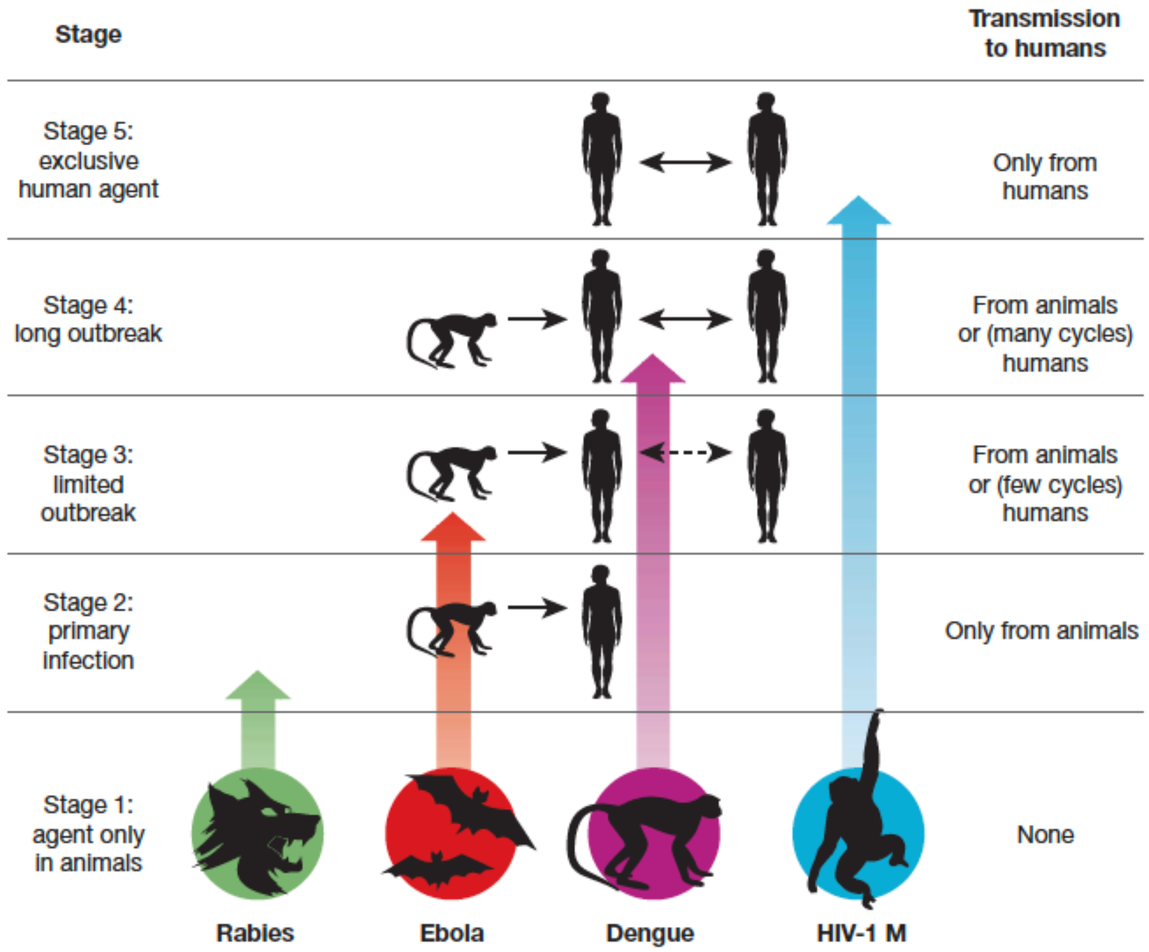
Stages of pathogen emergence



Behavior related to different stages

- Human contact patterns
- Vaccination behaviour
- Self protecting behaviour
- Travel patterns
- Human animal contacts

How does behaviour affect pathogen evolution?

Wolfe et al Nature 2007

Questions

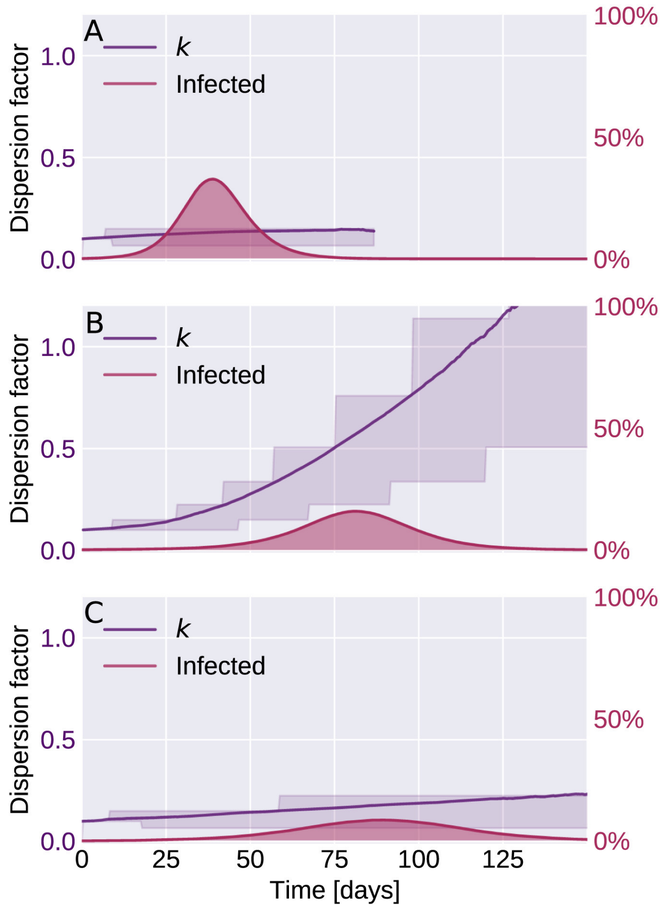
- Which human behaviours are important for pathogen evolution?
- How can these behaviours be quantified?
- Which evolutionary mechanisms do they influence?
- What are implications for intervention strategies?

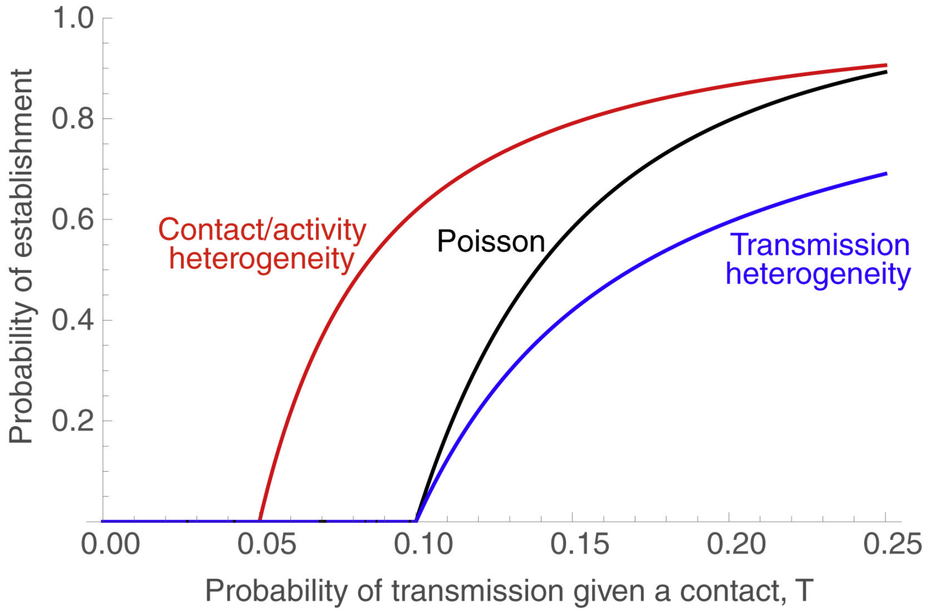
Example: contact patterns

- Did lockdowns influence the strain evolution of SARS-CoV2?
- More generally: how do heterogeneities in contact patterns influence evolution of a circulating pathogen?

Impact of lockdowns on evolution

Lower contact rate leads
to evolution of more
overdispersion in
viral loads





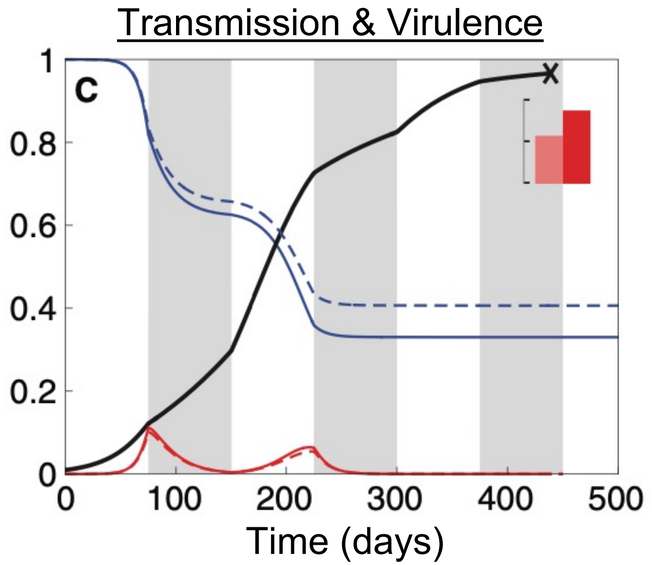
Current Biology

Probability of establishment of new strain changes with overdispersion

Nielsen et al 2022

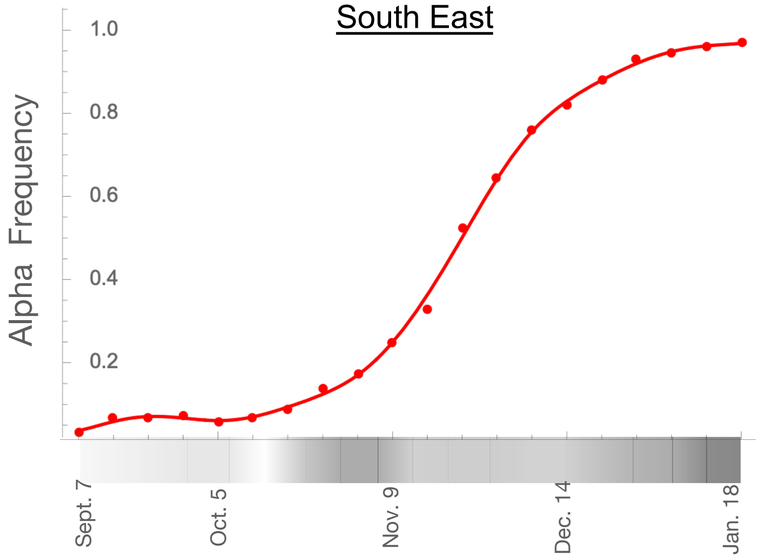
Otto et al 2021

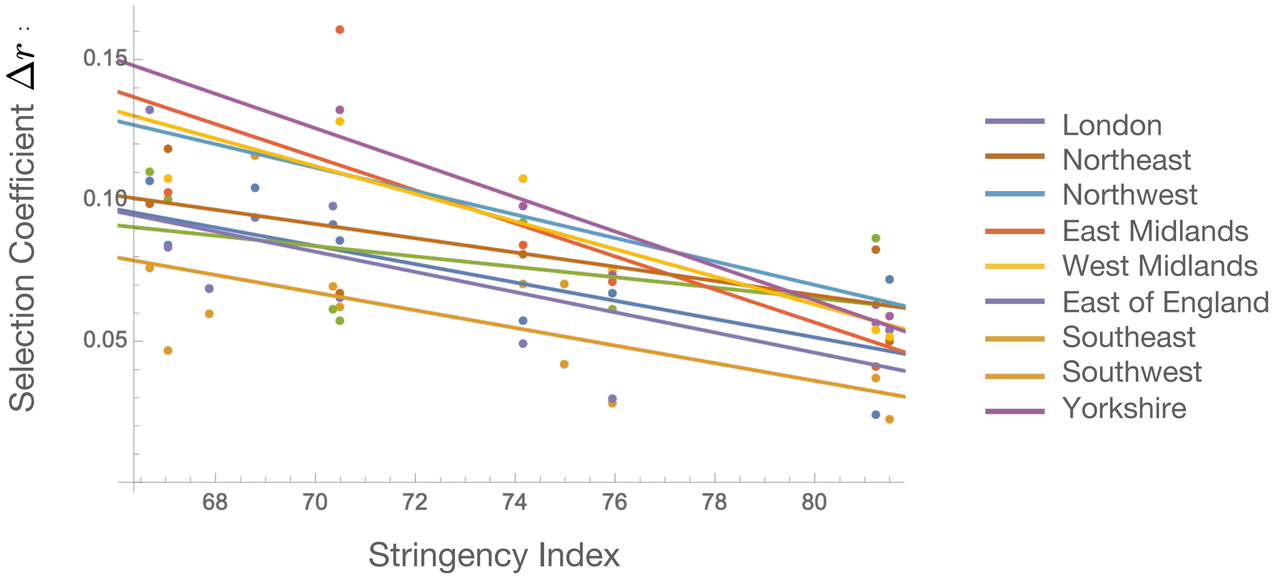
Transmission-Virulence Evolution in SARS-CoV-2



$$\frac{dp}{dt} = p(1-p)\Delta r$$

$$\Delta r = r_1 - r_2$$
$$= \Delta\beta S - \Delta v$$

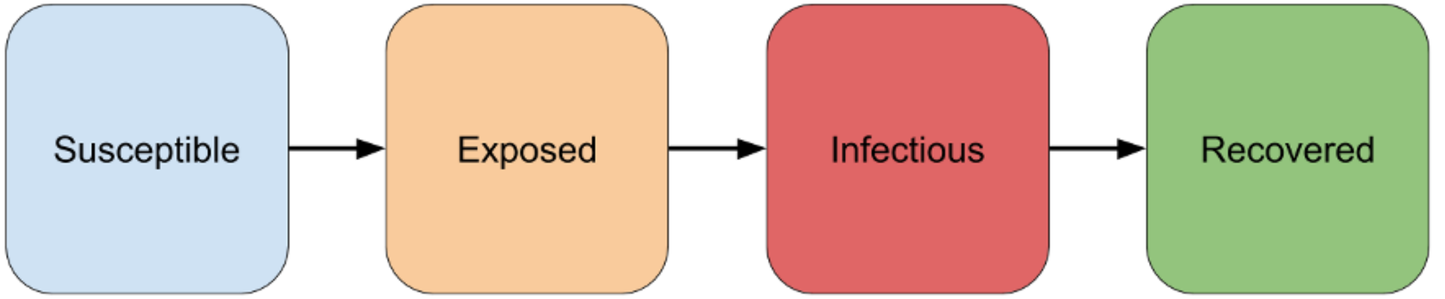




Day and Gandon, 2007. *Ecol. Lett.* 10: 876
Day et al. 2020. *Current Biology* 30:R849
Otto et al. 2021. *Current Biology* 31:R918

Models for behaviour changes

- Behaviour may change as a reaction to epidemic
- How do individuals make decisions for self protective behaviour?
- Interaction with evolution (higher virulence -> more self protective behaviour)?



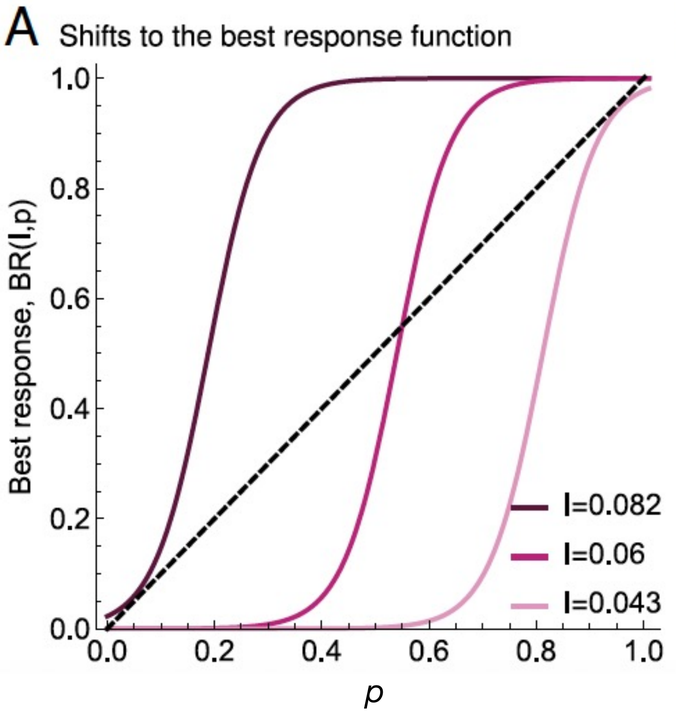
$$\dot{S} = -\beta(p)SI, \quad \dot{E} = \beta(p)SI - \delta E, \quad \dot{I} = \delta E - \gamma I, \quad \dot{R} = \gamma I,$$

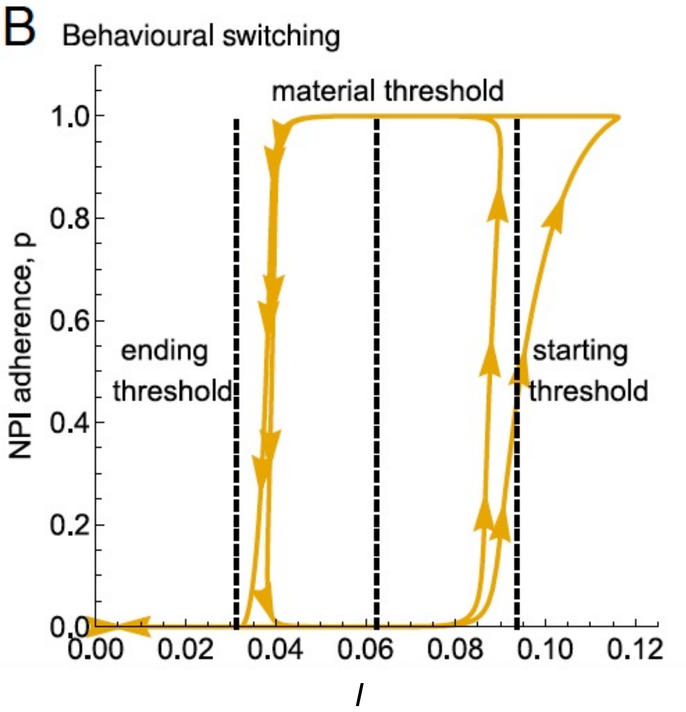
$$\dot{p} = \epsilon F(I,p)$$

$$F(I,p) = \mathrm{BR}(I,p) - p$$

$$u(I,p,q) = -\beta(q)I - cq - \theta(p-q)^2$$

$$\mathrm{BR}(I,p) = \frac{1}{1+\exp(\kappa(u(I,p,0)-u(I,p,1)))}$$





Morsky et al. 2023. The impact of threshold decision mechanisms of collective behaviour on disease spread. *PNAS* 120(19):e2221479120

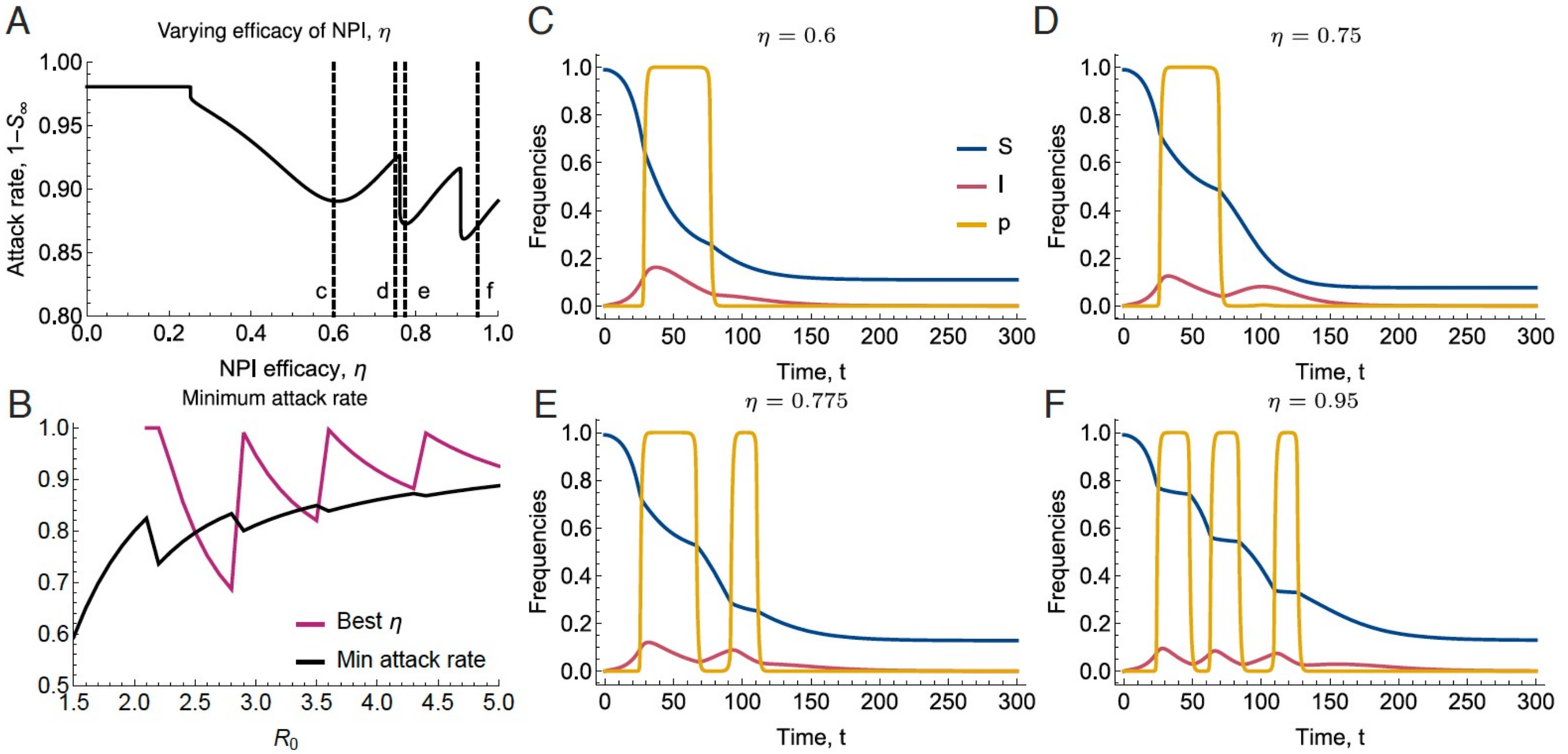
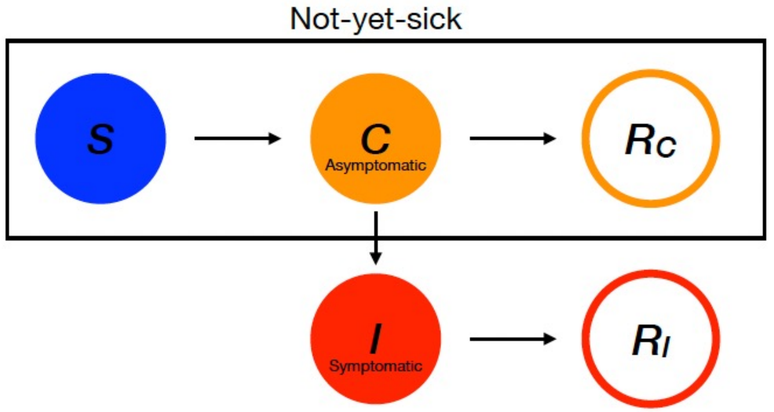


Fig. 2. The attack rate changes nonmonotonically with changing η, the efficacy of the NPI behavior. Panel *A* shows that there is a saw-tooth pattern in η and increasing number of behavior waves as η increases. Panel *B* depicts the minimum attack rate (black) and the NPI efficacy η needed to obtain it as a function of R_0 (varied by changing β_0). Panels *C*–*F* depict the time trajectories of the epidemic and behavioral change for different values of η, as marked by the vertical dashed lines on Panel *A*. Unless otherwise stated, the parameter values are taken from Table 1.

Morsky et al. 2023. The impact of threshold decision mechanisms of collective behaviour on disease spread. *PNAS* 120(19):e2221479120

The Decision Variable



- $\delta_i(t) \in \{0, 1\}$ is distancing strategy for an agent in state i
- $\alpha \in (0, 1)$ is effectiveness of distancing (if $\delta_i(t) = 1$ then contact rate is proportional to $1 - \alpha$)
- $d_i(t) = \mathbb{E}[\delta_i(t)]$ is frequency of state i agents with $\delta_i(t) = 1$
- Contact rate of class of state i individuals at time t is proportional to $d_i(t) \times (1 - \alpha) + (1 - d_i(t)) \times 1 = 1 - \alpha d_i(t)$

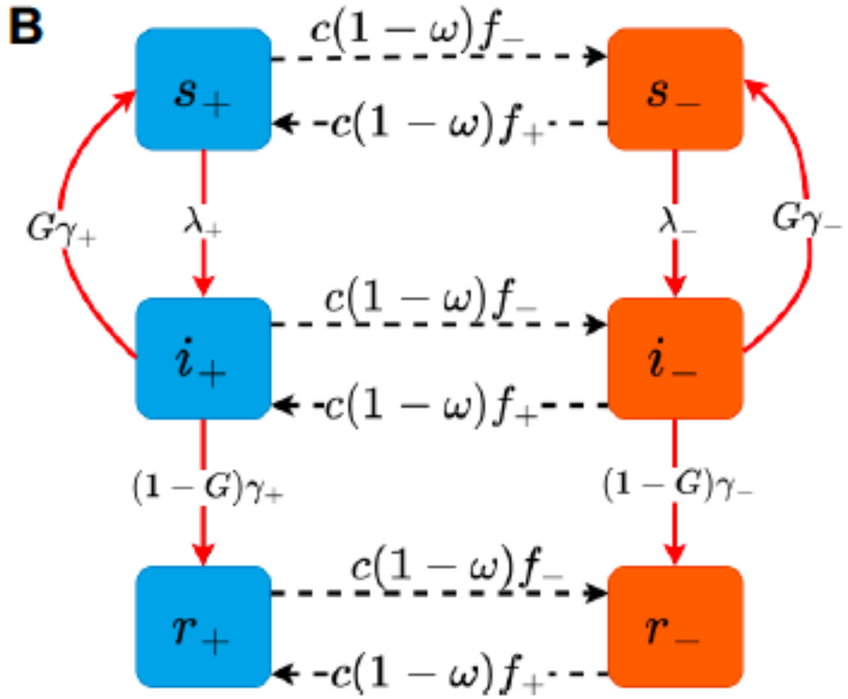
McAdam, D.A. and T. Day. Political economy of epidemic management. In prep

Coupling of behaviour and epidemics

Health positive population: self protection
Health neutral: no protection

Health positive opinion more popular with increasing prevalence

Could be coupled with virulence?



Teslya et al 2022

Questions for discussion

- What kind of data would we need?
- How can we quantify behaviour?
- How can we quantify impact of behaviour on evolution?
- What would this tell us about interventions?
- Self imposed behaviour change versus external restrictions