

Modeling Vaccination

Interventions

- **Non-pharmaceutical interventions**

- Sanitation
- Social distancing
- Masking
- Education

- **Pharmaceutical interventions**

- Therapeutics
 - Drugs, antivirals, antibody therapies
- Prophylaxis
 - Vaccines, antibody therapies

What do vaccines do?

- **Vaccine:** A preparation that is used to stimulate the body's immune response against pathogens.
- **Efficacy:** measured in a controlled clinical trial and is based on how many people who got vaccinated developed the 'outcome of interest' (usually disease) compared with how many people who got the placebo developed the same outcome.
- **Effectiveness:** a measure of how well vaccination works under real-world conditions to protect people against health outcomes such as infection, symptomatic illness, hospitalization, and death.

What do vaccines do?

- **Prevent infection** – move you from S $\rightarrow$ R
 - Measles, Oral polio vaccine
- **Prevent illness** – perhaps still transmission?
 - Inactivated polio vaccine, diphtheria
- **Prevent/reduce transmission** $\rightarrow$ reduce Beta
 - SARS-CoV-2, RTS,s
- **Accelerate clearance** $\rightarrow$ shorten L
 - SARS-CoV-2

How long does immunity last?
For simplicity now, we'll
assume that immunity is
lifelong

Herd Immunity

- Indirect protection to non-immune individuals due to the presence of immune individuals in the population

Critical Herd Immunity Threshold

- When indirect protection is high enough, the risk to non-immune individuals falls to 0 because the endemic equilibrium is 0

Critical Herd Immunity Threshold

$$R_0 = \frac{\beta S}{\gamma} = \beta SL$$

$$R_0 = \beta SL$$

$$1 = \frac{\beta SL}{R_0}$$

$$1 = \frac{1}{R_0} S \beta L$$

What fraction of Susceptibles
need to be immune in order for

$$\frac{1}{R_0} S$$

to remain?

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$$T_c = 1 - \frac{1}{R_0}$$

Imperfect Vaccine Effectiveness

$$T_C = 1 - \frac{1}{R_0}$$

$$T_C = P(\text{vaccinated}) * \text{effectiveness}$$

$$P(\text{vaccinated}) = \frac{1}{\text{effectiveness}} \left(1 - \frac{1}{R_0} \right)$$

T_C are those effectively immunized. We must account for vaccine failure

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Figures



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Reprints



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Omicron variant and booster COVID-19 vaccines

Talha Khan Burki

Published: December 17, 2021 • DOI: [https://doi.org/10.1016/S2213-2600\(21\)00559-2](https://doi.org/10.1016/S2213-2600(21)00559-2)



Check for updates



PlumX Metrics

The original strain of SARS-CoV-2 has an R_0 of 2.5, while the delta variant (B.1.617.2) has an R_0 of just under 7. Martin Hibberd, professor of emerging infectious diseases at London School of Hygiene & Tropical Medicine (London, UK), reckons omicron's R_0 could be as high as 10. In the UK, cases of omicron are doubling

Imperfect Vaccine Effectiveness

$$T_C = 1 - \frac{1}{R_0}$$

$$T_C = P(\text{vaccinated}) * \text{effectiveness}$$

$$P(\text{vaccinated}) = \frac{1}{\text{effectiveness}} \left(1 - \frac{1}{R_0} \right)$$

(ex) Assume R_0 :

OG SARS-CoV-2 is 2.5

Delta is 7

Omicron is 10

What fraction of the population needs to be vaccinated if we have a vaccine that is 100%, 90%, 70% or 50% effective in blocking transmission?

Exercises

(ex) Assume R_0 :

OG SARS-CoV-2 $R_0 = 2.5$: 60%

Delta is $R_0 = 7$: 86%

Omicron is $R_0 = 10$: 90%

What fraction of the population needs to be vaccinated if we have a vaccine that is 100% effective in blocking transmission?

Exercises

(ex) Assume R_0 :

OG SARS-CoV-2 $R_0 = 2.5$: 60%, 67%, 86%, 120%

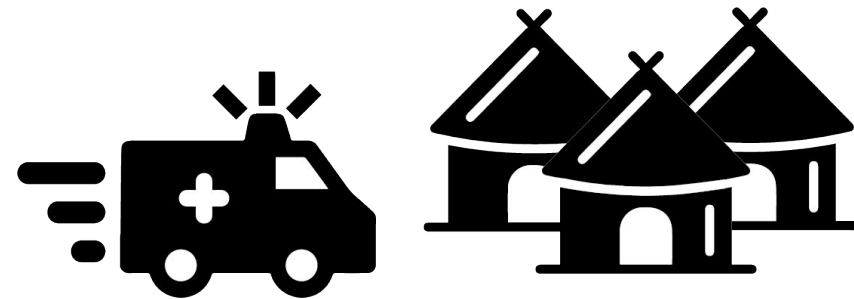
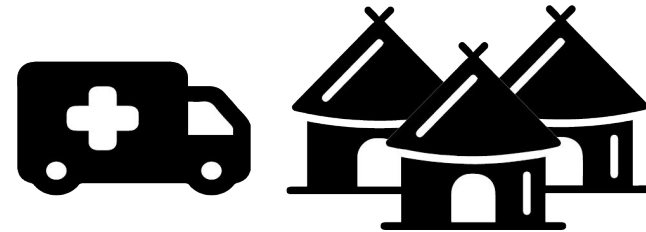
Delta is $R_0 = 7$: 86%, 95%, 122%, 170%

Omicron is $R_0 = 10$: 90%, 100%, 129%, 180%

What fraction of the population needs to be vaccinated if we have a vaccine that is 100%, 90%, 70% or 50% effective in blocking transmission?

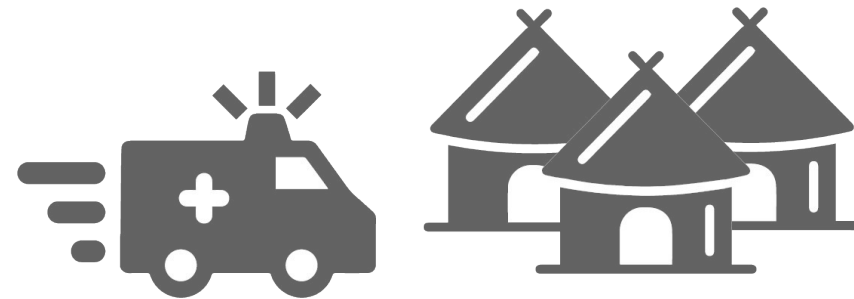
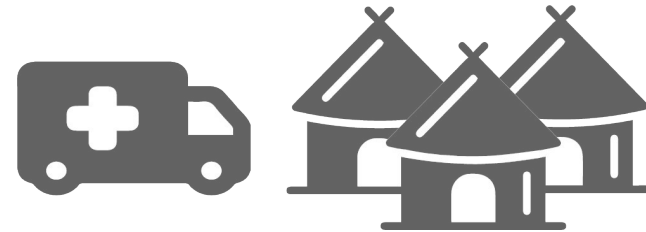
How is vaccination delivered?

- Routine
 - 1st dose
 - 2nd, 3rd, etc dose ... opportunity
- Supplemental immunization activities
- Outbreak response immunization



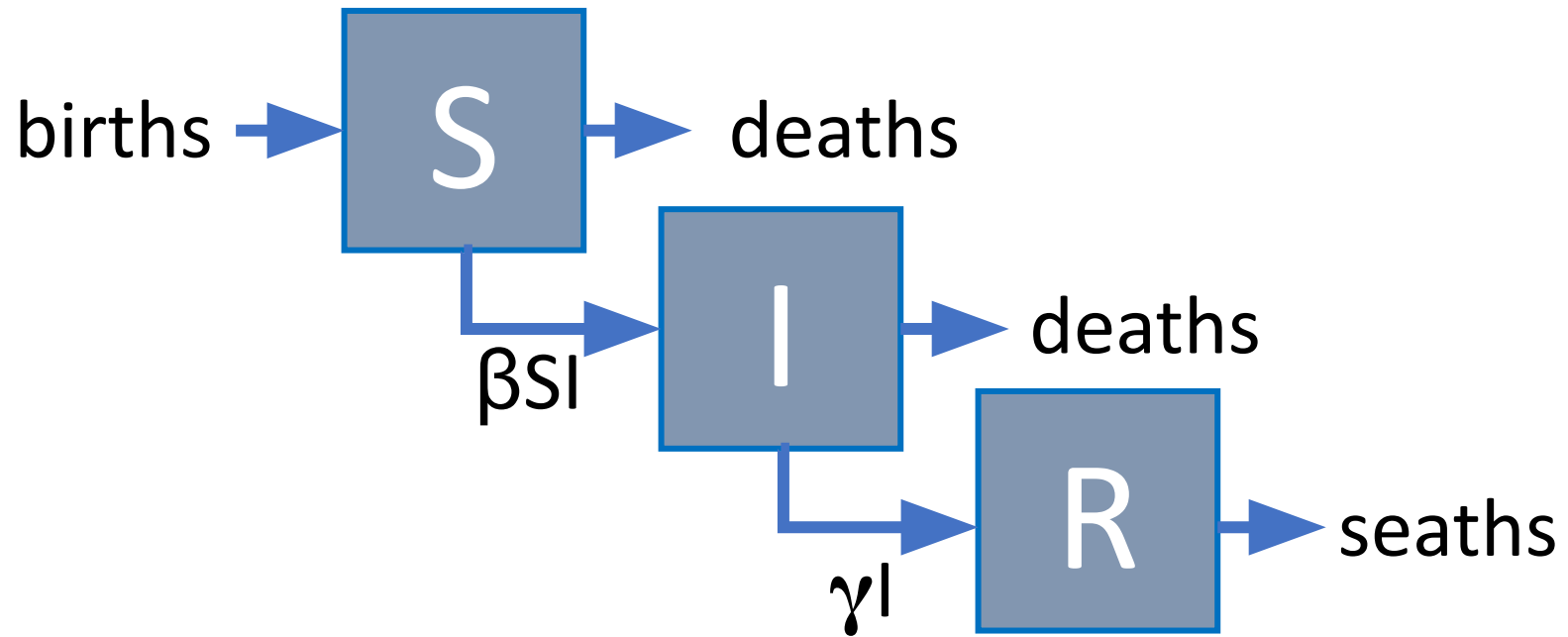
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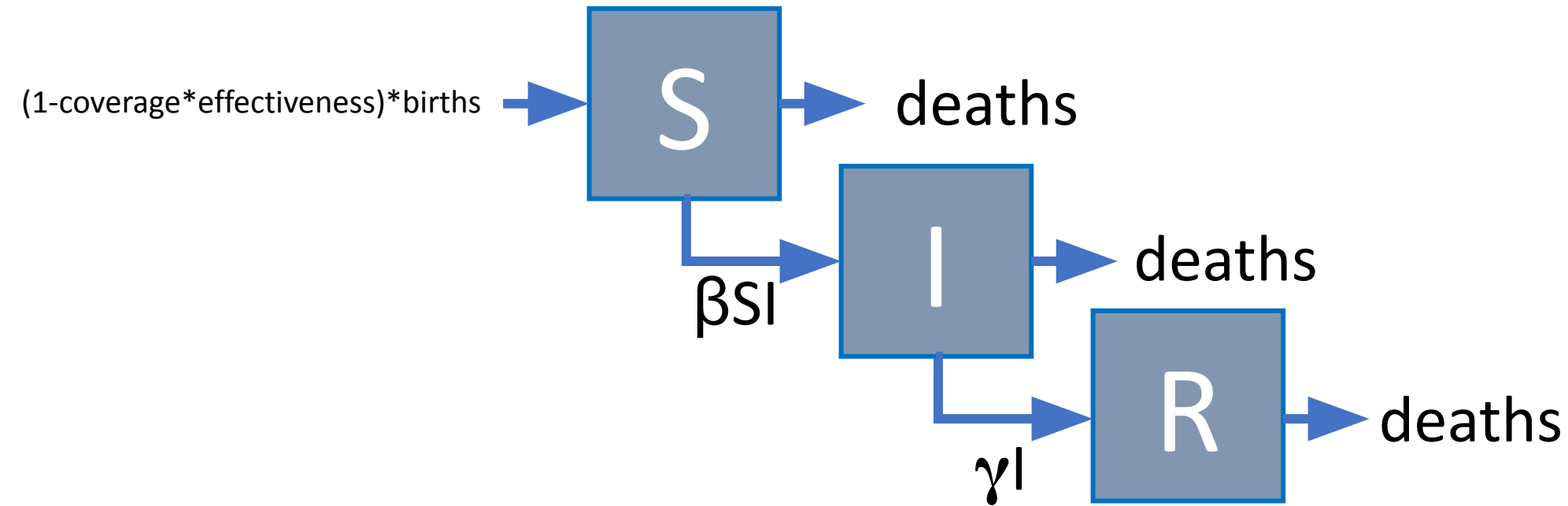


Vaccination with a single dose

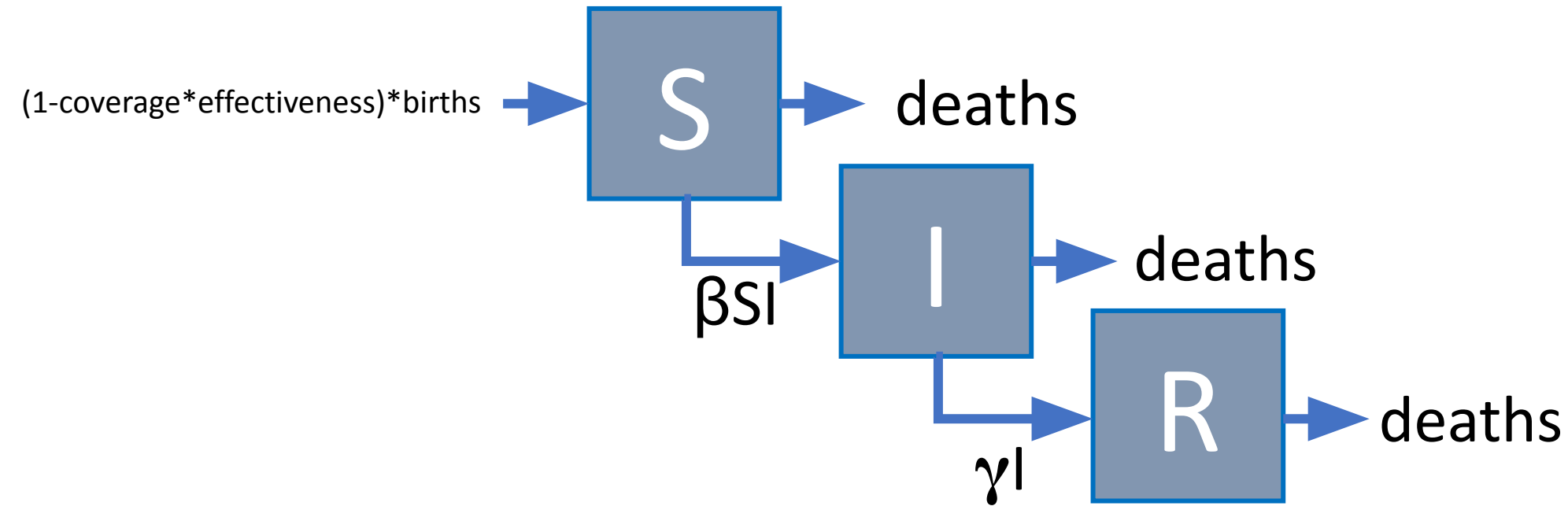
How do we represent vaccination in models?



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All models are approximations

Does this approximation seem reasonable?

Table 1 Recommended Child and Adolescent Immunization Schedule for Ages 18 Years or Younger, United States, 2025

These recommendations must be read with the notes that follow. For those who fall behind or start late, provide catch-up vaccination at the earliest opportunity as indicated by the green bars. To determine minimum intervals between doses, see the catch-up schedule (Table 2).

Vaccine and other immunizing agents	Birth	1 mo	2 mos	4 mos	6 mos	9 mos	12 mos	15 mos	18 mos	19–23 mos	2–3 yrs	4–6 yrs	7–10 yrs	11–12 yrs	13–15 yrs	16 yrs	17–18 yrs	
Respiratory syncytial virus (RSV-mAb [Nirsevimab])	1 dose depending on maternal RSV vaccination status (See Notes)				1 dose (8 through 19 months), See Notes													
Hepatitis B (HepB)	1st dose	← 2nd dose →			← 3rd dose →													
Rotavirus (RV): RV1 (2-dose series), RV5 (3-dose series)			1st dose	2nd dose	See Notes													
Diphtheria, tetanus, acellular pertussis (DTaP <7 yrs)			1st dose	2nd dose	3rd dose			← 4th dose →				5th dose						
Haemophilus influenzae type b (Hib)			1st dose	2nd dose	See Notes			← 3rd or 4th dose (See Notes) →										
Pneumococcal conjugate (PCV15, PCV20)			1st dose	2nd dose	3rd dose			← 4th dose →										
Inactivated poliovirus (IPV)			1st dose	2nd dose	← 3rd dose →							4th dose					See Notes	
COVID-19 (1vCOV-mRNA, 1vCOV-aPS)					See Notes													
Influenza (IIV3, cdlIV3)					1 or 2 doses annually									1 dose annually				
Influenza (LAIV3)											1 or 2 doses annually		1 dose annually					
Measles, mumps, rubella (MMR)					See Notes		← 1st dose →					2nd dose						
Varicella (VAR)							← 1st dose →					2nd dose						
Hepatitis A (HepA)					See Notes		2-dose series (See Notes)											
Tetanus, diphtheria, acellular pertussis (Tdap ≥7 yrs)														1 dose				
Human papillomavirus (HPV)														See Notes				
Meningococcal (MenACWY-CRM ≥2 mos, MenACWY-TT ≥2 years)			See Notes										1st dose		2nd dose			
Meningococcal B (MenB-4C, MenB-FHbp)														See Notes				
Respiratory syncytial virus vaccine (RSV [Abrysvo])														Seasonal administration during pregnancy (See Notes)				
Dengue (DEN4CYD: 9–16 yrs)														Seropositive in endemic dengue areas (See Notes)				
Mpox																		

Range of recommended ages for all children

Range of recommended ages for catch-up vaccination

Range of recommended ages for certain high-risk groups or populations

Recommended vaccination can begin in this age group

Vaccination is based on shared clinical decision-making

No Guidance/ Not Applicable

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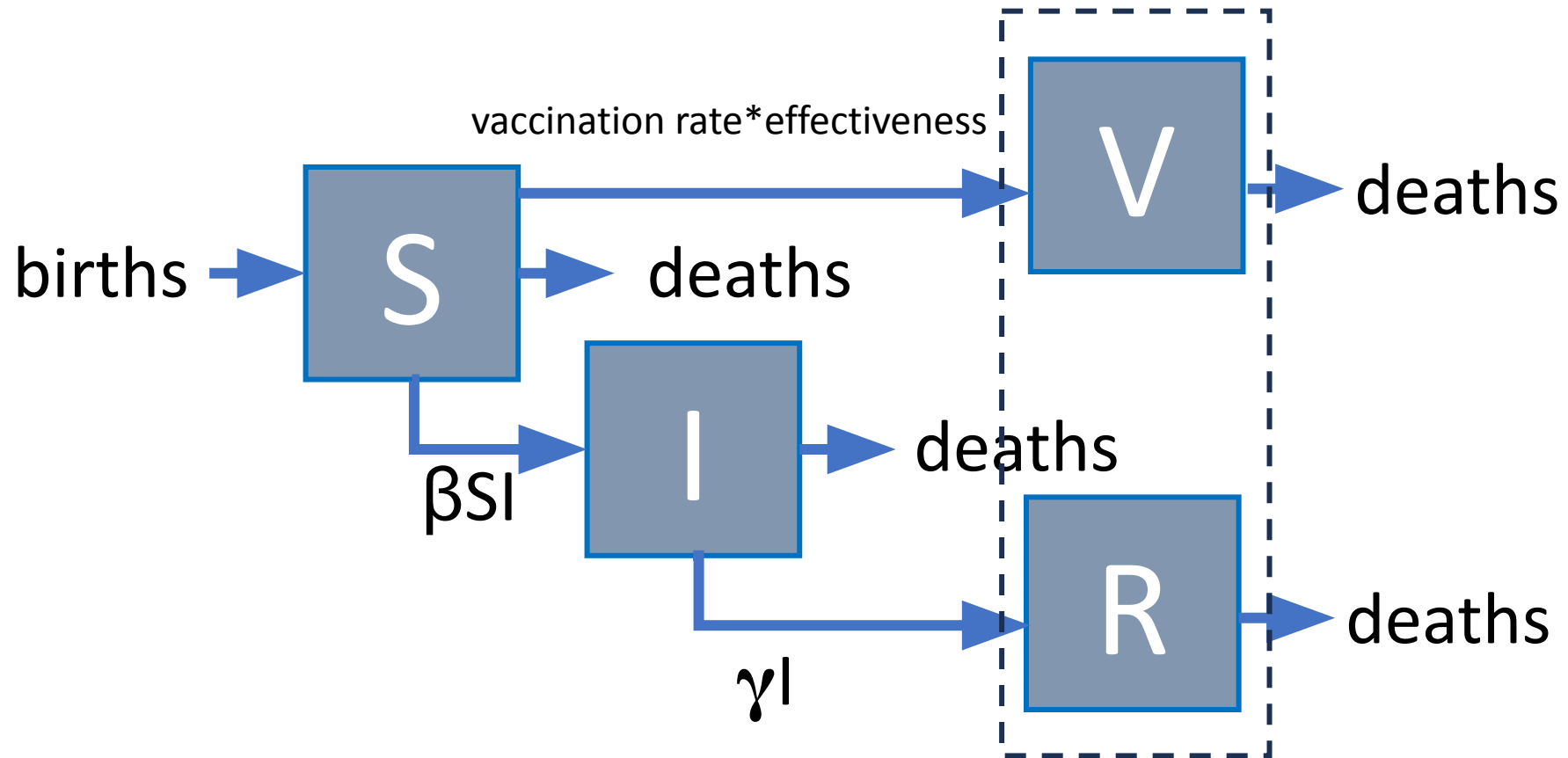
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What does it mean that these vaccines are received later?

How do we represent vaccination in models?



Maternal Immunity

- Antibodies from immune mothers are passively transferred to infant
- Infant cannot produce new antibodies. Transferred antibodies (and immunity) degrades approximately exponentially.

**Immunogenicity, effectiveness, and safety of measles vaccination in infants younger than 9 months:
a systematic review and meta-analysis**

Laura M Nic Lochlainn, Brechje de Gier, Nicoline van der Maas, Peter M Strebel, Tracey Goodman, Rob S van Binnendijk, Hester E de Melker, Susan J M Hahné

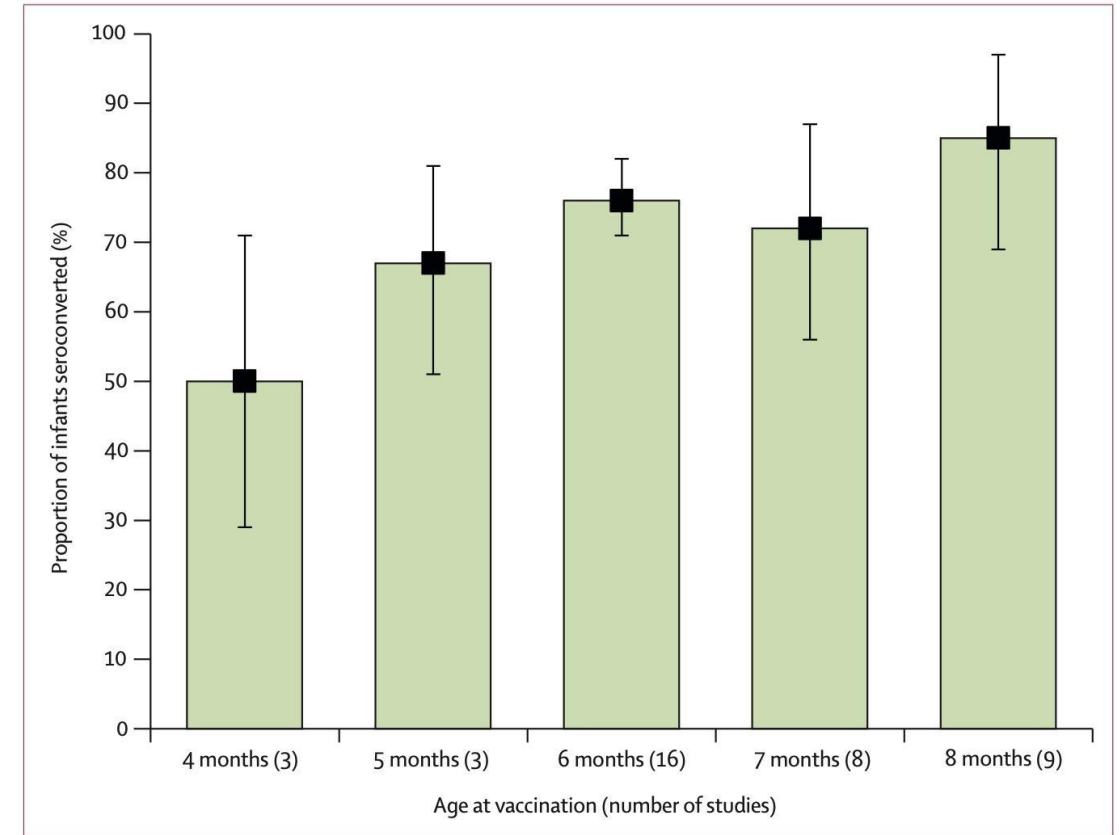
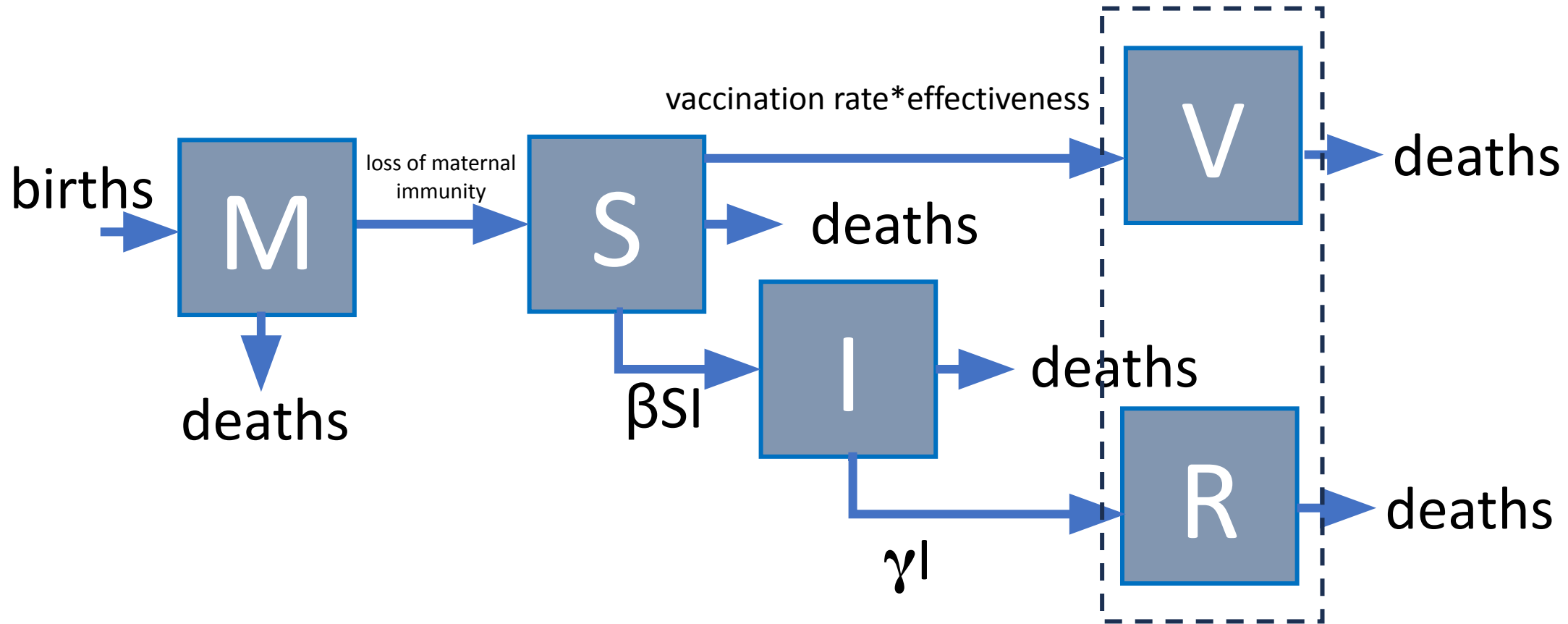
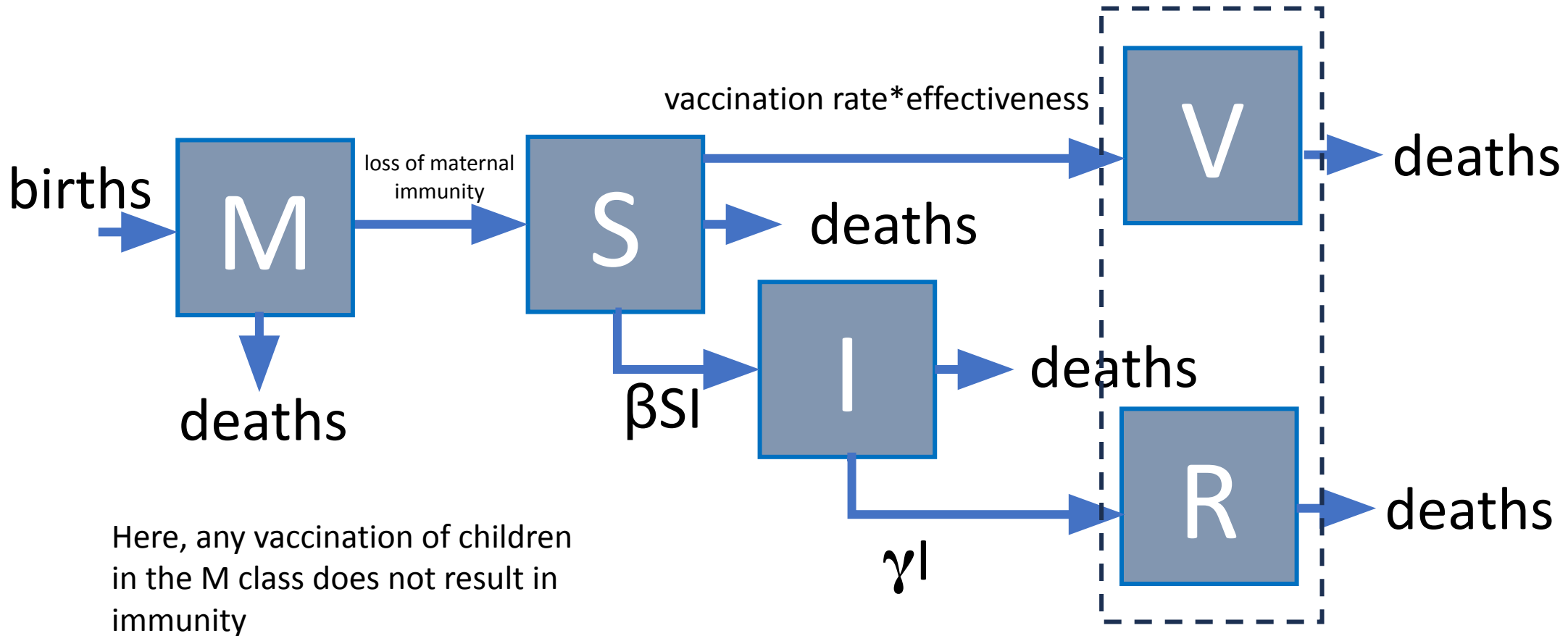


Figure 2: Pooled estimates of proportion of infants seroconverted, by age of MCV1 (4–8 months) with 95% CIs
MCV1=first dose of measles-containing vaccine.

Adding a Maternal Immunity Class

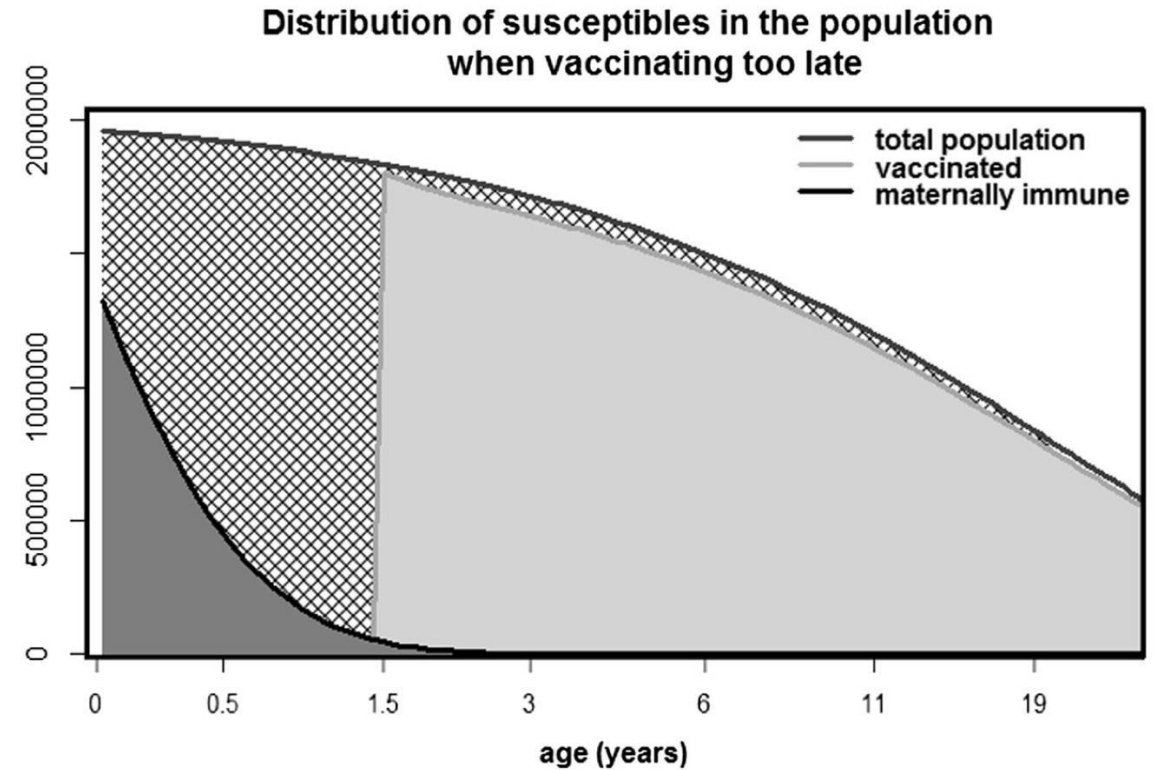
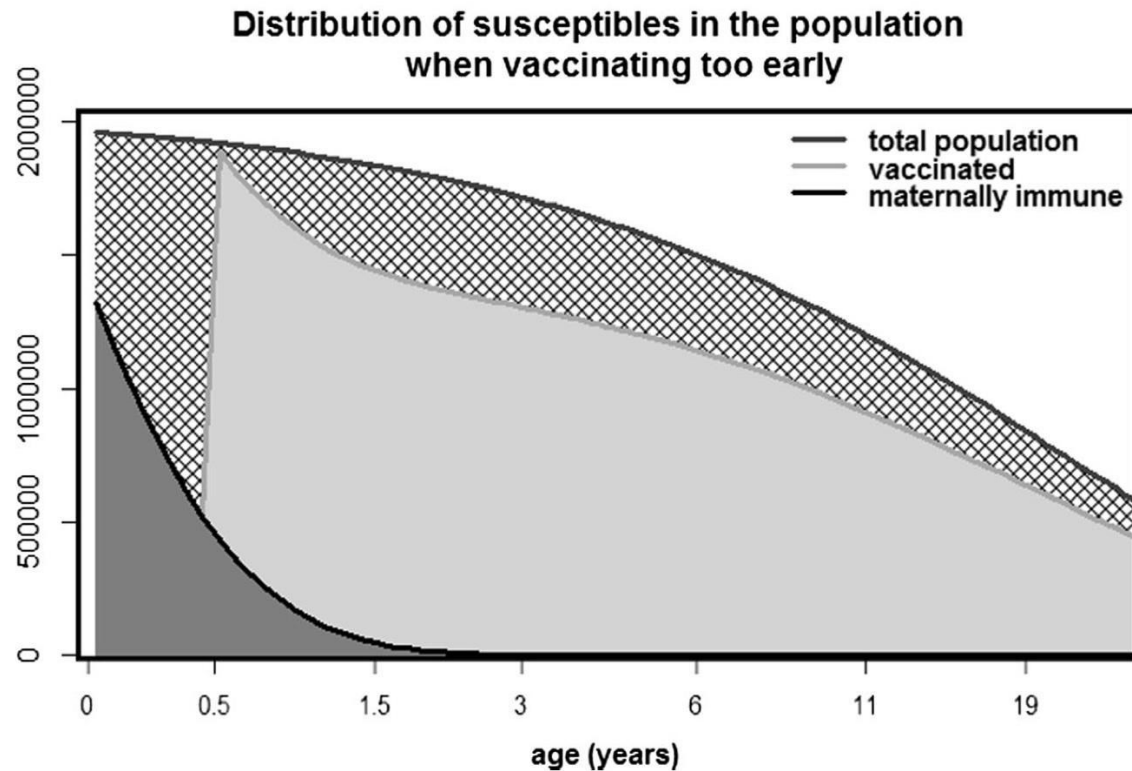


Adding a Maternal Immunity Class



Timing of the First Dose

Label y axis



Second Doses

Second Doses

- Routine Immunization
- Supplemental Immunization
- Outbreak Response Immunization

Second Doses

- Routine Immunization (Measles as an example)
 - Delivered through “well-child” visits at targeted ages
 - 1st dose recommended at 9-12 months, timing dependent on prevalence
 - 2nd dose recommended at 24 months or higher, varies by country. Goal is immunize those who failed to seroconvert with first dose
 - Formally, 2nd dose coverage is recorded as the fraction of children with 1st dose that receive a 2nd dose. However, this convention is not universal.
- Supplemental Immunization
- Outbreak Response Immunization

Second Doses

- Routine Immunization
- Supplemental Immunization (SIA)
 - Periodic, large-scale vaccination of all children (regardless of prior vaccination) within a target age group.
 - Modeled after PAHO strategy of “catch up”, “keep up”, “follow up”
 - Models have been useful in determining the frequency and age targets for these campaigns
 - Implementation in models as a single time point move from S to R, resulting in a large reduction in S class in the target age groups.
- Outbreak Response Immunization

Second Doses

- Routine Immunization
- Supplemental Immunization (SIA)
- Outbreak Response Immunization
 - Vaccination activities that are triggered by the occurrence of an outbreak
 - Indiscriminate targeting of all children within an age window (e.g. 6-59m)
 - Triggers (e.g. number of cases), speed, scale, and coverage of response varies by country and the organization conducting the ORI
 - Modelling has been useful in identifying age targets and evaluating the potential trade-offs between speed and coverage. As outbreak progresses there is less indirect (herd) benefit of each dose.