Modeling COVID-19 Incidence

Interim Presentation for Stat 222 (Spring 2023)

Background and movitation

- By mid-summer, 2021, vaccination eligibility for COVID-19 was widespread and preventive public health measures were significantly loosened
- Return to normalcy in the presence of vaccination led to concerns of the emergence of a vaccine-resistant strain
- In July 2021, Rella et al. (2021) published simulations of outbreak trajectories under various emergence probabilities
  - Resistant strains never established during periods of preventive public health measured
- On November 30, 2021, the first case of the Omicron variant (B.1.1.529) in the US was confirmed (CDC 2021)

Insights from Rella et al. (2021)

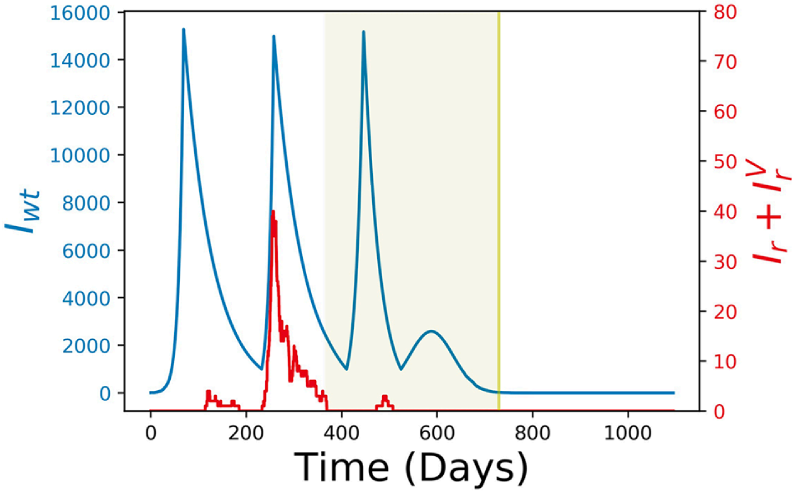


Figure 1: Low emergence probaility

Insights from Rella et al. (2021)

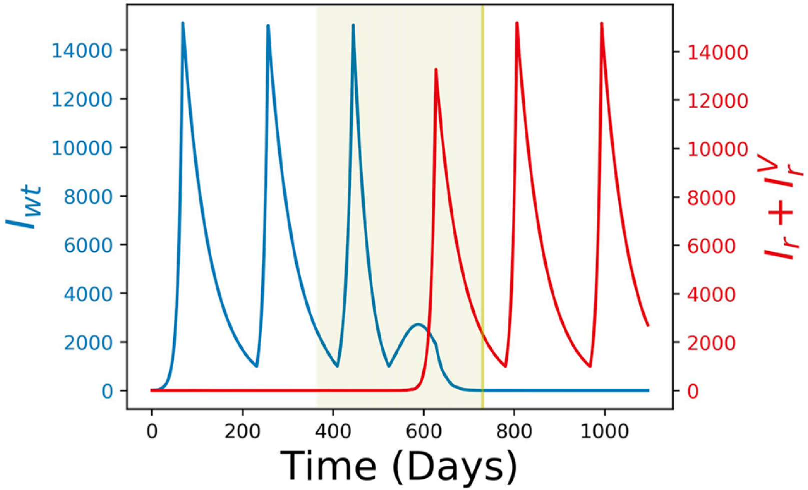
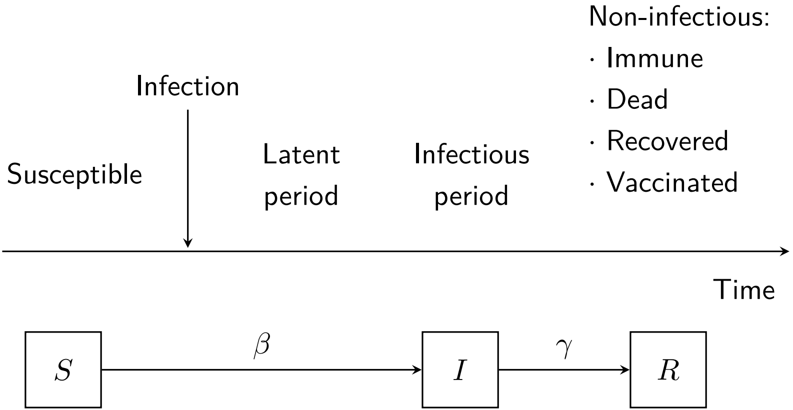


Figure 2: High emergence probaility

Basic concepts in infectious disease epidemiology

- *Infectious agent:* biological causal locus of an infectious disease
- *Contact:* interaction between potential hosts and the infectious agent
- *Infection:* entry of the infectious agent into the host
- *Latent period:* time between infection and infectiousness
- *Infectious period:* the period of time during which contact with hosts means contact with the infectious agent
- These periods make up the *natural history timeline* for infectious disease

Natural history timeline



Compartmental modeling: simple SIR case

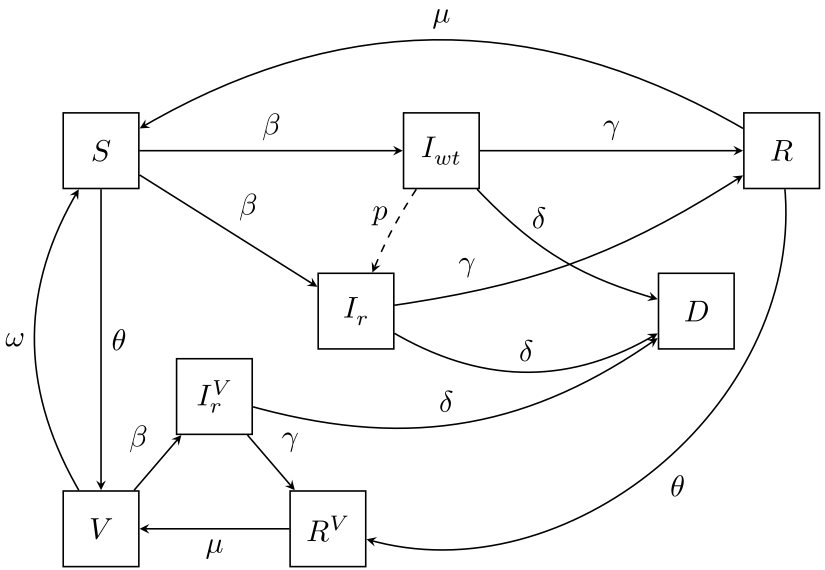
$$S \xrightarrow{\quad\beta\quad} I \xrightarrow{\quad\gamma\quad} R$$

$$\begin{cases} \frac{d}{dt}S = -\frac{\beta}{N}IS \\ \frac{d}{dt}I = \frac{\beta}{N}IS - \gamma I \\ \frac{d}{dt}R = \gamma I \end{cases}$$

$$S + I + R = N$$

See Harko, Lobo, and Mak (2014) for closed-form solutions.

Compartmental modeling: theory of Rella et al. (2021)



Modeling waves in epidemiologic trajectory

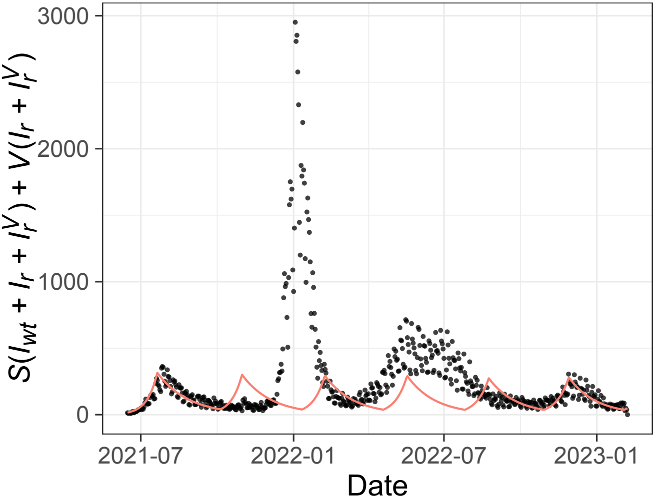
$$\beta(t) = R_0(t) \times \gamma \times N^{-1}$$

where

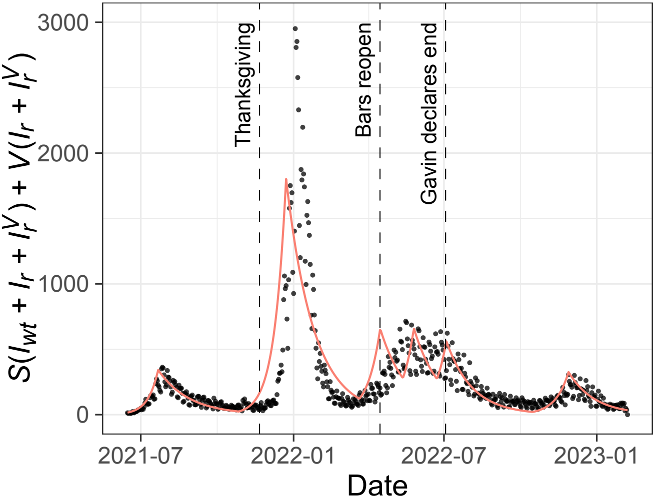
$$R_0(t) = \begin{cases} R_{0,\text{low}} & \text{if} \quad I > N \times p_h \quad \text{and} \quad R_0(t - \Delta t) = R_{0,\text{high}} \\ R_{0,\text{high}} & \text{if} \quad I \times p_h \times p_l \quad \text{and} \quad R_0(t - \Delta t) = R_{0,\text{low}} \end{cases}$$

where $I = I_{wt} + I_r + I_r^V$

Preliminary fit with time-invariant p_h and p_l



Preliminary fit with time-varying p_h and p_l



Parameter specification (time-permitting)

Parameter	Value	Interpretation
θ	250.6335	Vaccination rate (vaccines per day)
δ	7.3 $\times$ 10,000	Death rate (deaths per day)
R_{0_h}	2.2	R_0 during low caution
R_{0_l}	0.65	R_0 during high caution
γ	1/14	Inv. disease duration (days)
μ	1/(30 $\times$ 12)	Inv. duration of natural immunity
ω	1/(30 $\times$ 12)	Inv. duration of vaccine protection

Parameter specification (time-permitting)

Parameter	Value	Interpretation
$p_{h,1}$	$1/350$	Maximum prevalence before preventive measures in 1st wave
$p_{h,2}$	$1/63$	Maximum prevalence (2nd)
$p_{h,3}$	$1/165$	Maximum prevalence (3rd)
$p_{h,4}$	$1/325$	Maximum prevalence (4th)
$p_{l,1}$	$1/(350 \times 15)$	Allowable prevalence before before loosening measures (1st)
$p_{l,2}$	$1/(63 \times 15)$	Allowable prevalence (2nd)
$p_{l,3}$	$1/(165 \times 2.5)$	Allowable prevalence (3rd)
$p_{l,4}$	$1/(325 \times 17)$	Allowable prevalence (4th)

References

CDC. 2021. "First Confirmed Case of Omicron Variant Detected in the United States." *First Confirmed Case of Omicron Variant Detected in the United States*. https://www.cdc.gov/media/releases/2021/s1201-omicron-variant.html.

Harko, Tiberiu, Francisco SN Lobo, and MK3197716 Mak. 2014. "Exact Analytical Solutions of the Susceptible-Infected-Recovered (SIR) Epidemic Model and of the SIR Model with Equal Death and Birth Rates." *Applied Mathematics and Computation* 236: 184–94.

Rella, Simon A, Yuliya A Kulikova, Emmanouil T Dermitzakis, and Fyodor A Kondrashov. 2021. "Rates of SARS-CoV-2 Transmission and Vaccination Impact the Fate of Vaccine-Resistant Strains." *Scientific Reports* 11 (1): 15729.