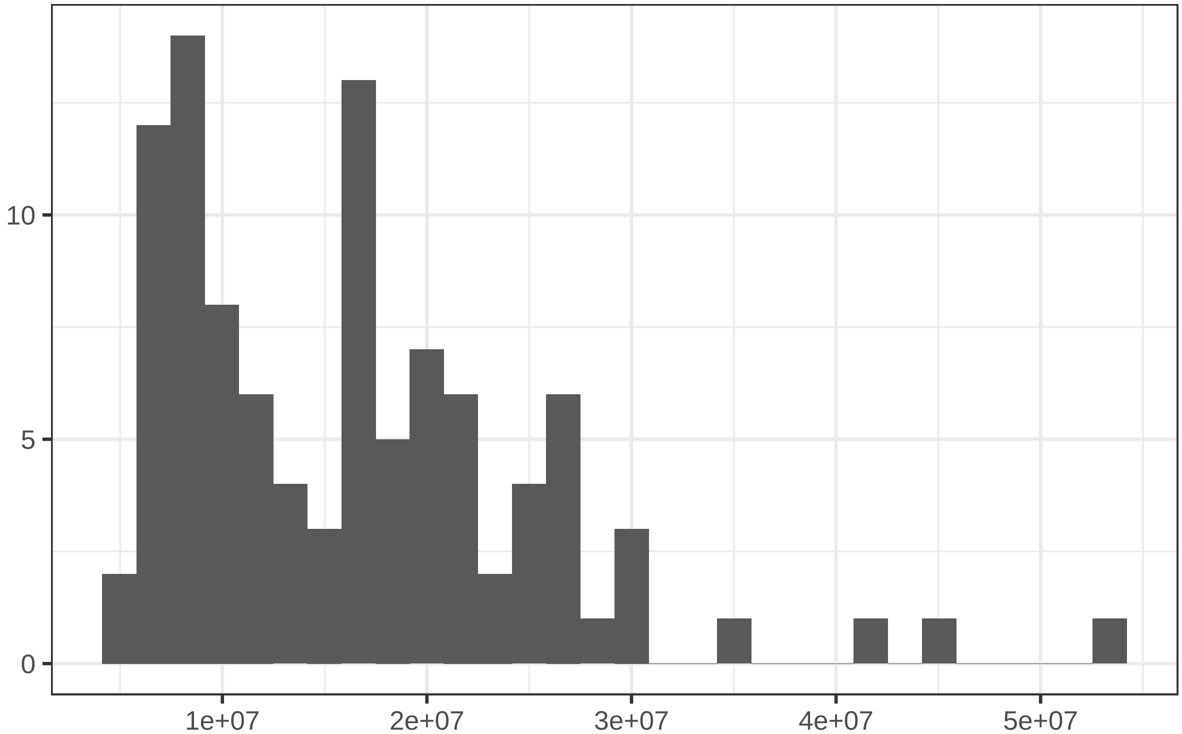
Cost, preclinical, inexperienced manufacturer; USD
12.5
10.0
7.5
5.0
2.5
0.0
0e+00
1e+07
2e+07
3e+07


Cost, Phase I, experienced manufacturer; USD
10
5
0
0e+00
2e+07
4e+07


Cost, Phase I, inexperienced manufacturer; USD
10
5
0
0e+00
1e+07
2e+07

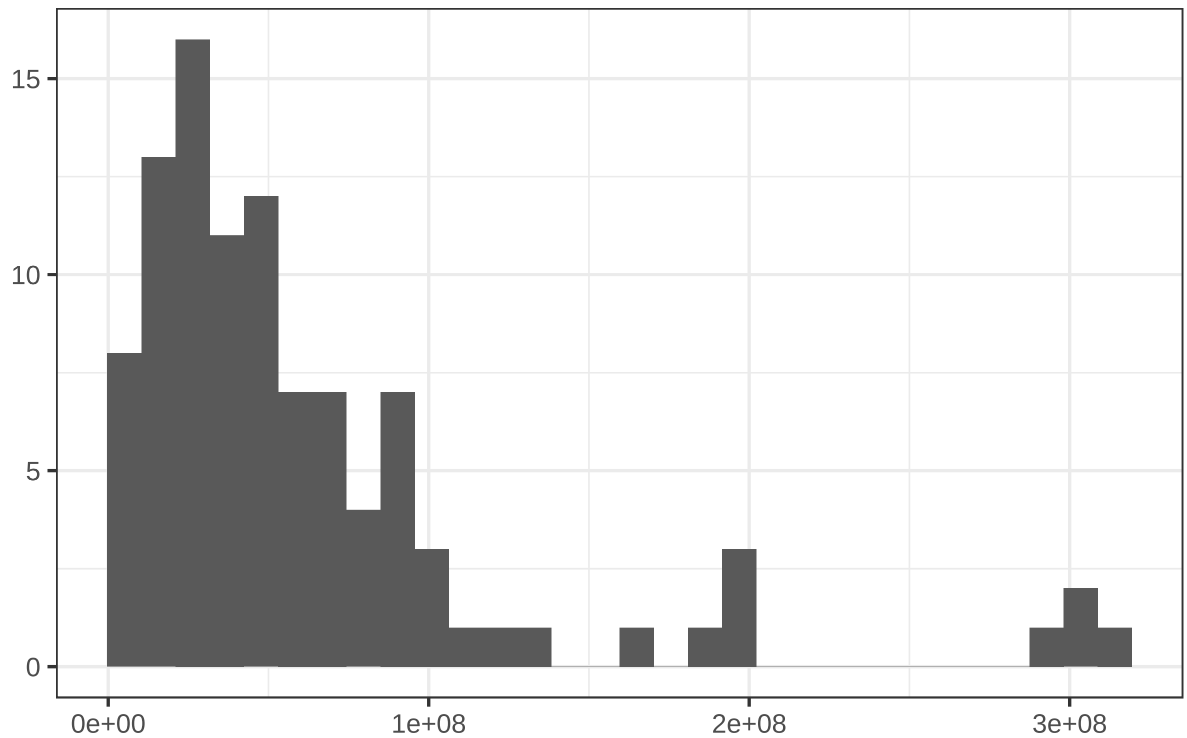

Cost, Phase II, experienced manufacturer; USD
15
10
5
0
0.00e+00
2.50e+07
5.00e+07
7.50e+07
1.00e+08

Cost, Phase II, inexperienced manufacturer; USD

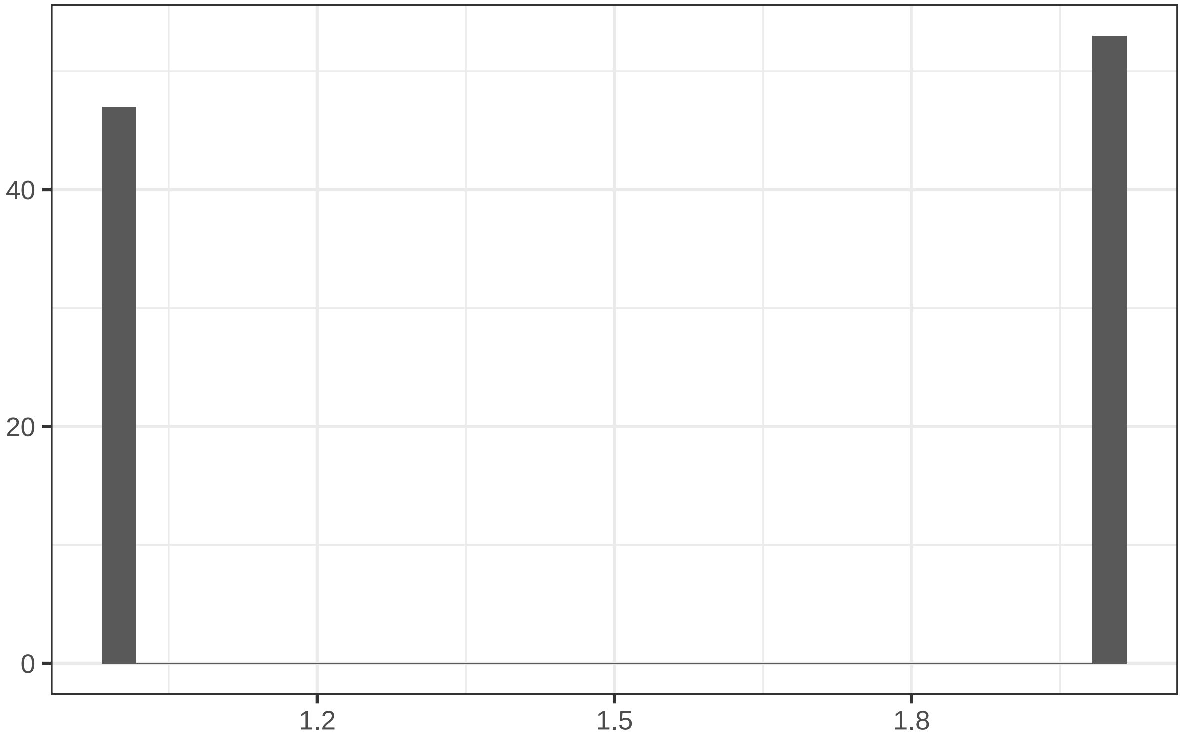


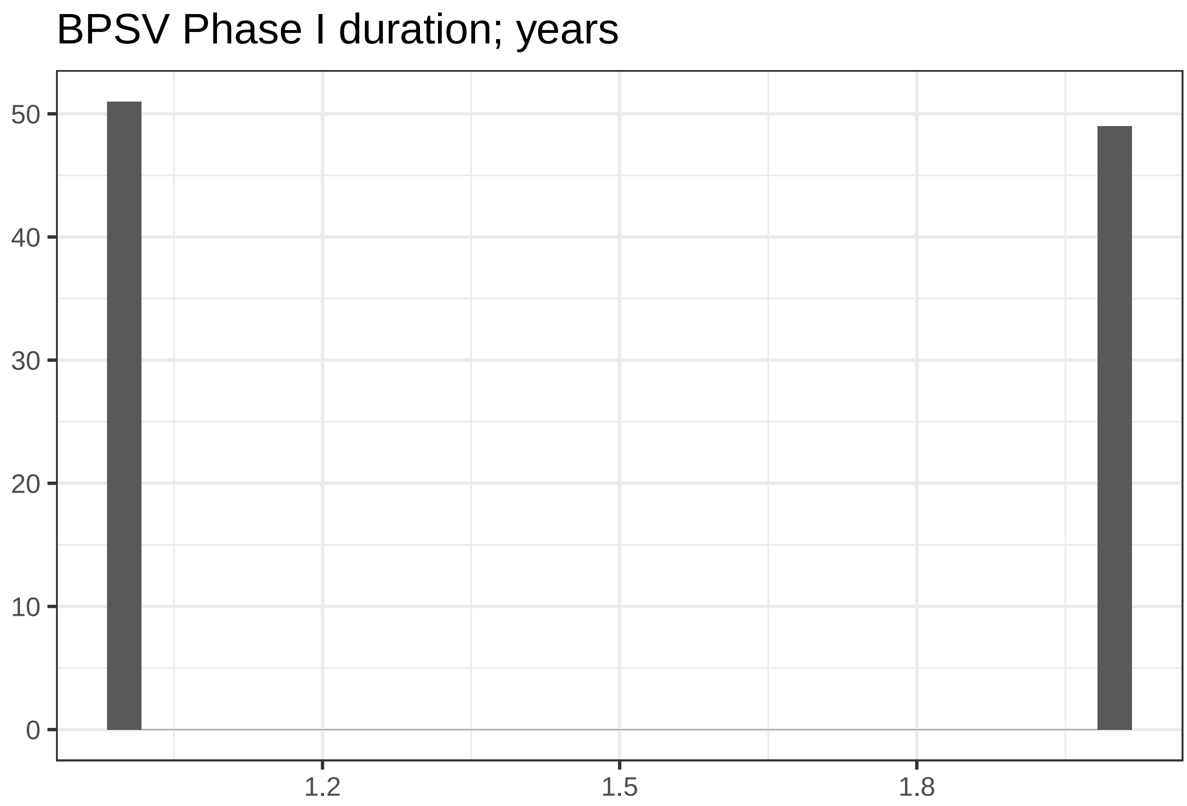

Cost, Phase III, experienced manufacturer; USD
20
10
0
0.0e+00
2.5e+08
5.0e+08
7.5e+08

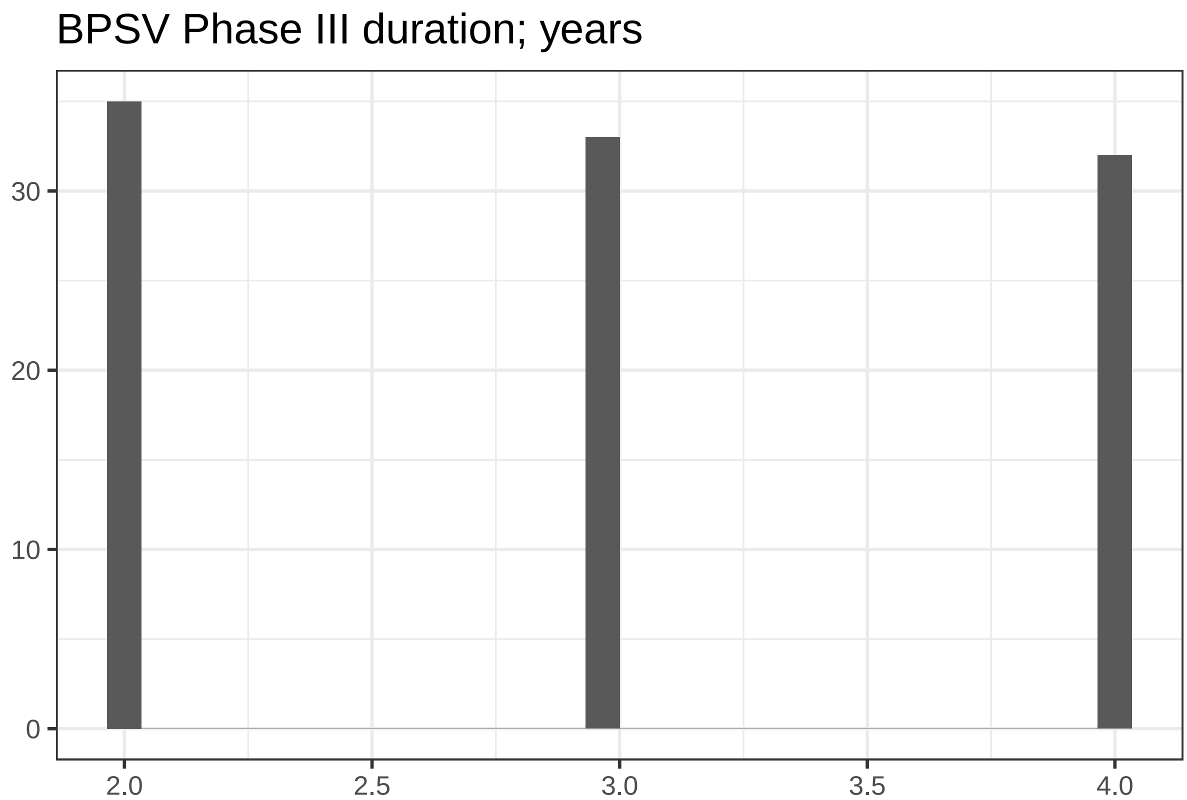
Cost, Phase III, inexperienced manufacturer; USD



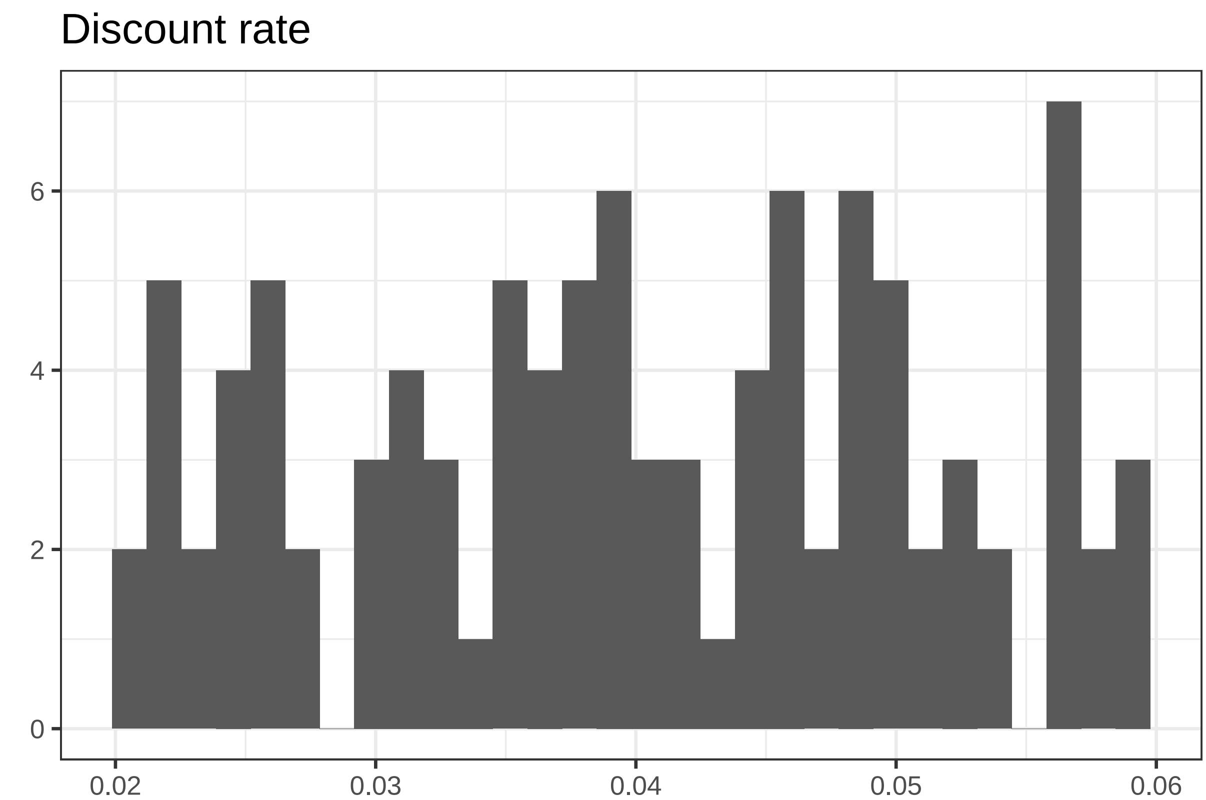
BPSV preclinical duration; years




BPSV Phase I duration; years
50
40
30
20
10
0
1.2
1.5
1.8



BPSV Phase III duration; years
30
20
10
0
2.0
2.5
3.0
3.5
4.0



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