Dynamical modeling of infectious diseases

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Global Health Expert Perspectives Webinar
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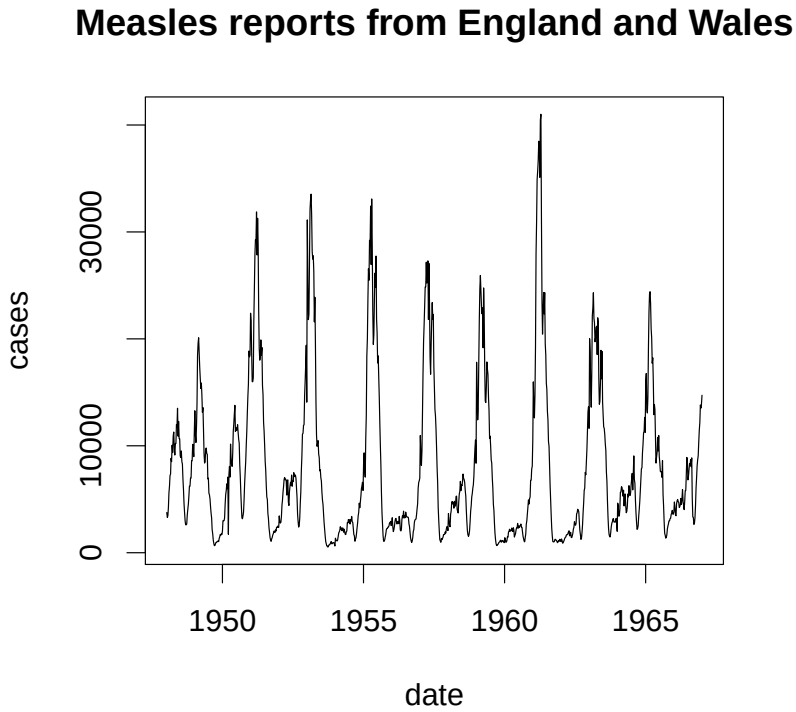
What is dynamical modeling?



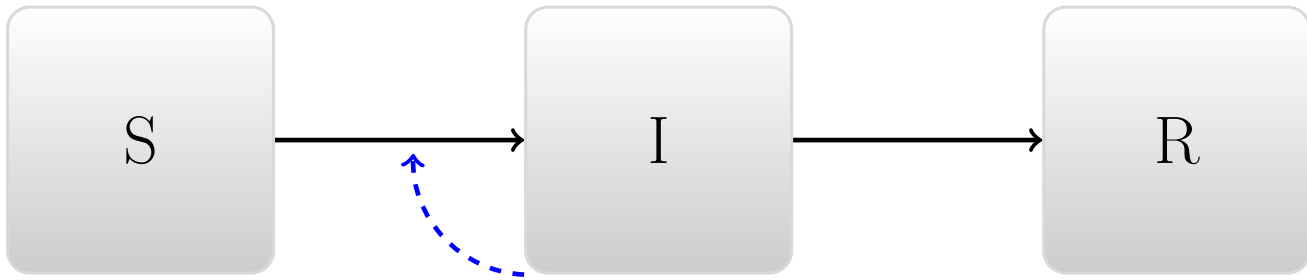
- A way to connect scales
- Start with rules about how things change in short time steps
  - Usually based on *individuals*
- Calculate results over longer time periods
  - Usually about *populations*

Example: Post-death transmission and safe burial

- How much Ebola spread occurs before vs. after death
- Highly context dependent
  - Funeral practices, disease knowledge
- *Weitz and Dushoff Scientific Reports 5:8751.*

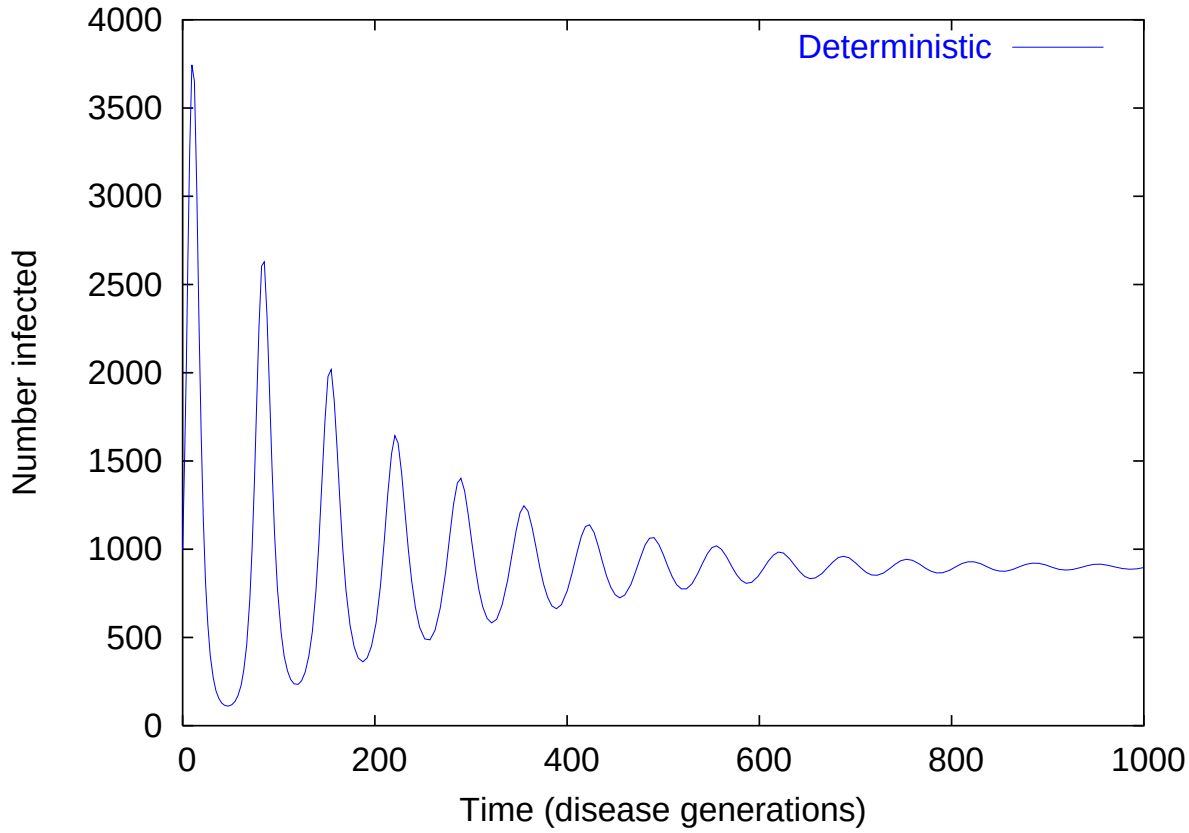
Simple dynamical models use compartments

Divide people into categories:

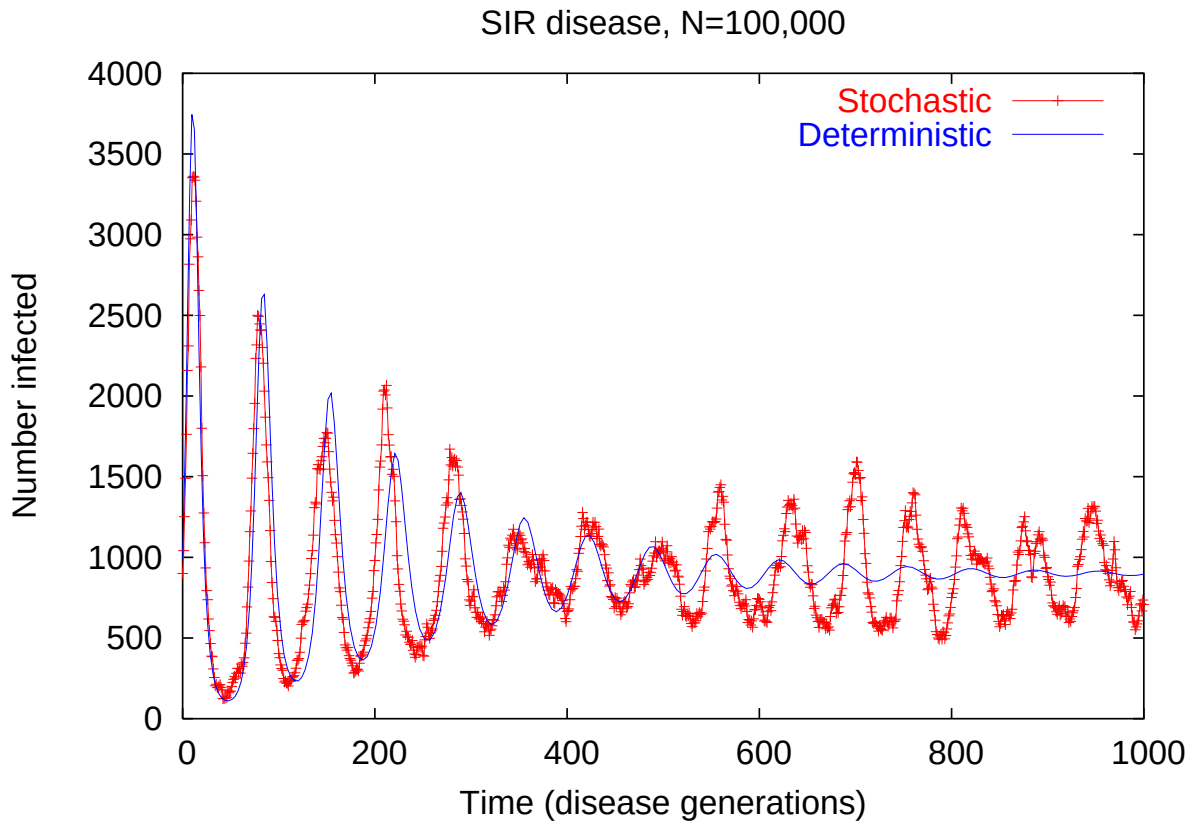


- Susceptible $\rightarrow$ Infectious $\rightarrow$ Recovered
- Individuals recover independently
- Individuals are infected by infectious people

Deterministic implementation

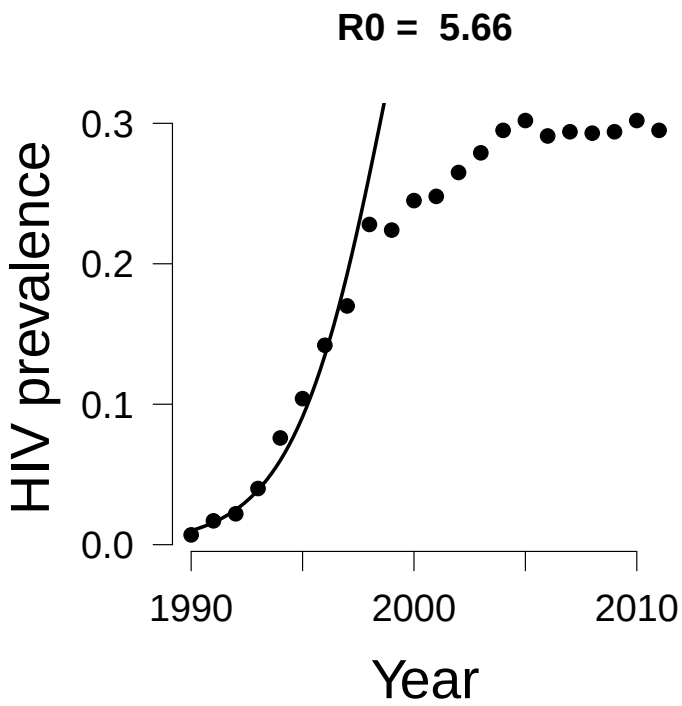


Individual-based implementation

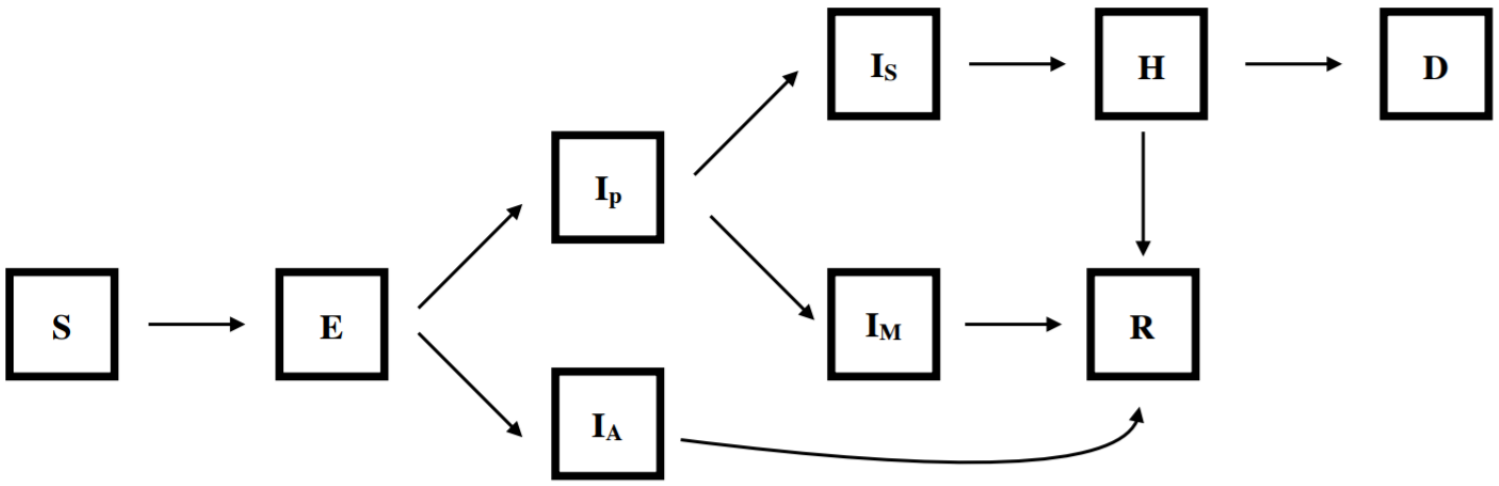


Disease tends to grow exponentially at first

- I infect three people, they each infect 3 people . . .
- How fast does disease grow?
- How quickly do we need to respond?



More detailed dynamics



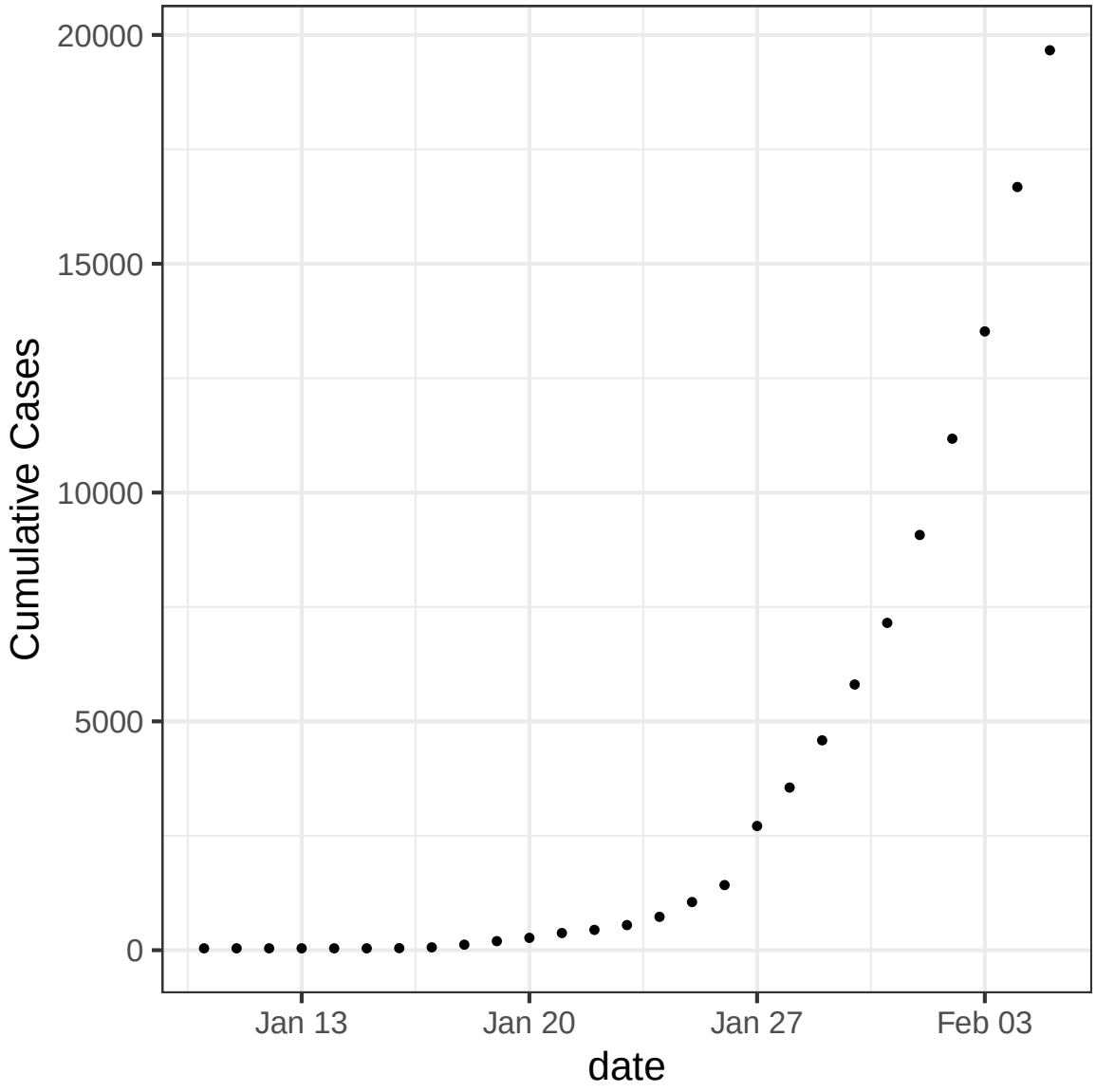
S = susceptible
E = exposed

I_p = pre-symptomatic
I_A = asymptomatic
I_S = symptomatic, severe case
I_M = symptomatic, minor case

H = hospitalized
R = recovered
D = dead

Childs et al., http://covid-measures.stanford.edu/

Exponential growth



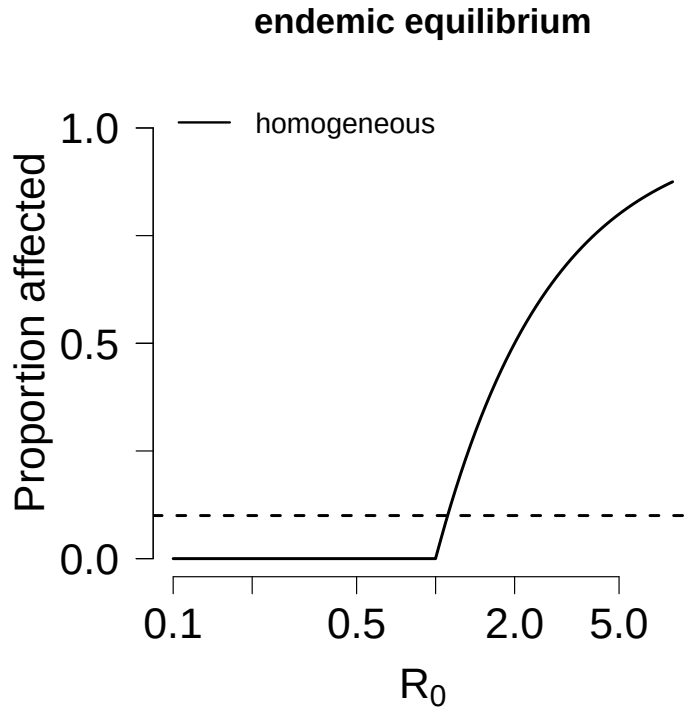
Mike Li, https://github.com/wzmli/corona

There are natural thresholds

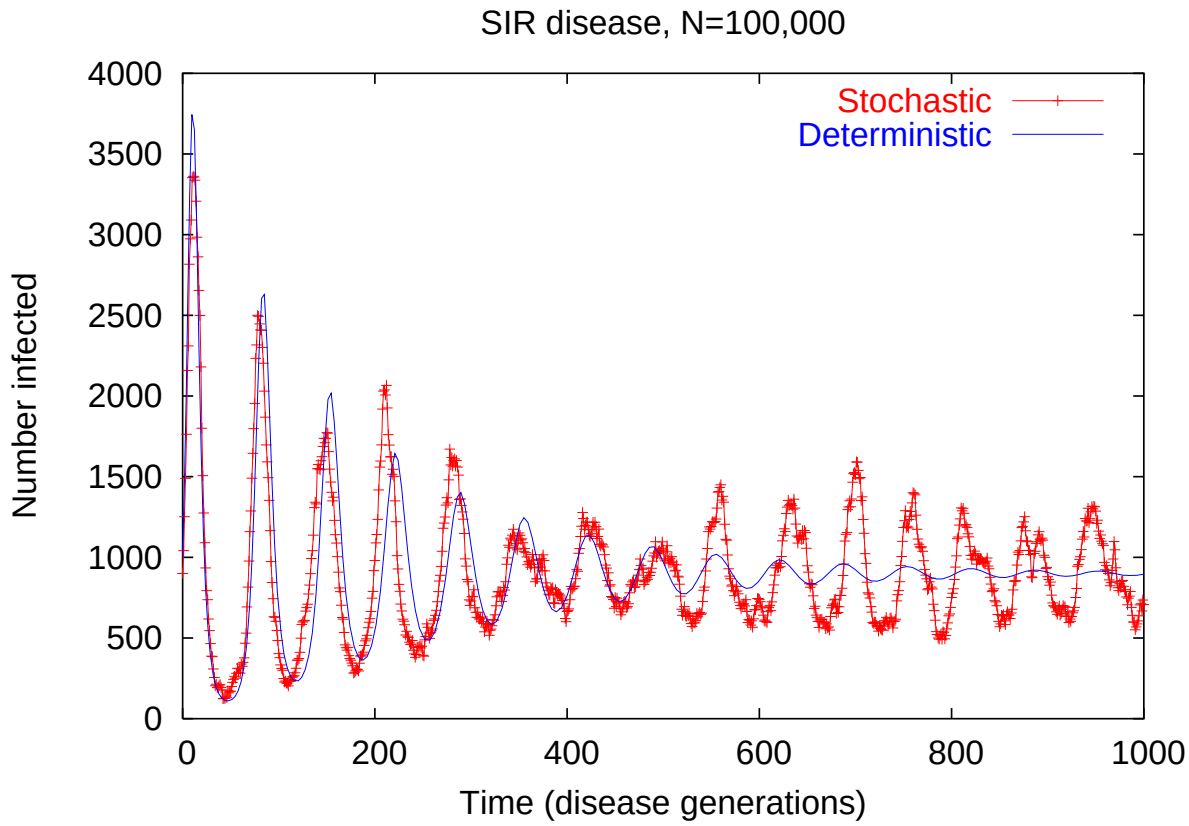
- $\mathcal{R}$ is the number of new infections per infection
- A disease can invade a population if and only if $\mathcal{R} > 1$.
- The value of $\mathcal{R}$ in a naive population is called $\mathcal{R}_0$

Non-linear response

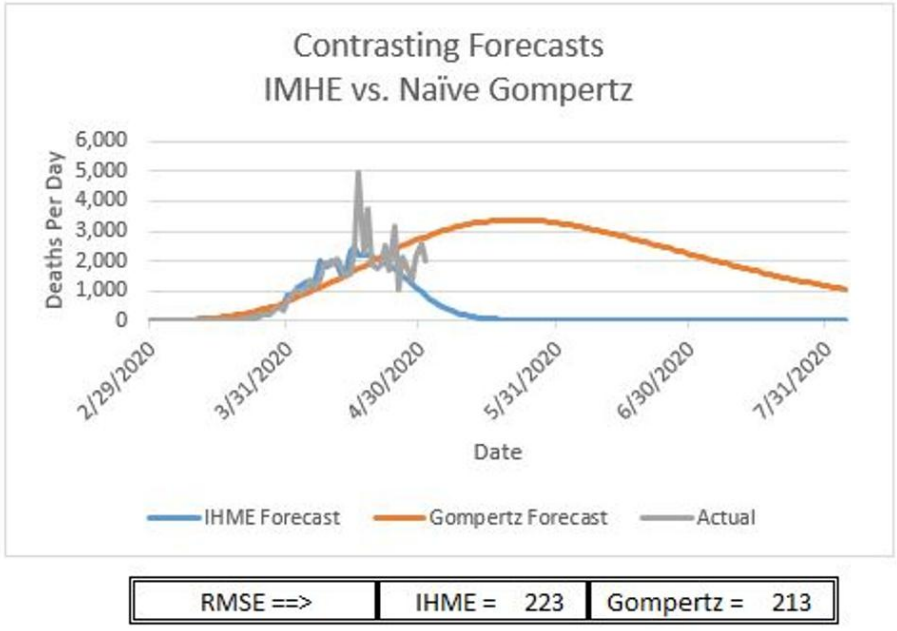
- $\mathcal{R} = \beta/\gamma = \beta D = (cp)D$
  - c: Contact Rate
  - p: Probability of transmission (infectivity)
  - D: Average duration of infection



Disease incidence tends to oscillate



What is *not* dynamical modeling?

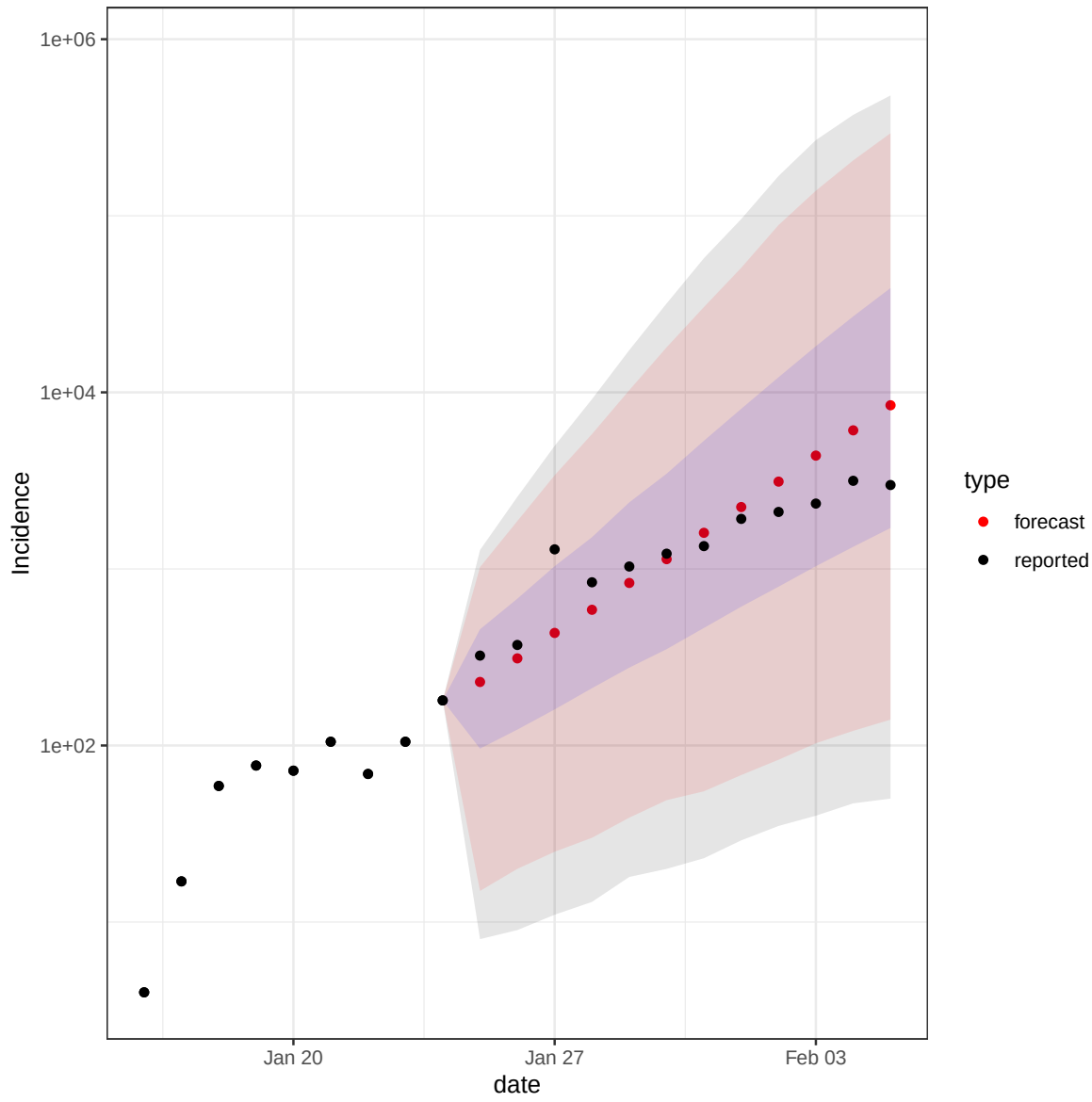


RMSE ==>	IHME = 223	Gompertz = 213

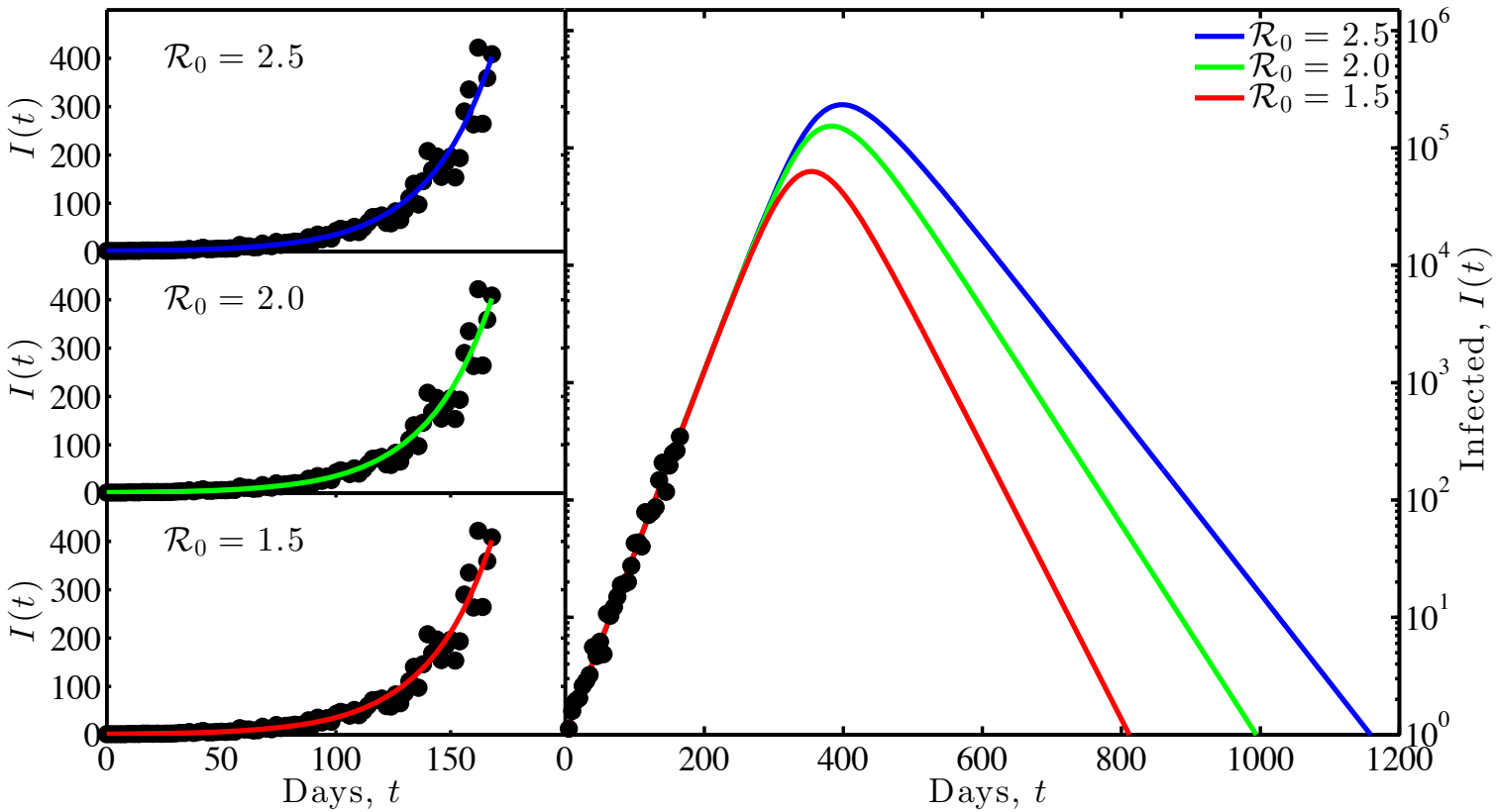
https://tinyurl.com/forbes-ihme

- Phenomenological modeling uses history and statistics
- Does not incorporate mechanistic processes

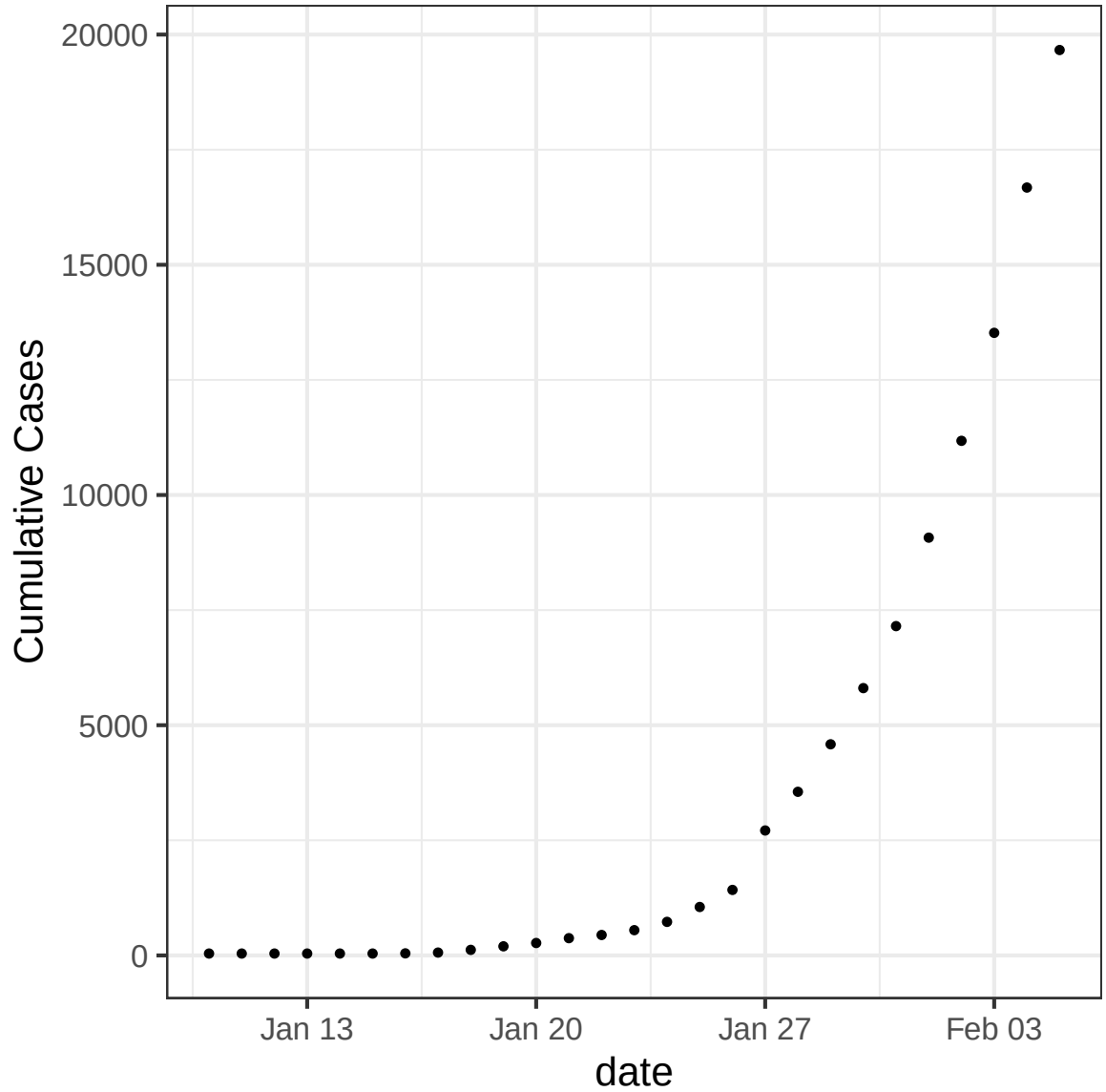
Coronavirus forecasting



Linking


$\mathcal{R}_0 = 2.5$
$\mathcal{R}_0 = 2.0$
$\mathcal{R}_0 = 1.5$
$I(t)$
Days, t
Infected, $I(t)$

Coronavirus speed

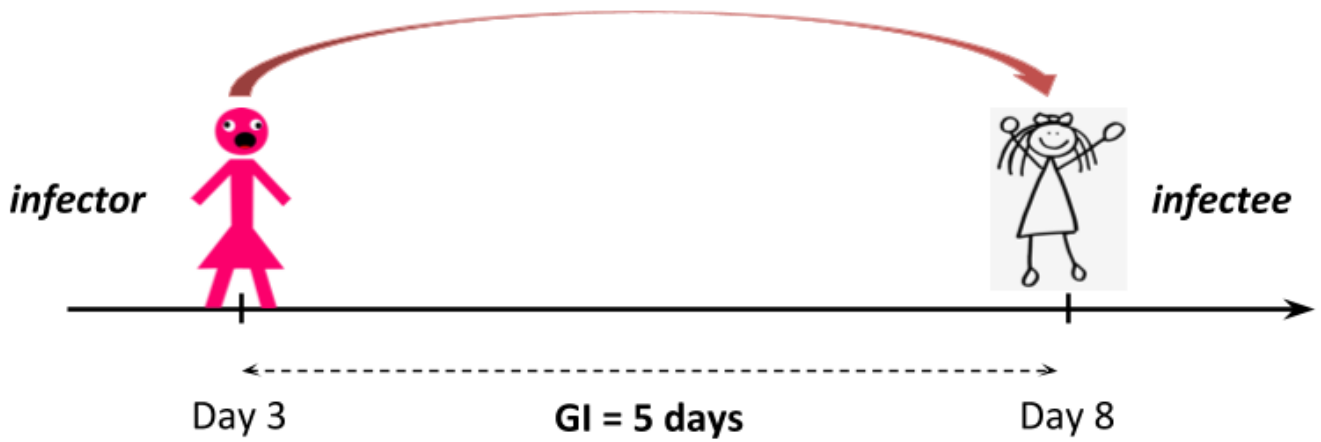


How long is a disease generation? (present)

Definition

Generation Interval:

Interval between the time that an individual is infected by an infector and the time this infector was infected

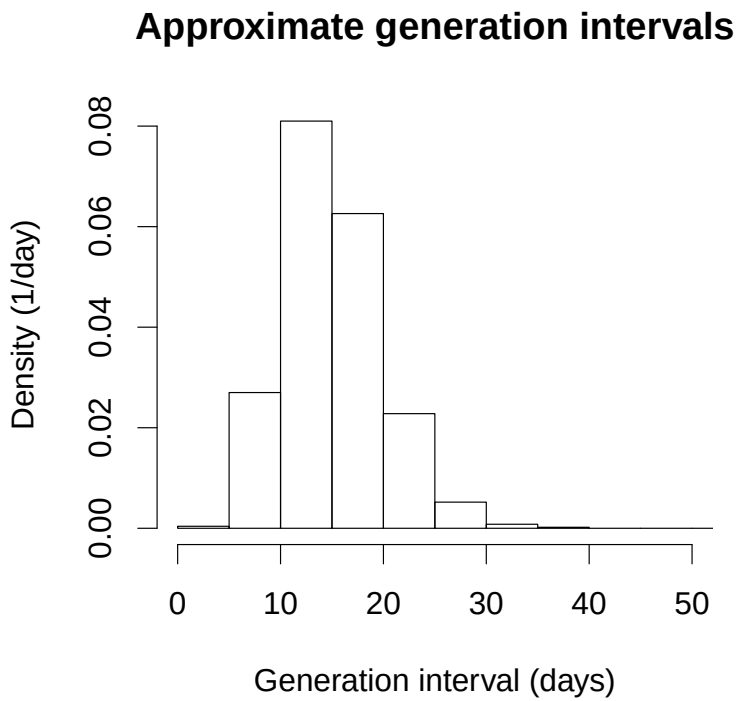


Generation intervals

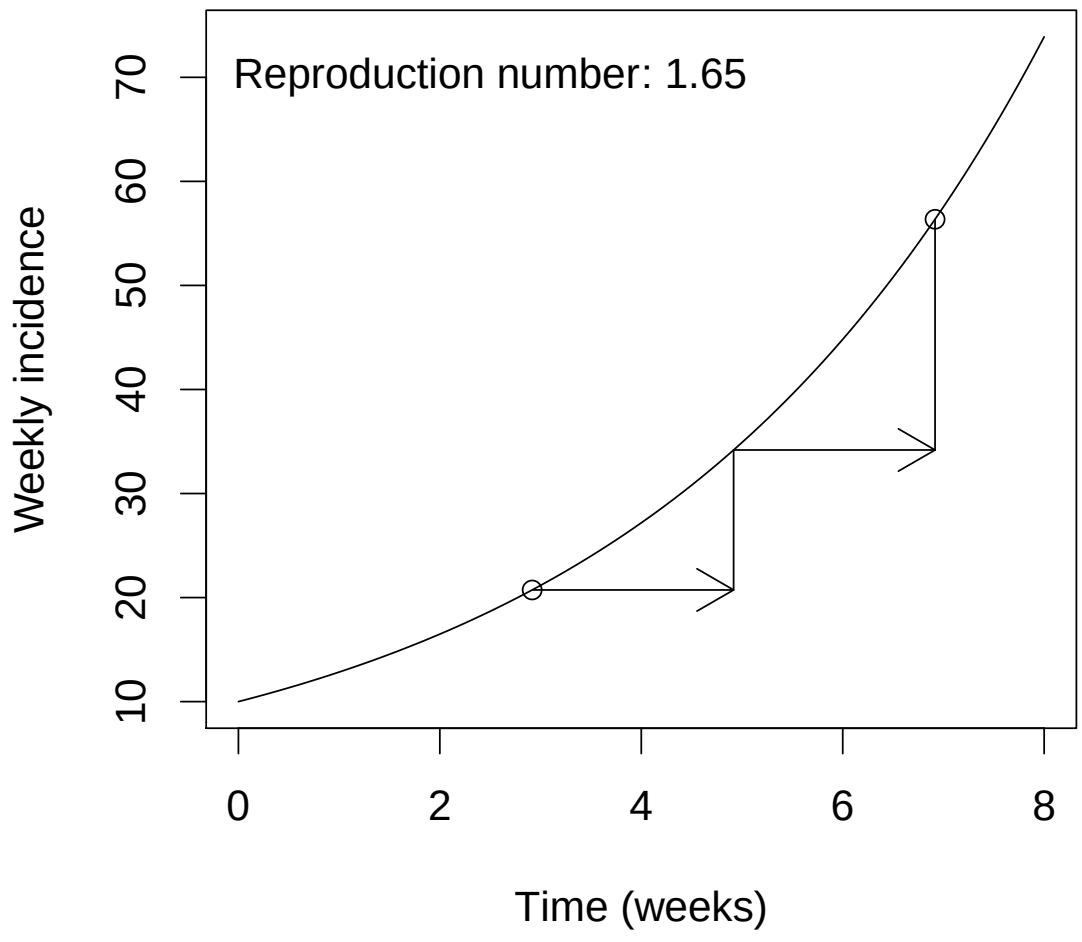
- Sort of the poor relations of disease-modeling world
- Ad hoc methods
- Error often not propagated

Generation intervals

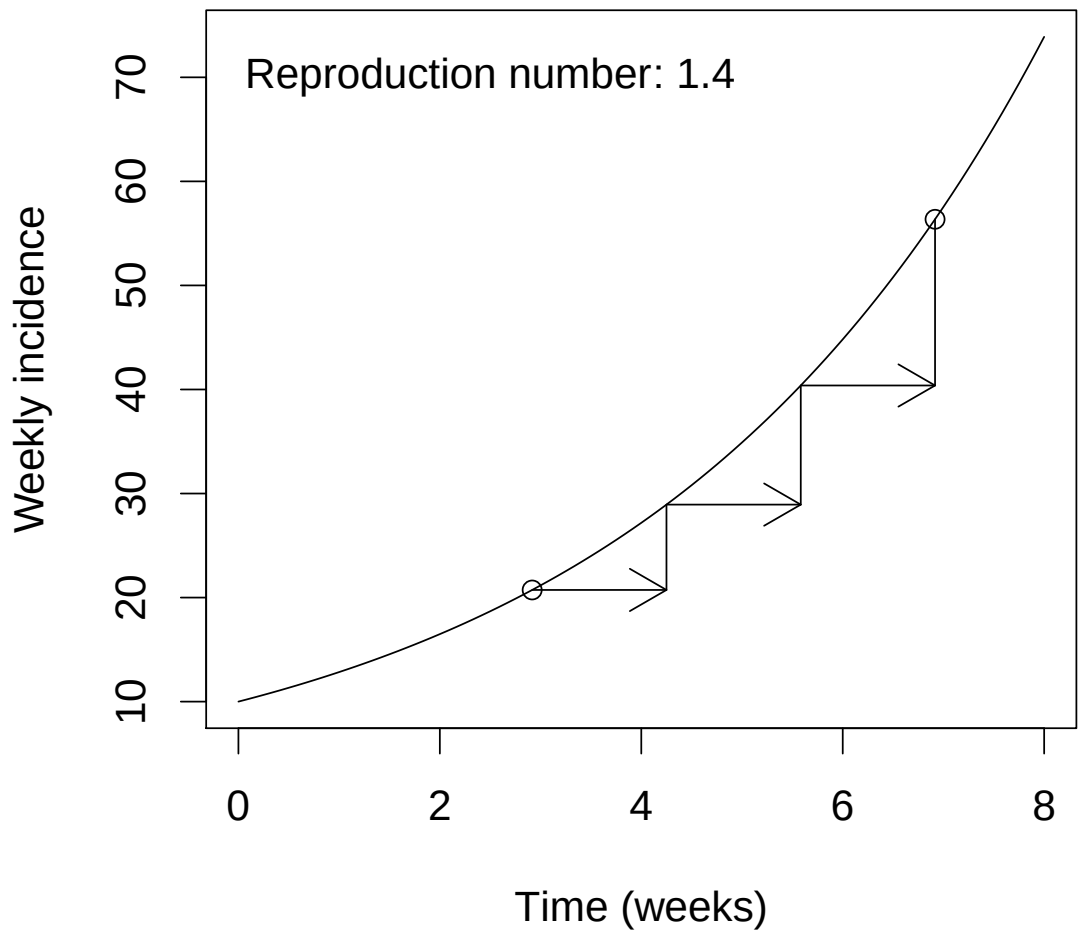
- The generation distribution measures the time between generations of the disease
  - Interval between "index" infection and resulting infection
- Generation intervals provide the link between $\mathcal{R}$ and r



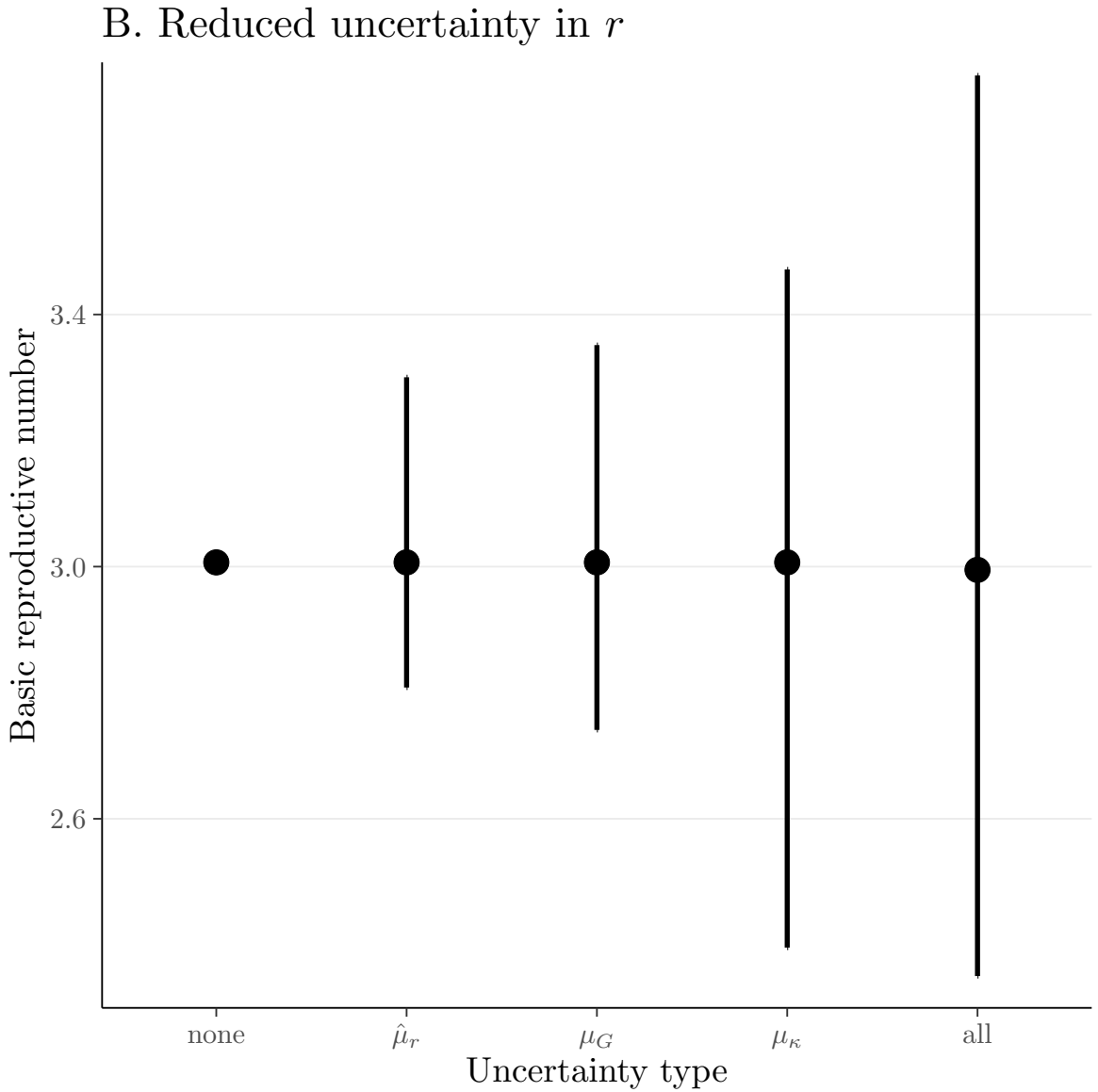
Generations and $\mathcal{R}$



Generations and $\mathcal{R}$

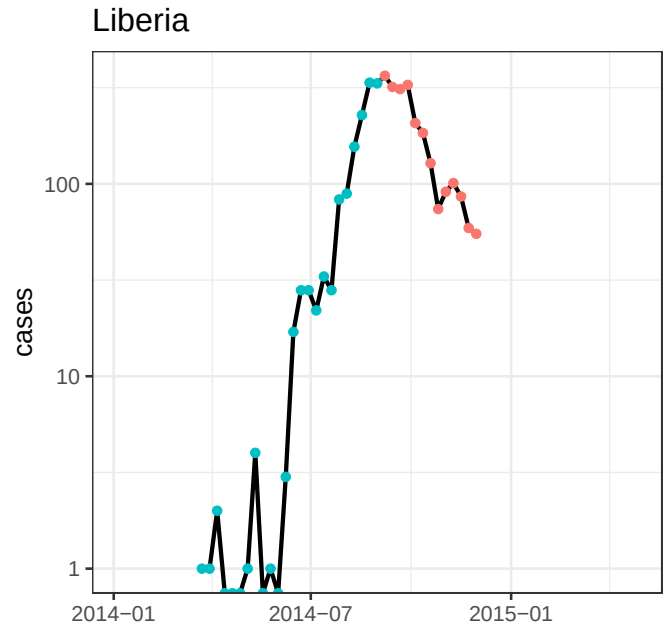


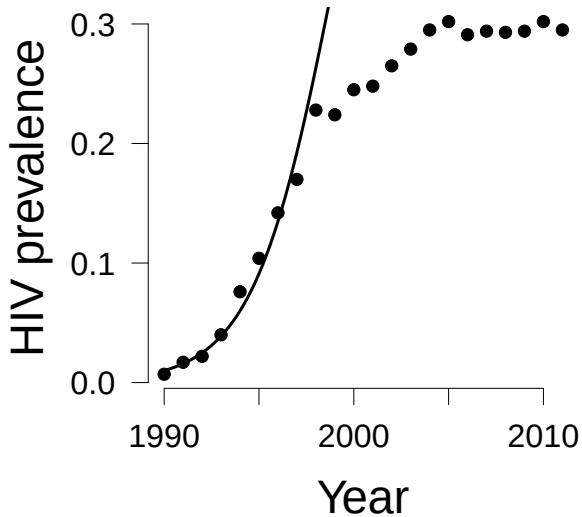
Propagating error for coronavirus



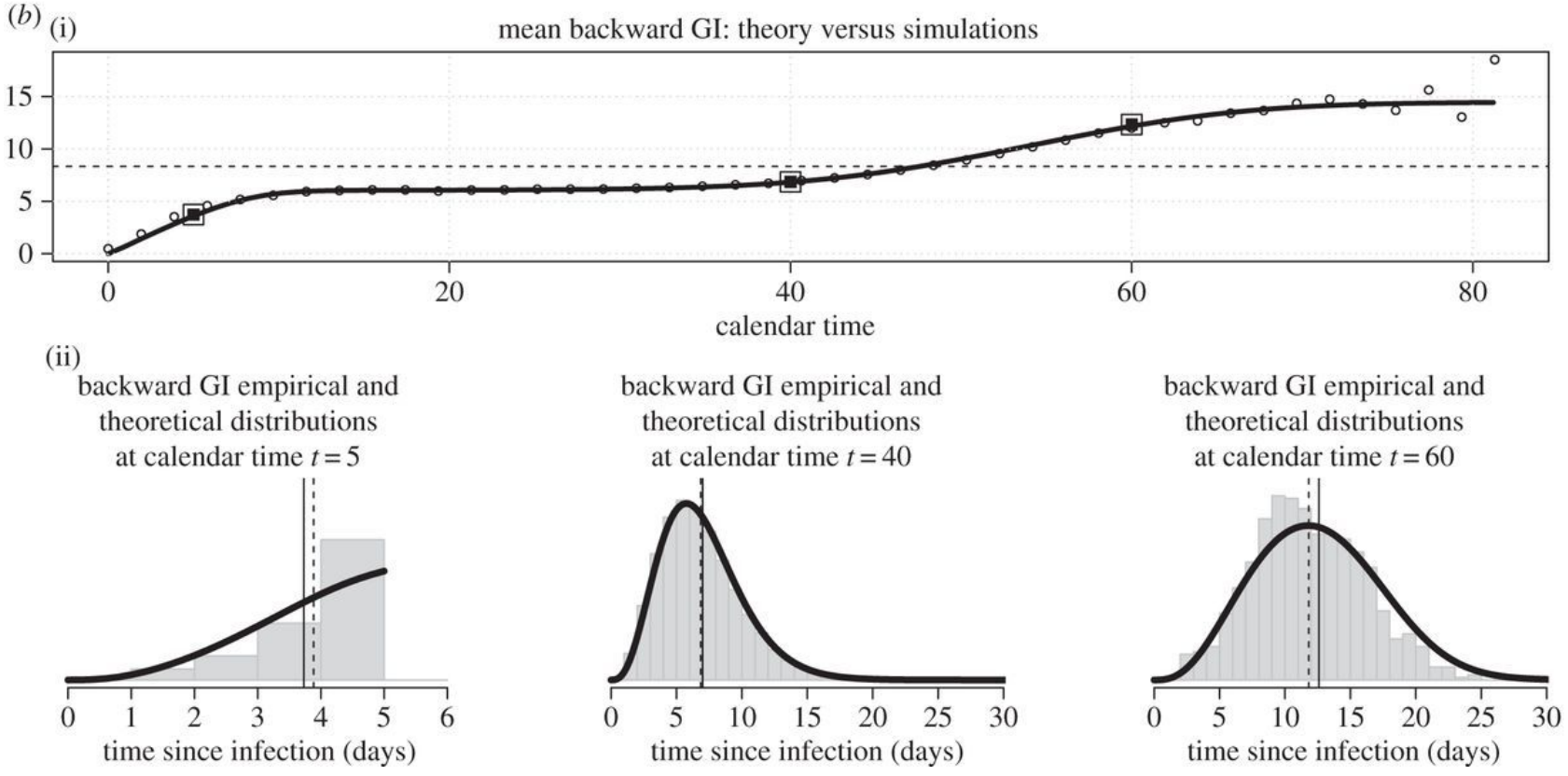
Growing epidemics

- Generation intervals look *shorter* at the beginning of an epidemic
  - A disproportionate number of people are infectious right now
  - They haven't finished all of their transmitting



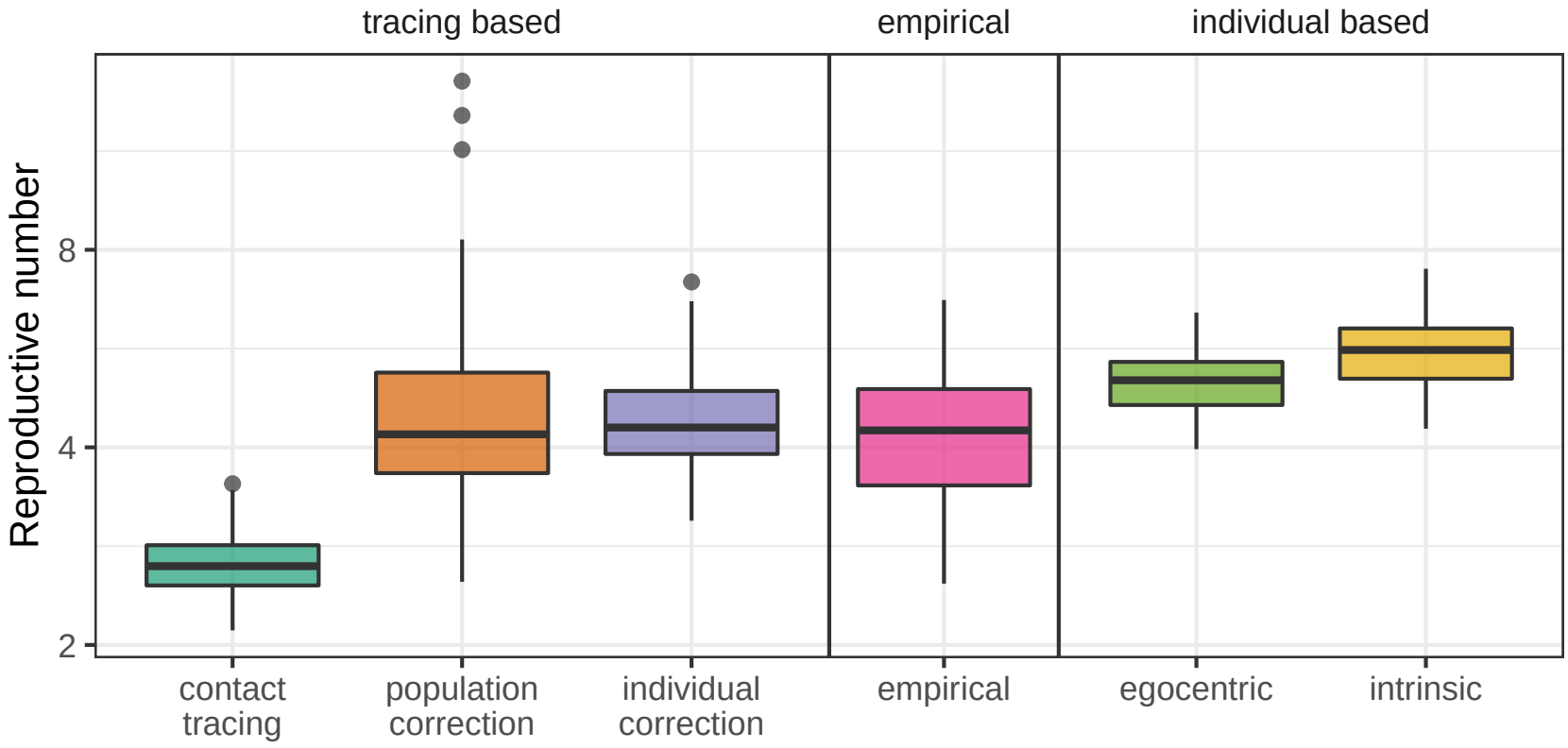


Backward intervals

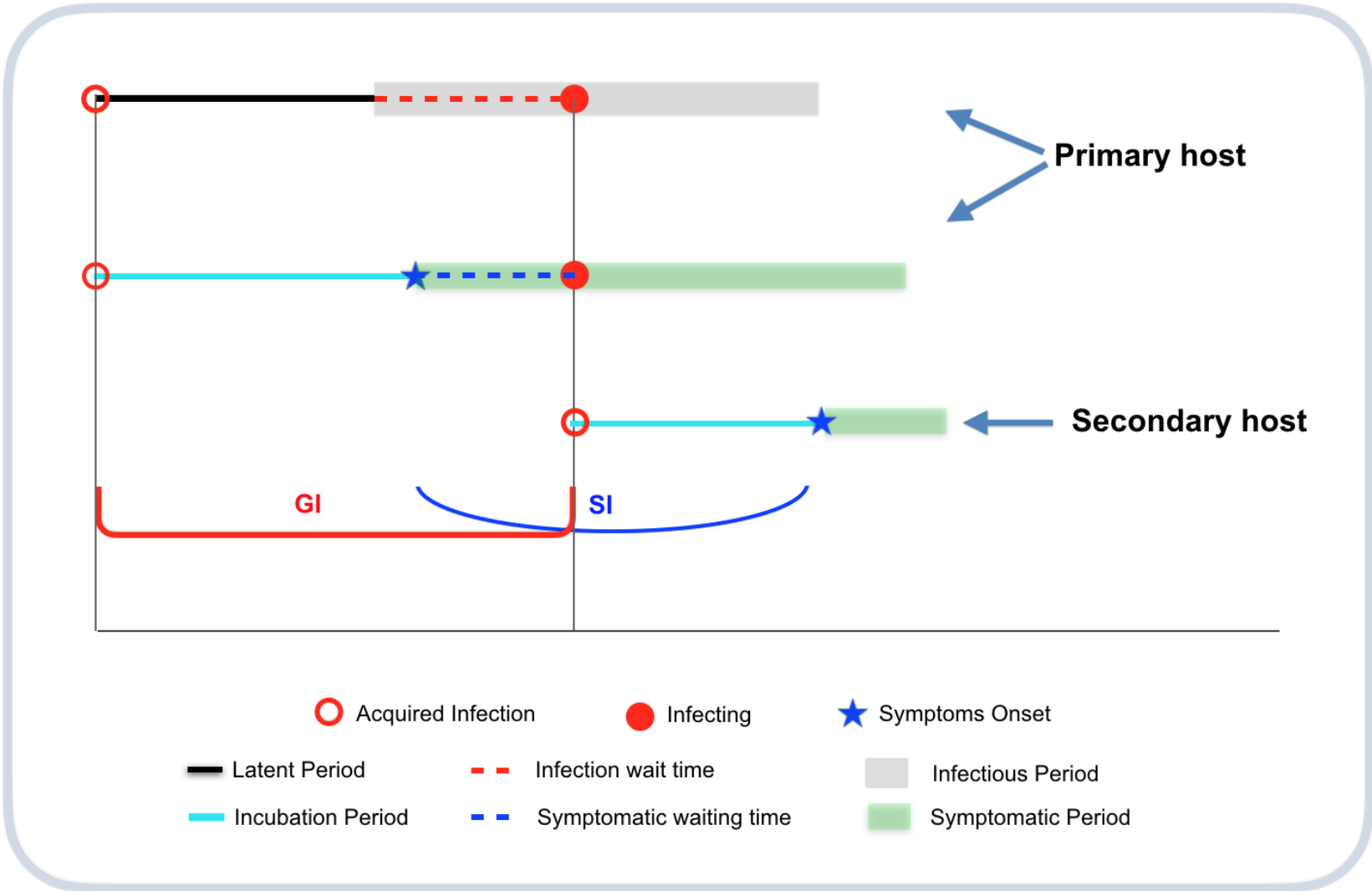


Champredon and Dushoff, 2015. DOI:10.1098/rspb.2015.2026

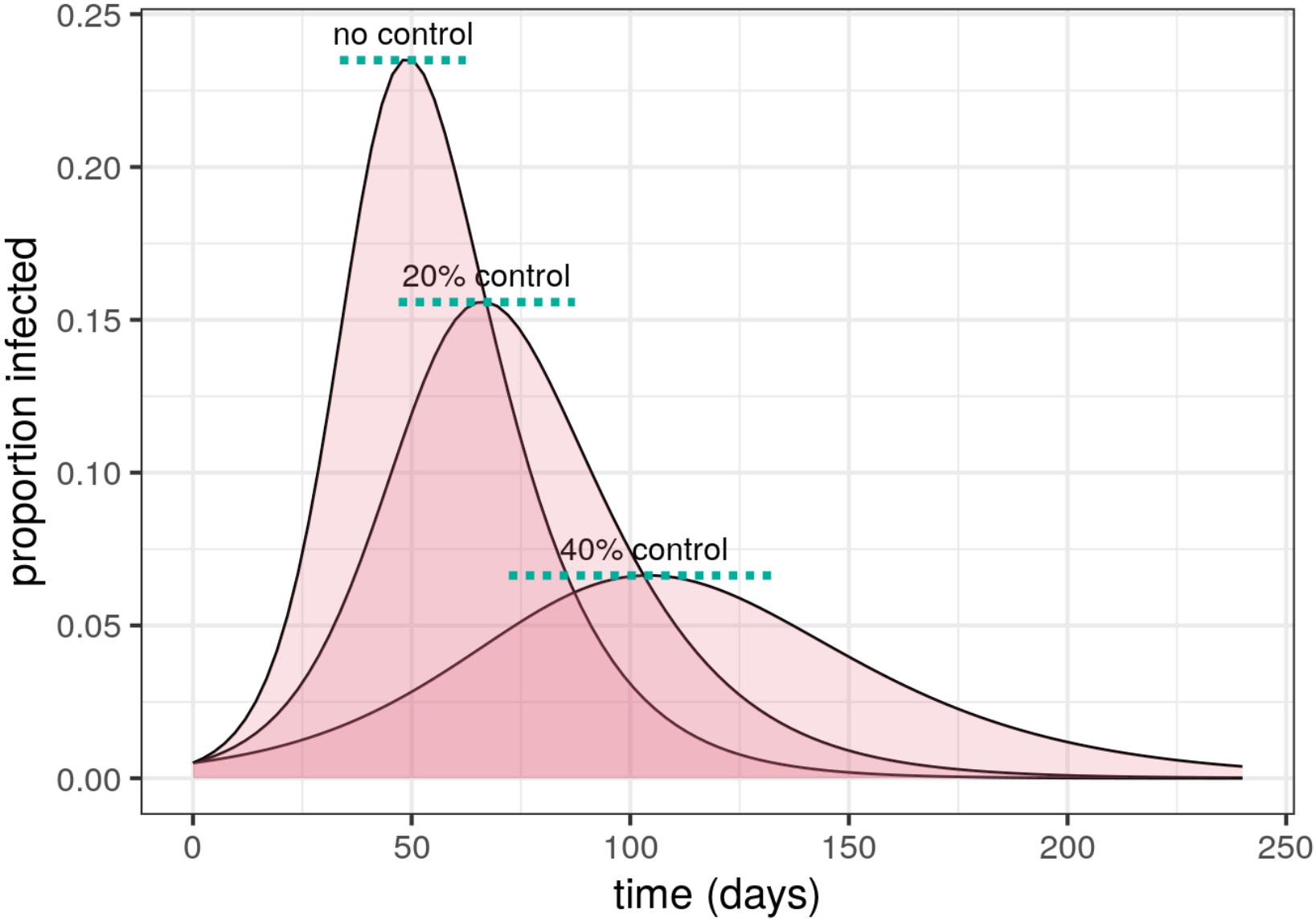
Outbreak estimation



Serial intervals

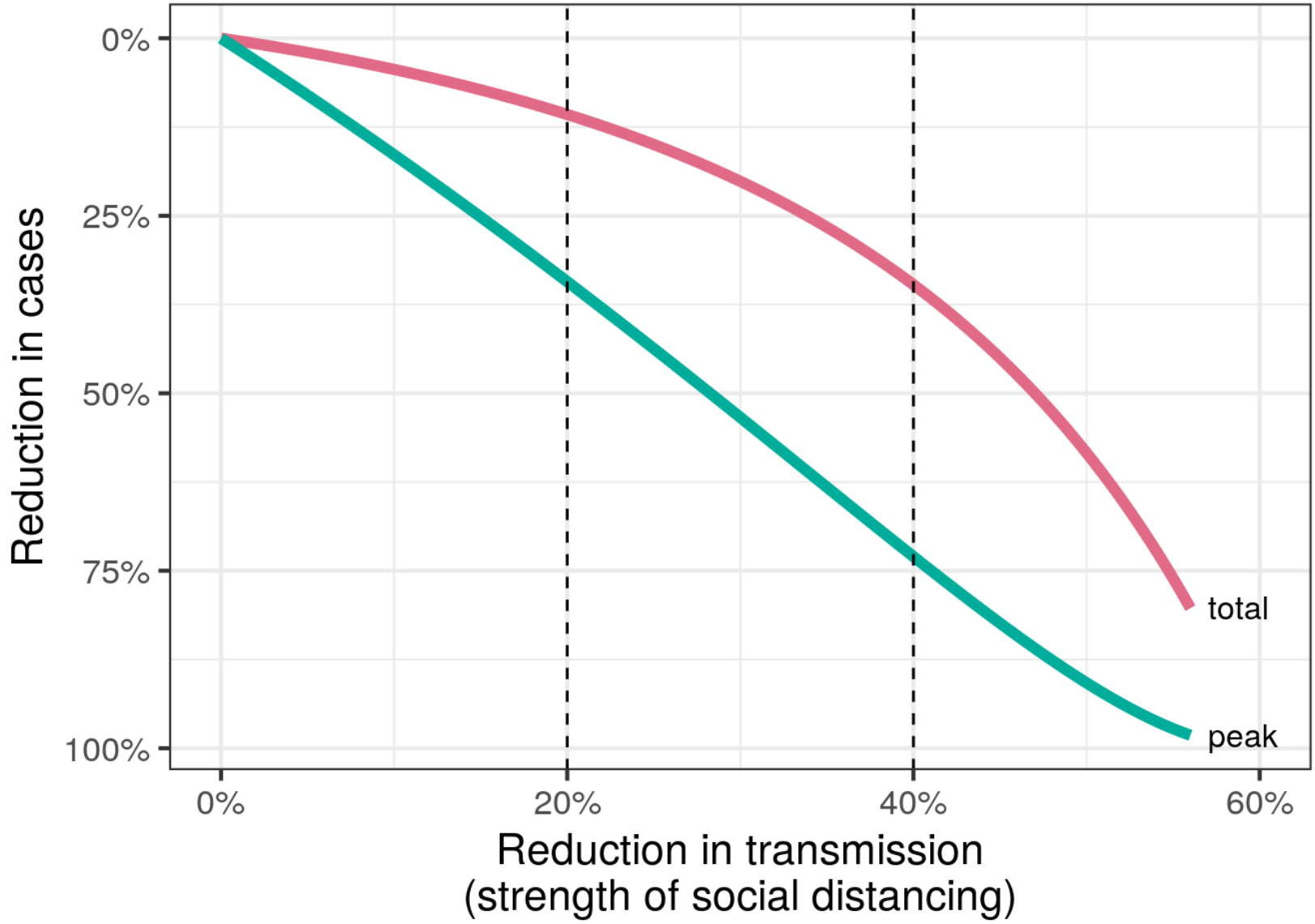


Flattening the curve



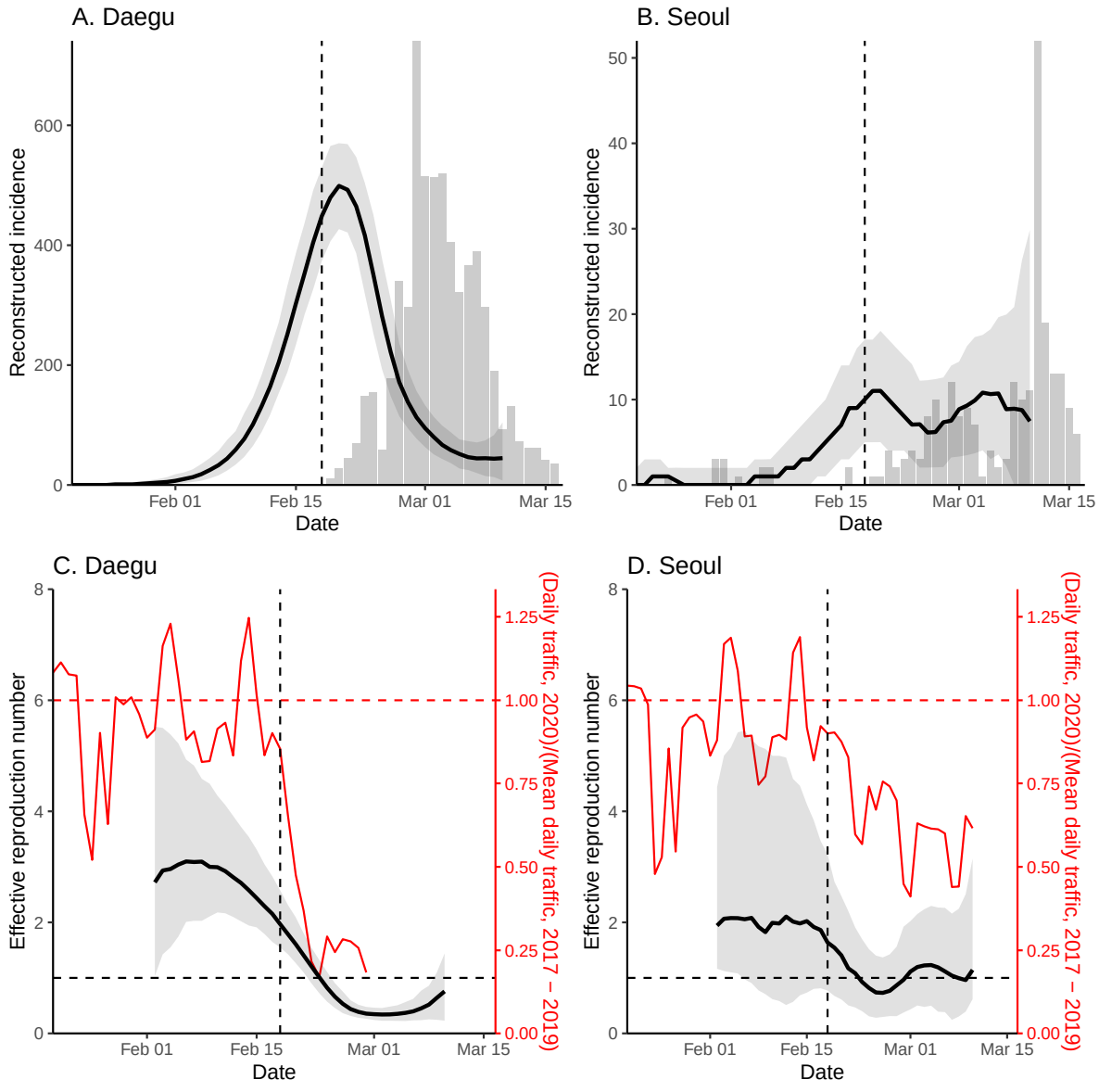
Bolker and Dushoff, https://github.com/bbolker/bbmisc/

Flattening the curve



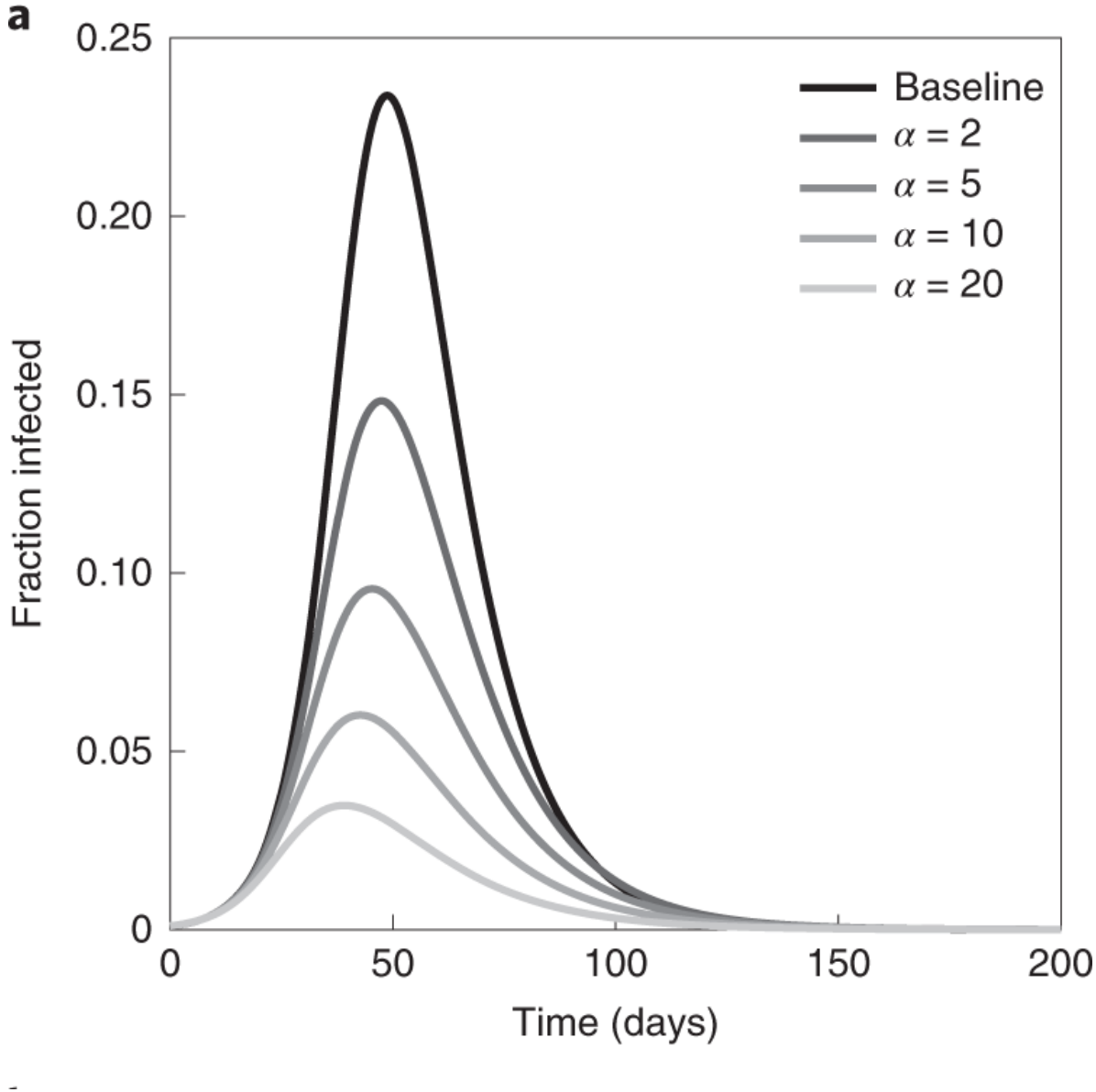
Bolker and Dushoff, https://github.com/bbolker/bbmisc/

What happens when we open?



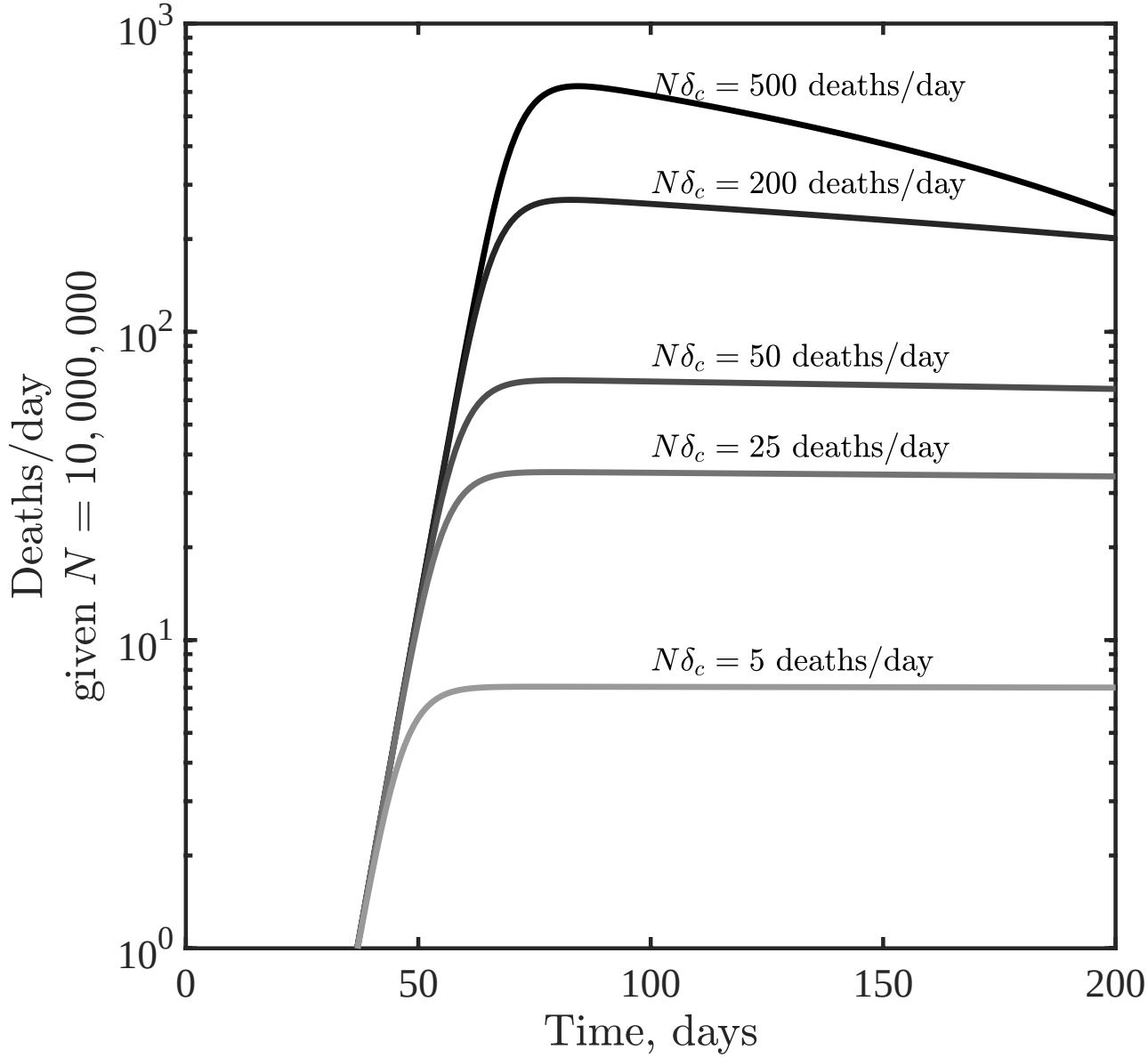
Park et al., https://doi.org/10.1101/2020.03.27.20045815

Making use of immunity



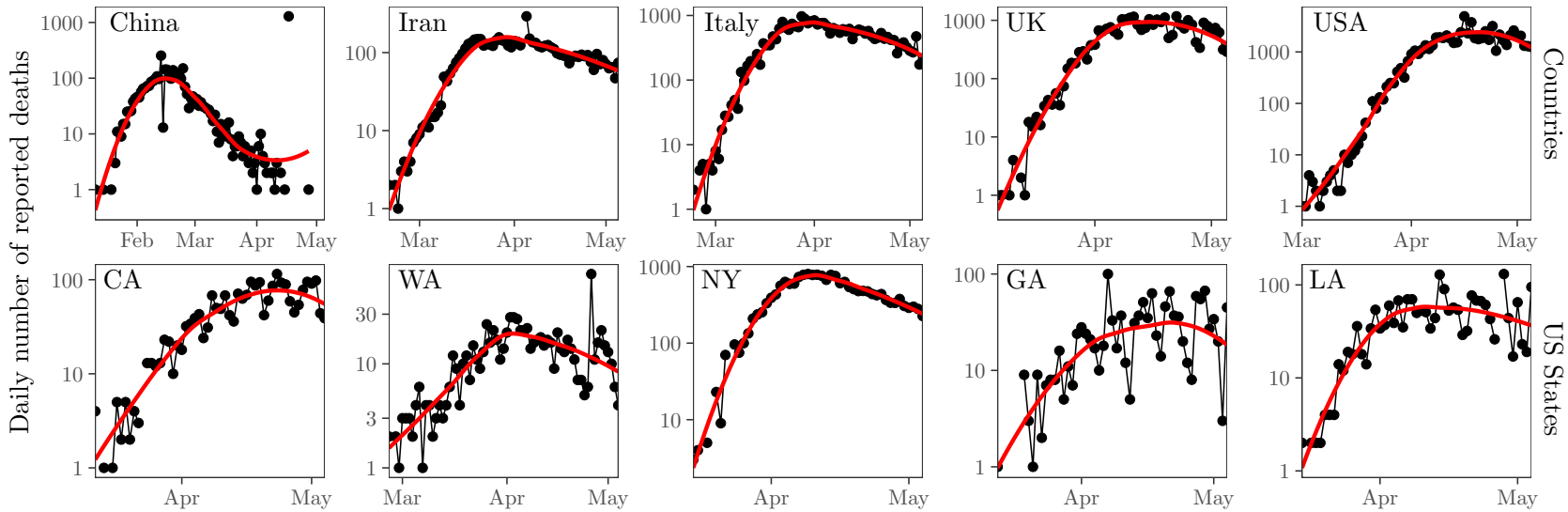
Weitz et al., https://www.nature.com/articles/s41591-020-0895-3

Modeling responses



Weitz et al., https://github.com/jsweitz/covid19-git-plateaus

Modeling responses



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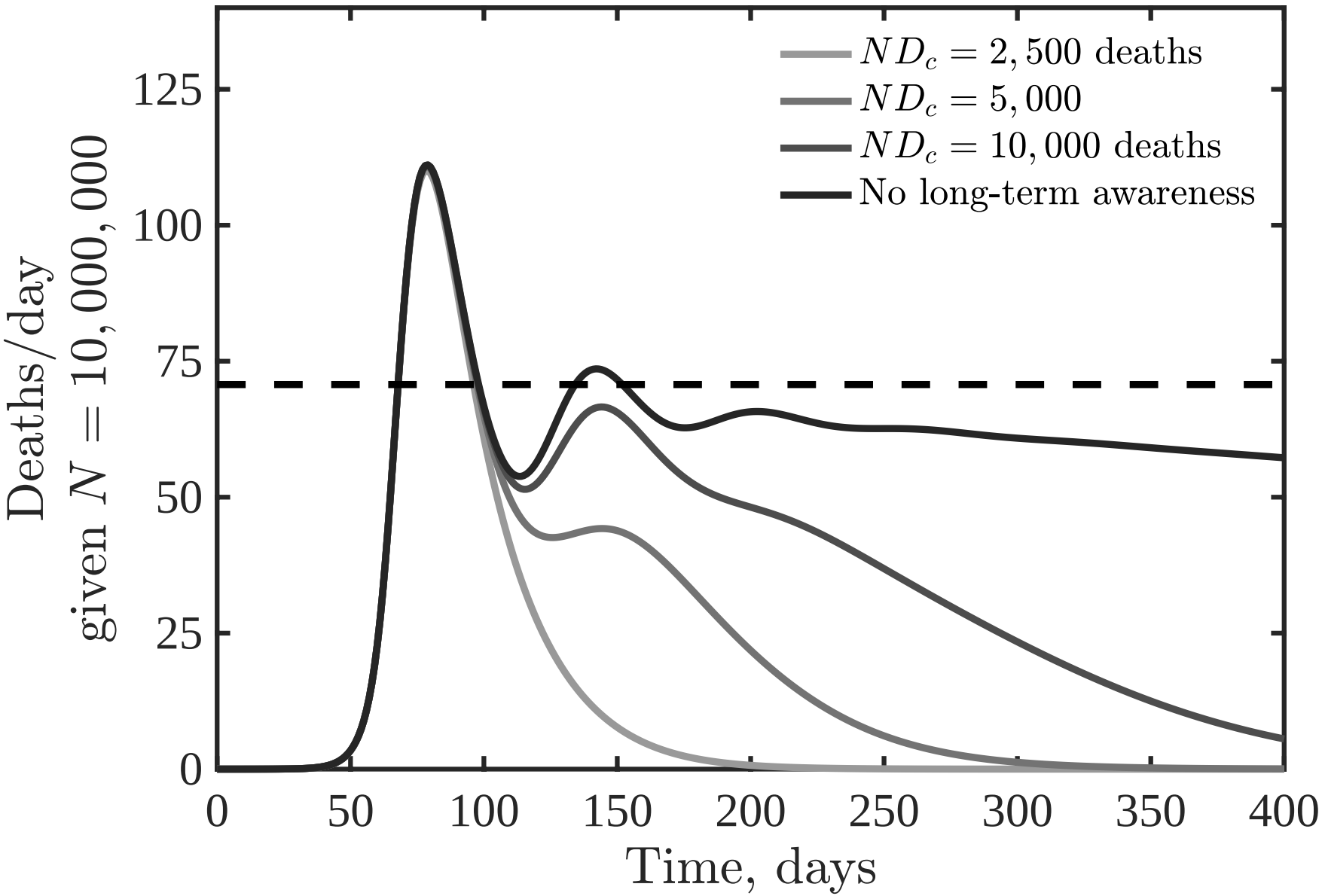
Modeling responses



Going forward

- Statistical methods for inference and understanding uncertainty
- Work with policymakers to evaluate and tune strategies for gradual opening

Thanks

- Department
- Collaborators
  - Bolker, Champredon, Earn, Li, Ma, Park, Weitz, many others
- Funders: NSERC, CIHR