Presentation outline

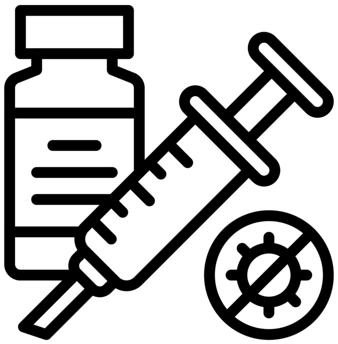
- Feifan, 5 min: Introduction
    - Big picture
        - What is epidemiology?
        - Why is it important? (Real world usage of compartment models?)
    - Basic SIR model(Deterministic, Stochastic model)
        - Include Scheme, ODE
    - General concepts: Basic Reproduction Number, Herd Immunity Thres., …
- Amy, 5 min: Model（Our own model)
    - Brief explanation of Parsons paper? (concept about epidemic outcomes with stochastic sim.: fizzle, burnout, persist)
    - Why vaccines matter? (current news reference?)
    - Introduce our version of SIR with vaccination event (Scheme, ODEs, probably the simplest one with constant vaccination rate)
- Jacob, 5 min: Results
    - Stochastic/Deterministic simulations
        - Visualizations
        - focus on defining epidemic outcome classification method with reasonable justification
    - Brief idea for future works
        - Extension of analytical work for estimating burnout probability in model with vaccination?
        - Maybe good to include different model definitions we discussed?
        - Just a word about waning immunity?

Background of our question : Get familiar with the question: How does vaccination strategy affect the disease transmit?

1. Why we care about this question
2. Find an example to prove the vaccination is important, bring the critical point (Use some data)
3. Eg: MMR without vaccination how it spreads in Texas to prove why vaccination is important

Vaccination in Epidemic Modeling

Jacob Kang, Feifan Li, Amy Wang

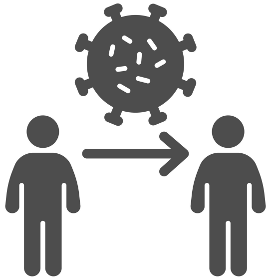


Background Info

What is Epidemiology?

Epidemiology is the study of disease spread in populations.

- Identify **patterns** and **causes** of diseases in groups of people.
- Provide **evidence** for public health decisions/policies.
- Develop strategies to **prevent**, **control**, and **eliminate** disease

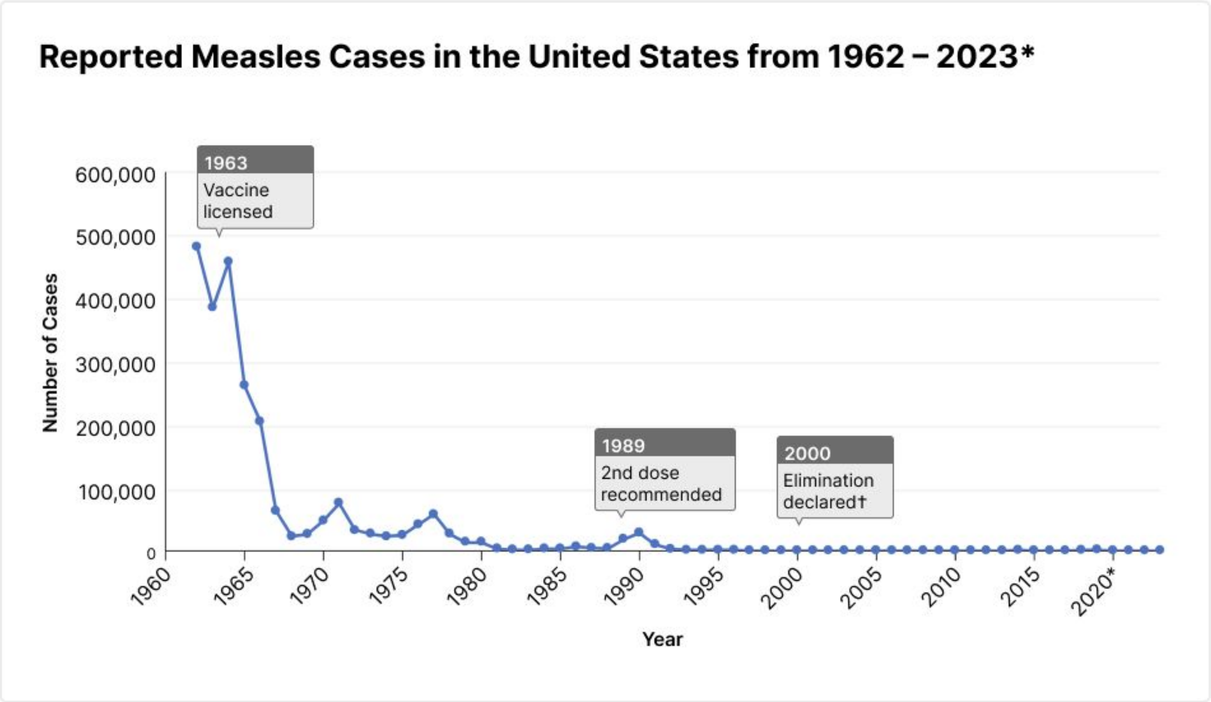


Why do we care about vaccination?

Disease	Before vaccination	After vaccination
Smallpox	30%->50% death rate	1%-11% death rate
COVID-19	9.79% death rate	5.01% death rate
Ebola	40% death rate	Local outbreaks can be controlled with vaccines
Measles	2.6mil deaths per year	128k deaths per year

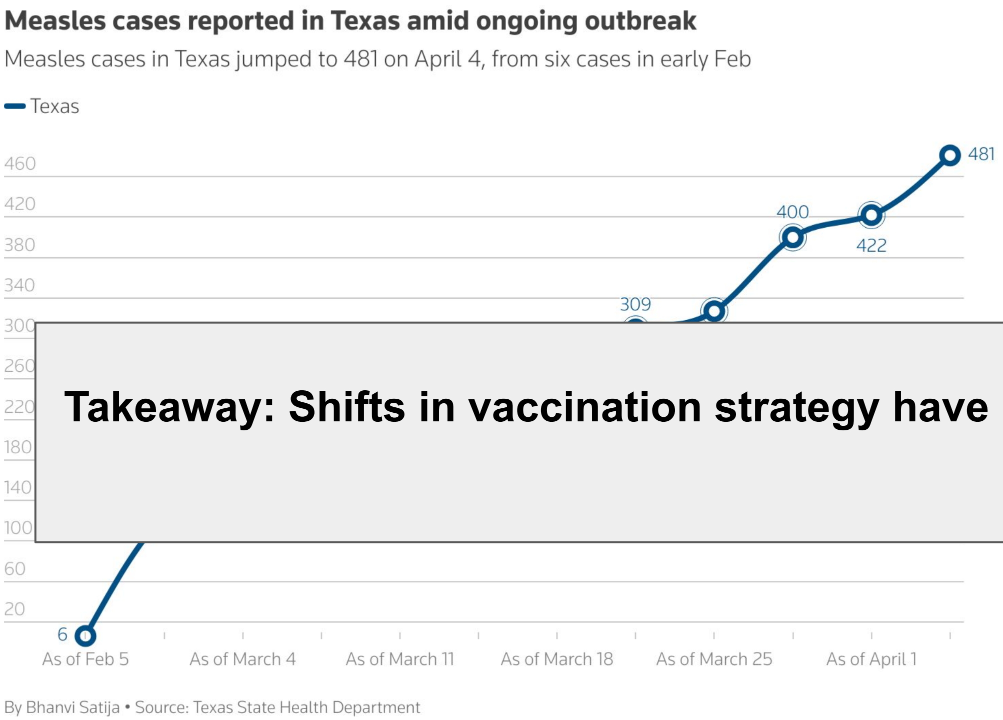
Source: State and country health department, C.D.C;The government of the Hong Kong Special Administrative Region; National Institute Of Health, N.I.H; World Health Organization, W.H.O

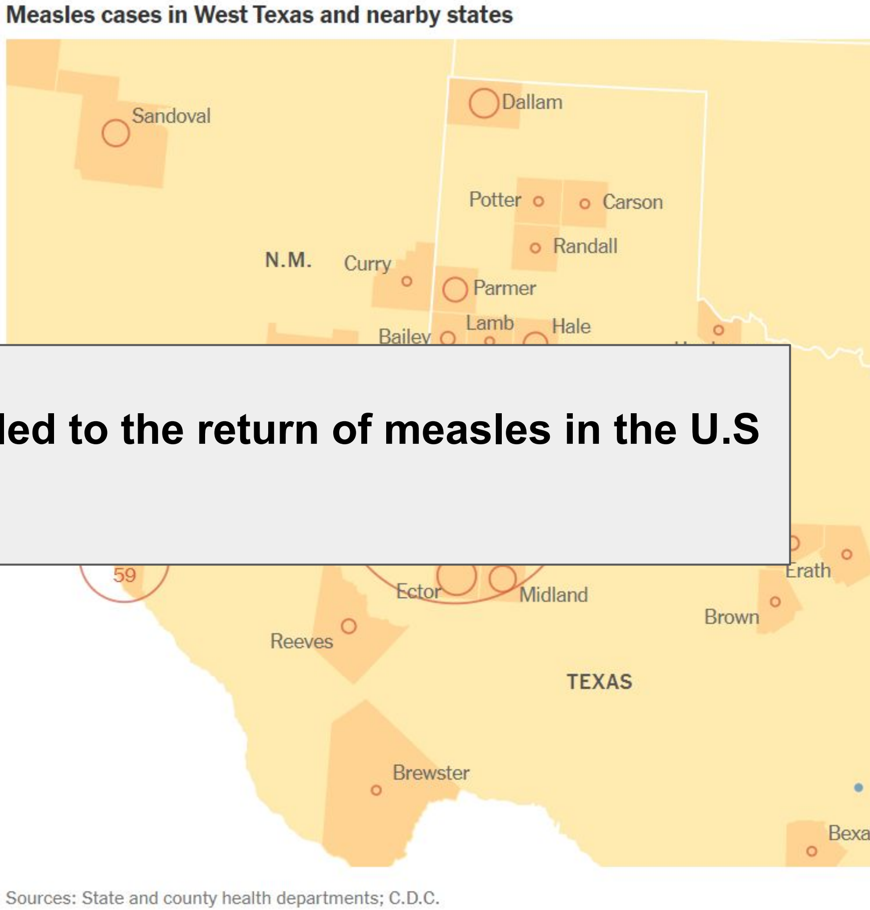
Real life examples - Vaccination in current events



Source: State and country health department, C.D.C

Real life examples - Vaccination in current events





Takeaway: Shifts in vaccination strategy have led to the return of measles in the U.S

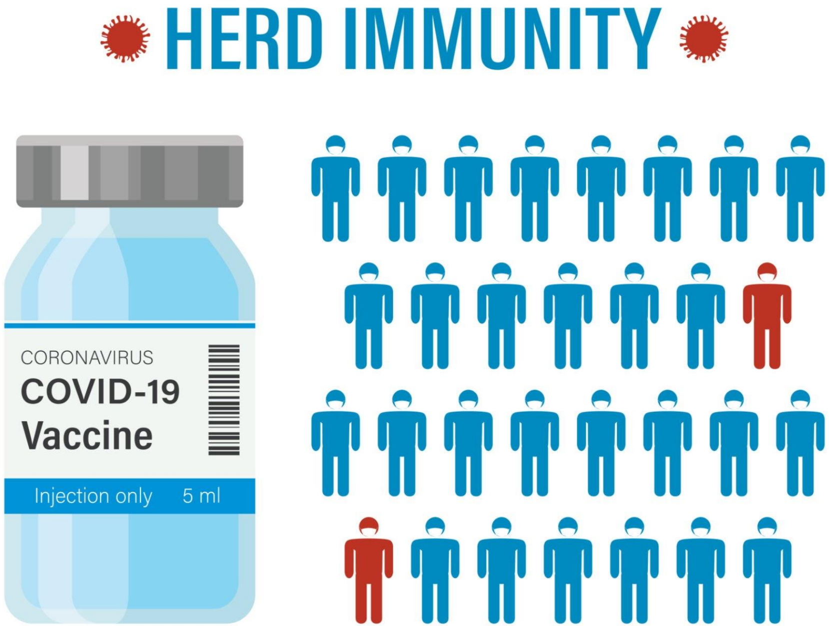
Herd Immunity

Sufficient fraction of the population immunized

↓

Outbreak no longer possible

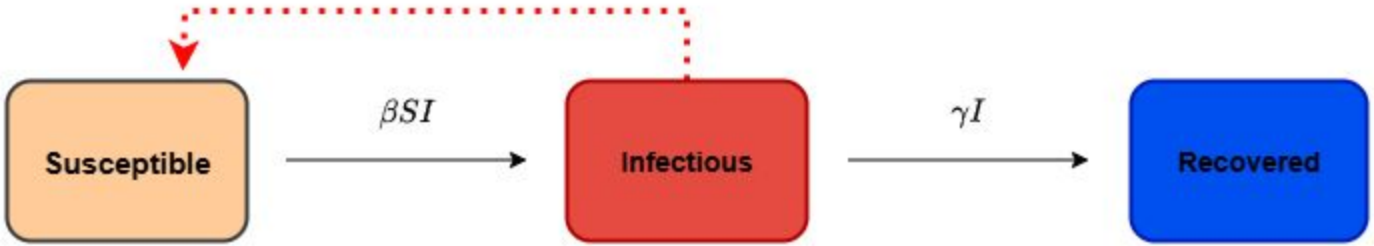
$$HerdImmunityThreshold(HIT) = 1 - \frac{1}{R_0}$$



How does vaccination strategy affect the epidemic progression?

What is the SIR model?

SIR Model



$$\frac{dS}{dt} = -\beta SI$$
$$\frac{dI}{dt} = \beta SI - \gamma I$$
$$\frac{dR}{dt} = \gamma I$$

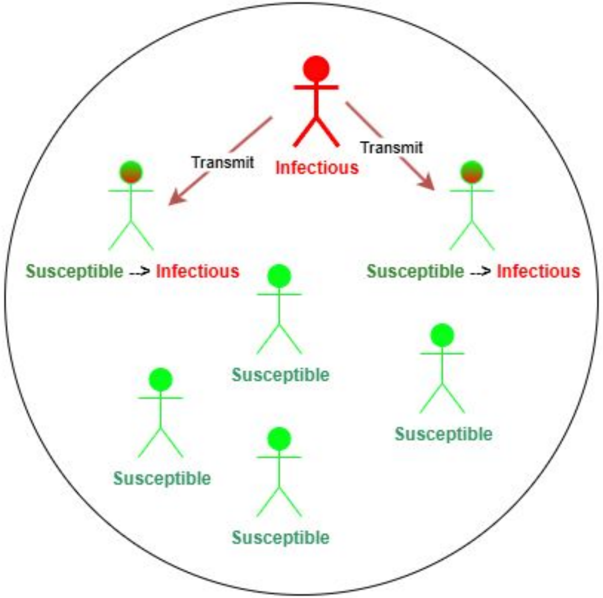
β: Transmission Rate

γ: Recovery Rate

Basic Reproduction Number

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

The average number of new infections caused by a single infectious individual in an otherwise susceptible population.



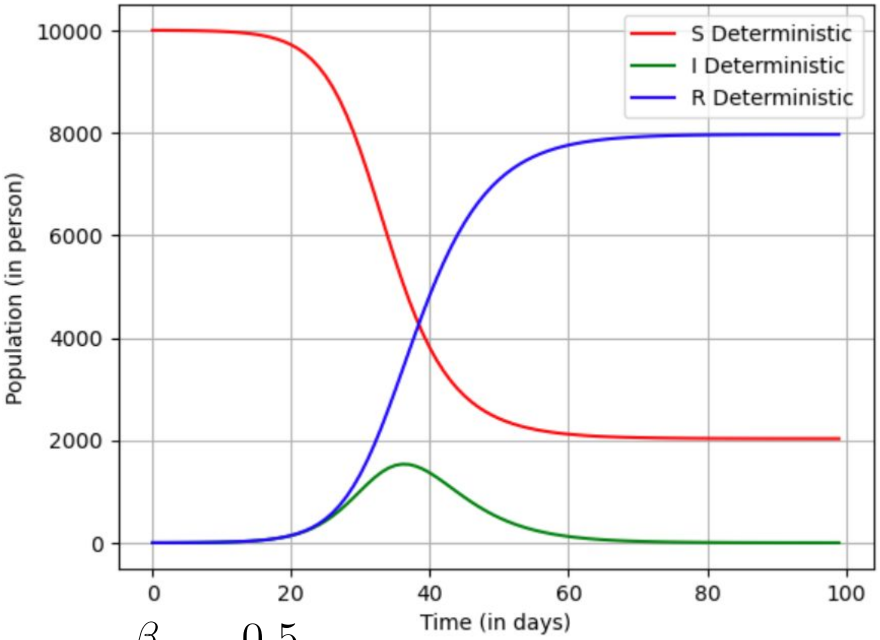
$$R_0 = 2$$

Indicates Strength / Transmissibility of the disease.

Two ways to model:
Deterministic vs. Stochastic

Varying values of R_0, Deterministic Simulation

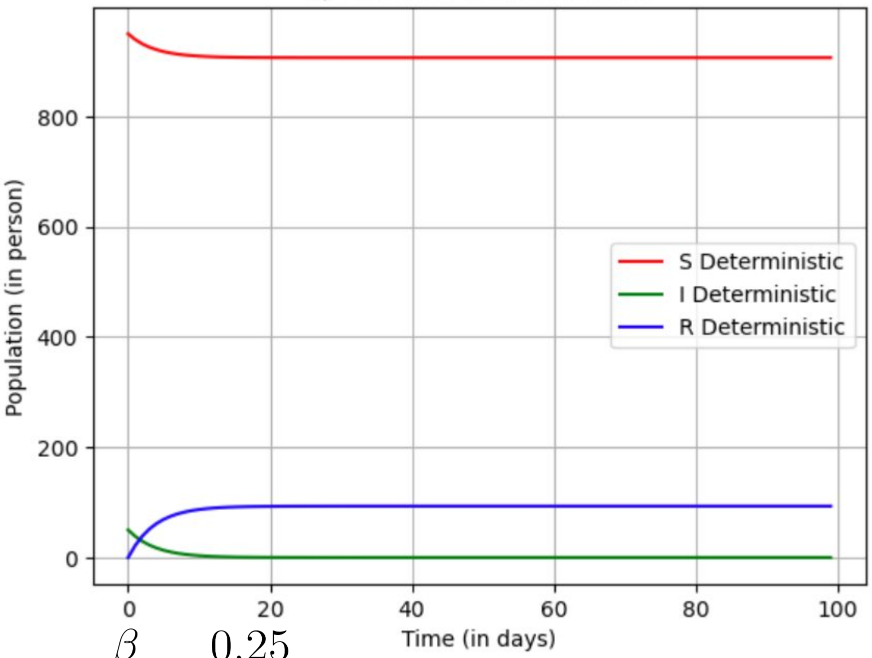
$$R_0 > 1$$



$$R_0 = \frac{\beta}{\gamma} = \frac{0.5}{0.25} = 2$$

N = 10000, I(0) = 1, Time Frame = [0, 100]

$$R_0 < 1$$

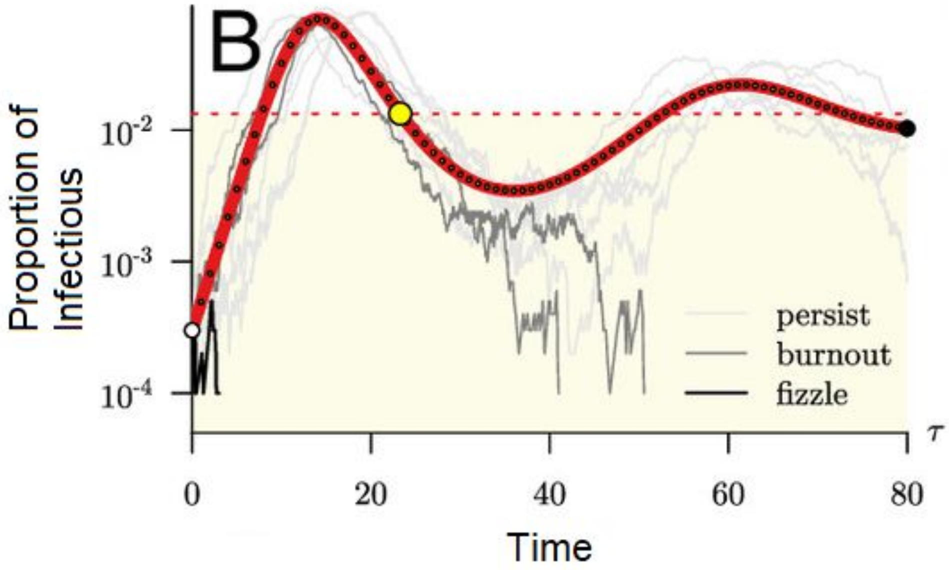


$$R_0 = \frac{\beta}{\gamma} = \frac{0.25}{0.5} = 0.5$$

N = 1000, I(0) = 50, Time Frame = [0, 100]

Stochastic Simulation

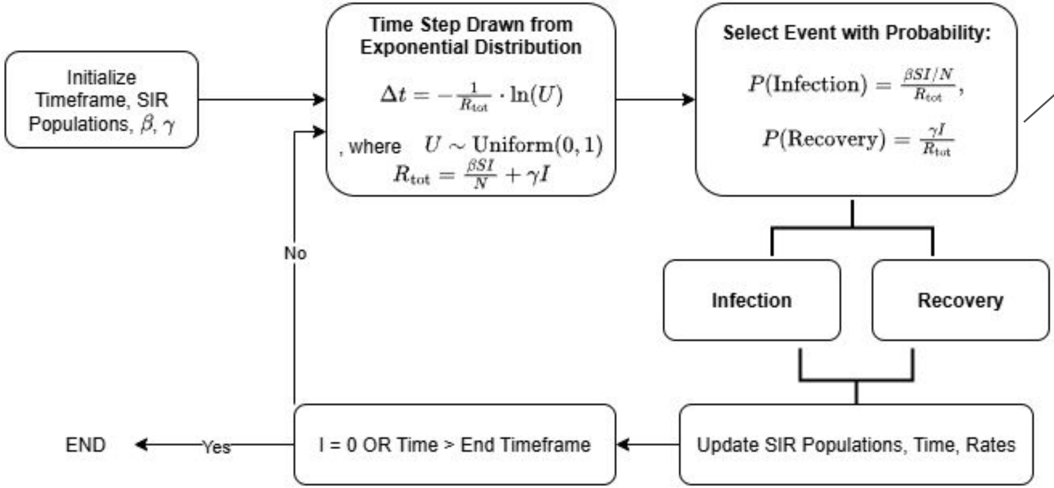
In 2024 paper [1] by Parsons et al., stochastic simulation of SIR model is utilized



Stochastic SIR model, Gillespie Algorithm

Time between events in poisson process follows Exponential Distribution

Event	Reaction	Rate
Infection	$S \rightarrow I$	$\frac{\beta S I}{N}$
Recovery	$I \rightarrow R$	γI

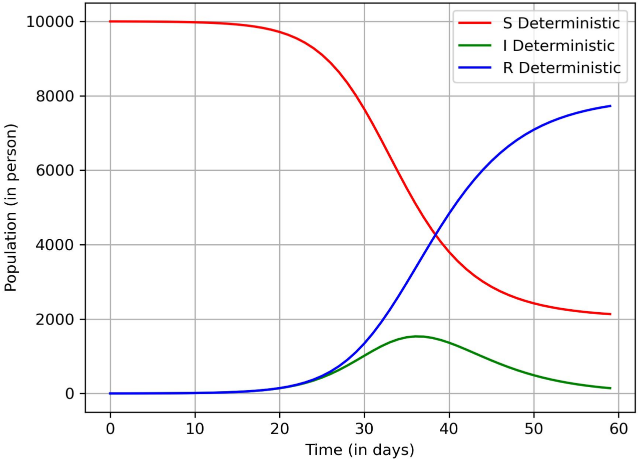


Events in poisson process Randomly & Independently

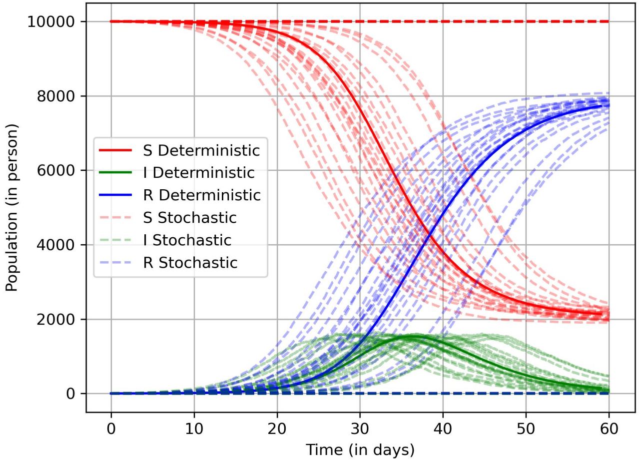
Deterministic vs. Stochastic SIR Models

- **Deterministic:** Based solely on the ODEs we saw previously
- When given the same conditions, exhibit the same outcome each time.

- **Stochastic:** Events are randomly determined, based on *Gillespie algorithm*
- When given the same conditions, exhibits various *outcomes* and behavior.



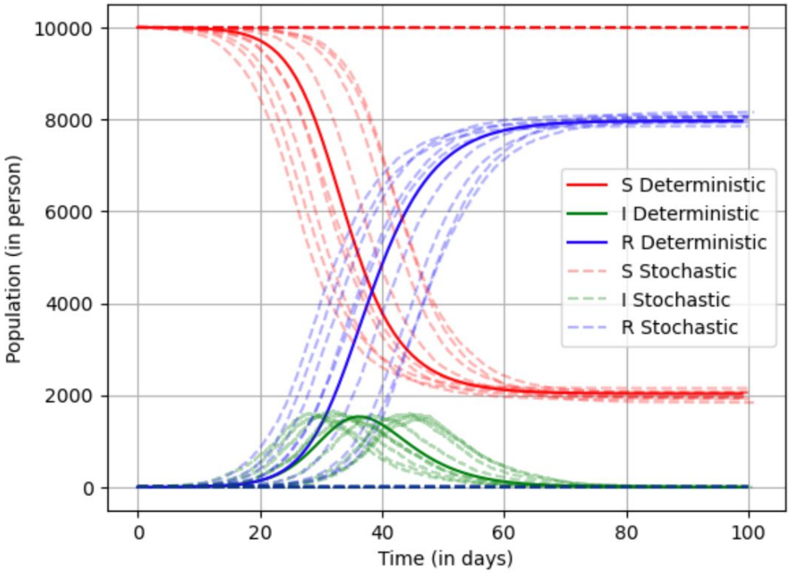
R_0=2, N = 10000, I(0) = 1, Time Frame = [0, 60]



R_0=2, N = 10000, I(0) = 1, Time Frame = [0, 60], 50 Stochastic Runs

Varying values of R_0, Stochastic Simulation

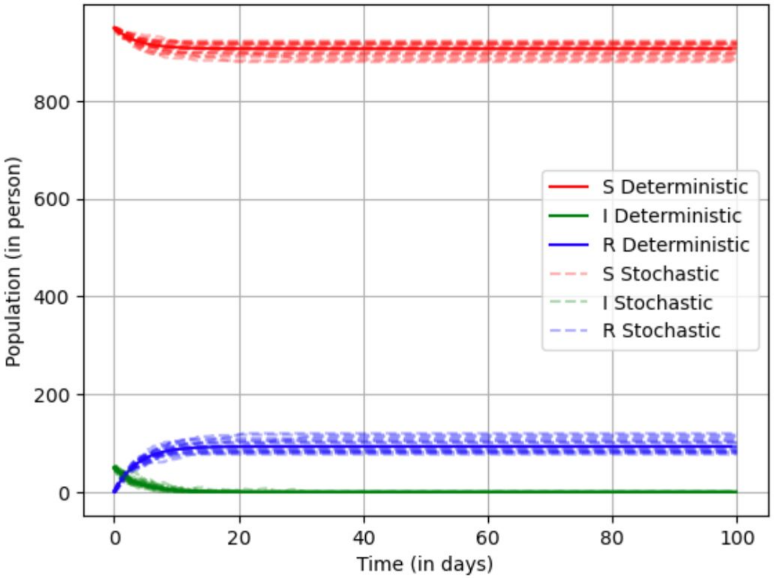
$$R_0 > 1$$



$$R_0 = \frac{\beta}{\gamma} = \frac{0.5}{0.25} = 2$$

N = 10000, I(0) = 1, Time Frame = [0, 100], 20 Stochastic Simulation

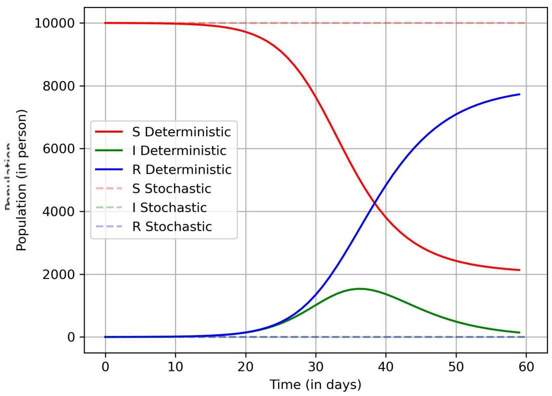
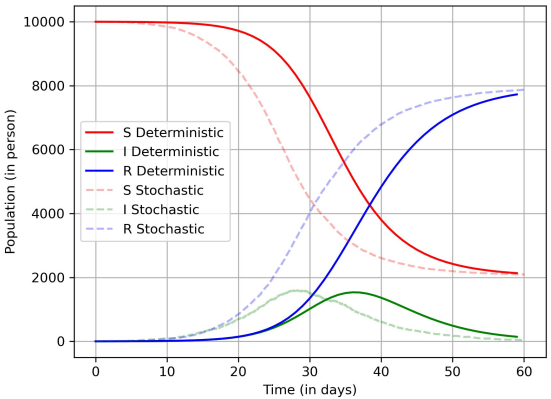
$$R_0 < 1$$

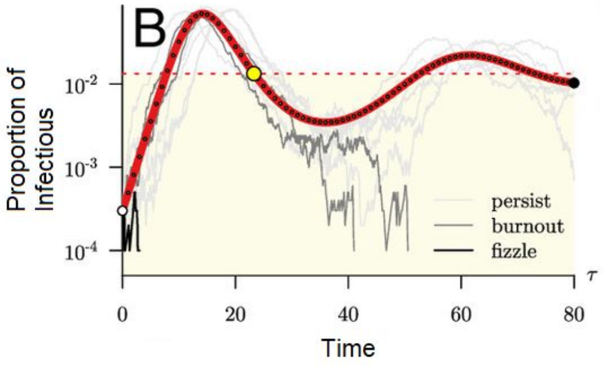


$$R_0 = \frac{\beta}{\gamma} = \frac{0.25}{0.5} = 0.5$$

N = 1000, I(0) = 50, Time Frame = [0, 100], 20 Stochastic Simulation

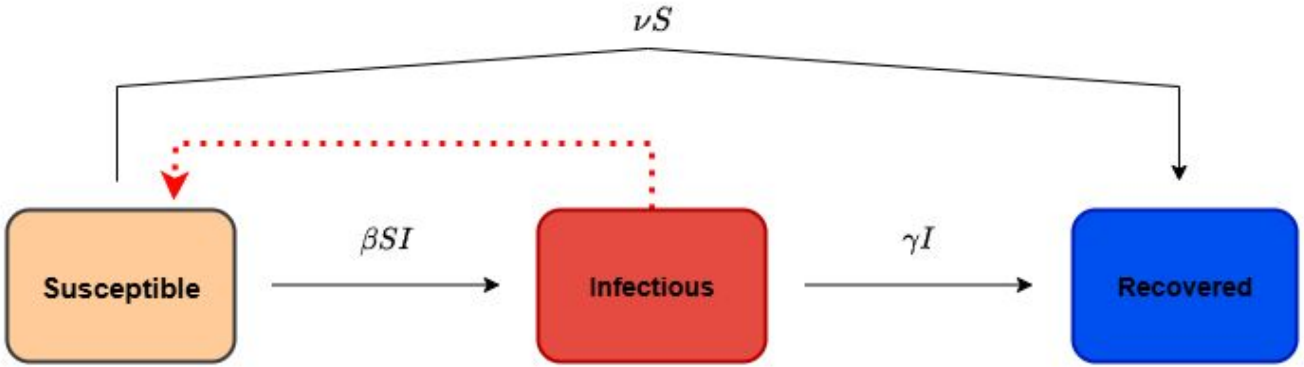
Epidemic Outcomes in Stochastic Simulation

Fizzle	Burnout
	
R_0=2, N = 10000, I(0) = 1, Time Frame = [0, 60]	R_0=2, N = 10000, I(0) = 1, Time Frame = [0, 60]



Incorporating Vaccination

SIR Model with **Vaccination** Event (SIRV)



$$\frac{dS}{dt} = -\beta SI - \nu S$$

$$\frac{dI}{dt} = \beta SI - \gamma I$$

$$\frac{dR}{dt} = \gamma I + \nu S$$

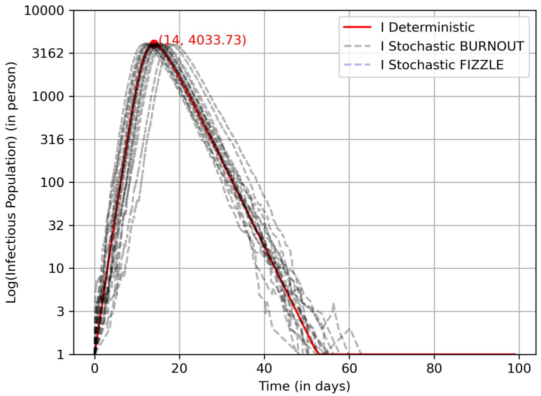
$\boldsymbol{\nu}$: Vaccination Rate

Vaccination gives **Full Recovery**

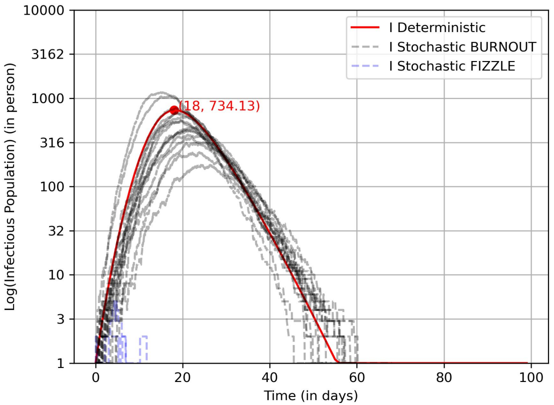
Log-Scaled Infectious Trajectories

$$R_0 = \frac{\beta}{\gamma} = \frac{1}{0.25} = 4$$

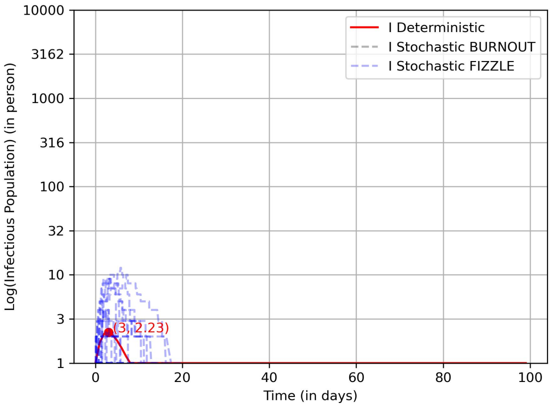
$\nu = 0$



$\nu = 0.05$



$\nu = 0.5$

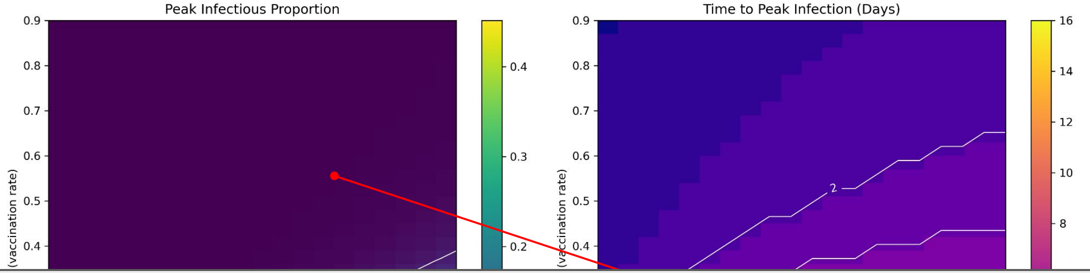


Increasing Vaccination Rate →

- Peak of Infectious trajectories SOONER
- Peak Infectious population INCREASE

Why? Higher v → Faster Depletion of Susceptible pool → Faster Increase in Infectious pool

Peak Infectious Proportion / Time



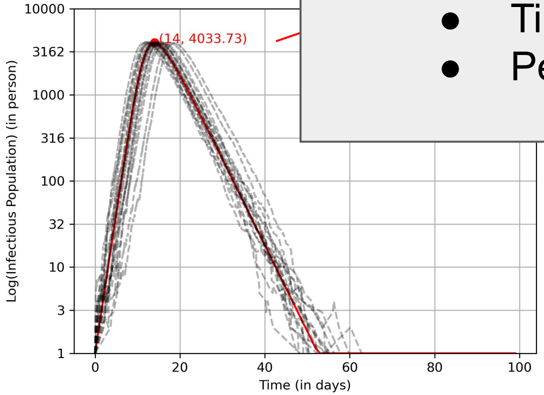
Increasing Vaccination Rate → Decrease in Susceptible pool →

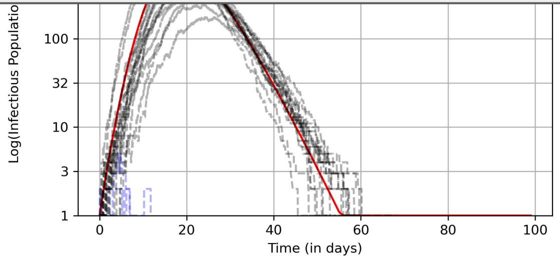
as R_0 Increases,

- Time to Peak Infectious SOONER
- Peak Infectious population DECREASE

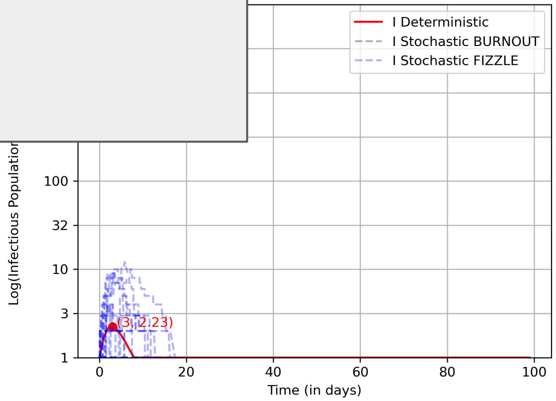
$$_0 = \frac{\beta}{\gamma} = \frac{1}{0.25} = 4$$

$$\nu = 0$$





$$\nu = 0.5$$

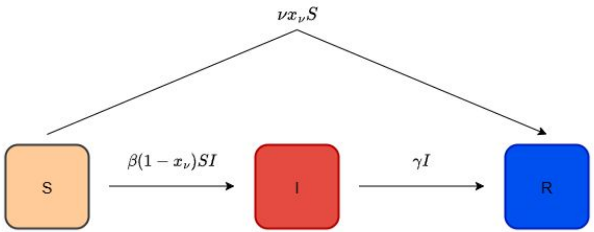


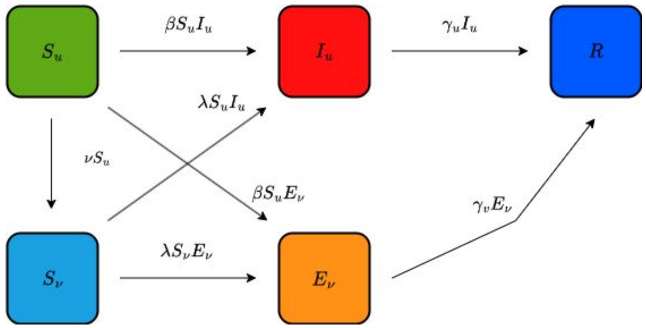
Future Work

- We aim to assess the differential effects of time-dependent and time-independent vaccination strategies on epidemic dynamics, with an emphasis on their capacity to suppress transmission under varying epidemiological conditions.

$$\nu(t) = \begin{cases} ?, & t < t_\nu \\ ?, & t \geq t_\nu \end{cases}$$

- Future work will investigate the influence of alternative vaccination strategies on disease dynamics by extending the model to account for susceptible replenishment driven by waning immunity and the birth and death processes





References

[1] Todd L. Parsons et al. “The probability of epidemic burnout in the stochastic SIR model with vital dynamics”. en. In: Proceedings of the National Academy of Sciences 121.5 (2024), e2313708120. ISSN: 0027-8424, 1091-6490. DOI: 10.1073/pnas.2313708120. URL: https://pnas.org/doi/10.1073/pnas.2313708120.

Thank you!