# Dynamics of lockdown simulations and COVID-19 in Northern Ireland

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# Compartmental modelling: SIR

Start as **susceptible**,
become **infected**,
then **recover**.

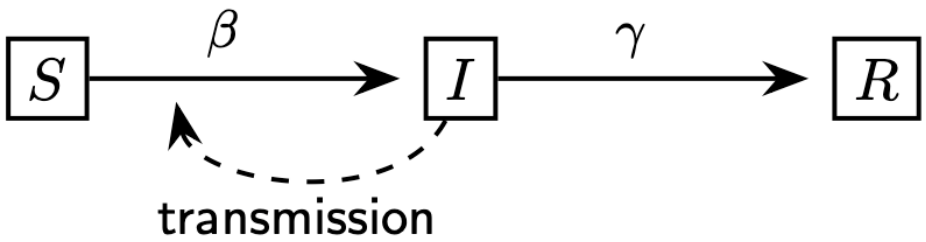



Figure 1: SIR model

Change in size of each sub-population given by an ODE:

$$\begin{aligned}
\frac{\mathrm{d}S}{\mathrm{d}t} &= -\frac{1}{N}\beta SI \\
\frac{\mathrm{d}I}{\mathrm{d}t} &= \frac{1}{N}\beta SI - \gamma I \\
\frac{\mathrm{d}R}{\mathrm{d}t} &= \gamma I
\end{aligned}$$

where $N = S + I + R$ is the total population.

# Compartmental modelling: SEIRD and SEIIRD

Include **exposed** compartment for a latency period.
Record the fraction of those infected who become **deceased**.

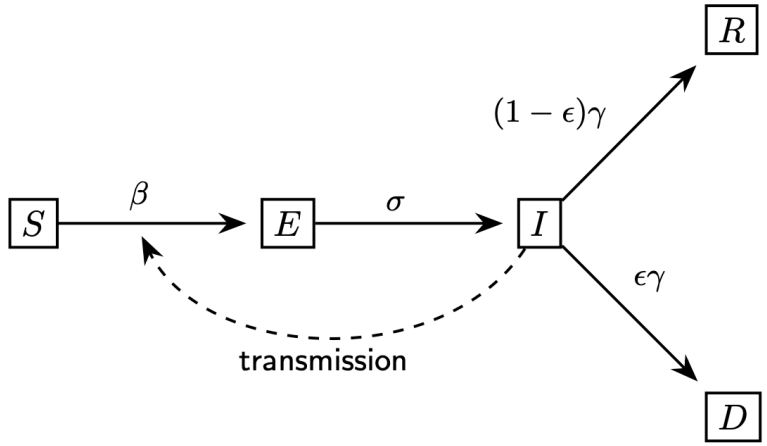



Figure 2: SEIRD model

Infectious cases can be separated by severity of symptoms: **Subclinical** (no symptoms) may progress to **Clinical**.

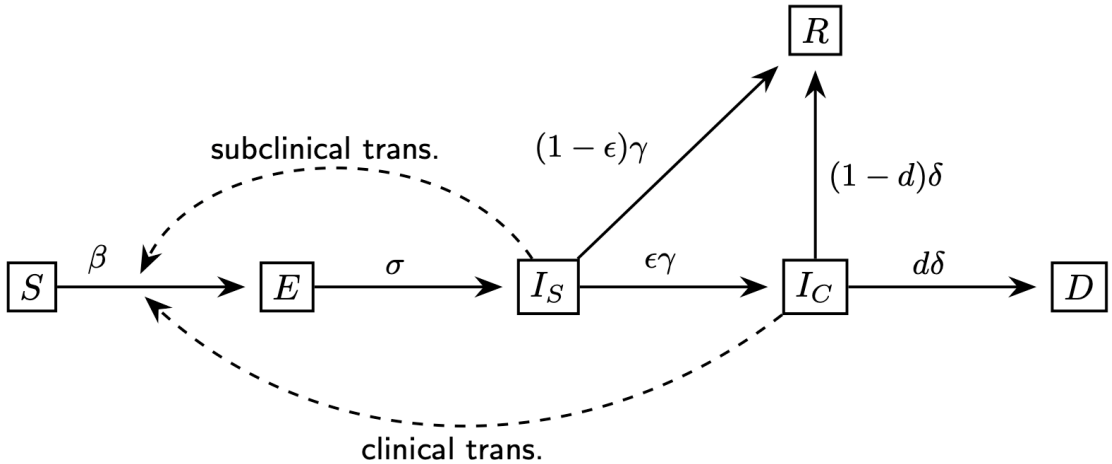



Figure 3: SEIIRD model

# Compartmental modelling: SEIIRD with hospitalisation

For comparison with DoH data and for projecting healthcare demands, track numbers in **hospital** ($H_1$) and **ICU** ($H_2$) as separate compartments.

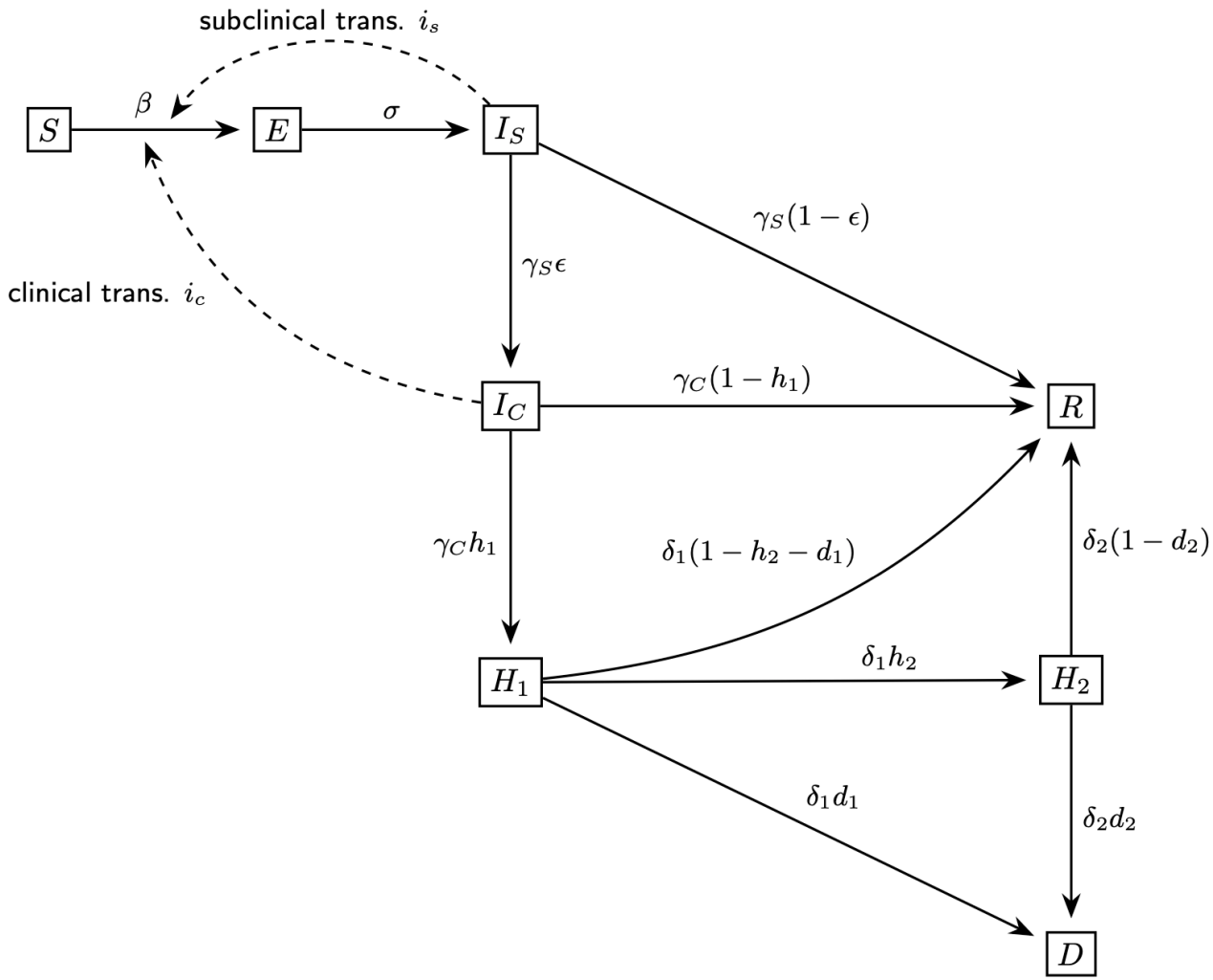



Figure 4: SEIIRD model with hospitalisation

# Compartmental modelling: Age-structured SEIIRD

COVID-19's effects on these clinical outcomes varies strongly with age.

Split the population into 20-year age class $i = 1, \ldots, 5$ and track the numbers of each age class in each compartment (40 ODEs).

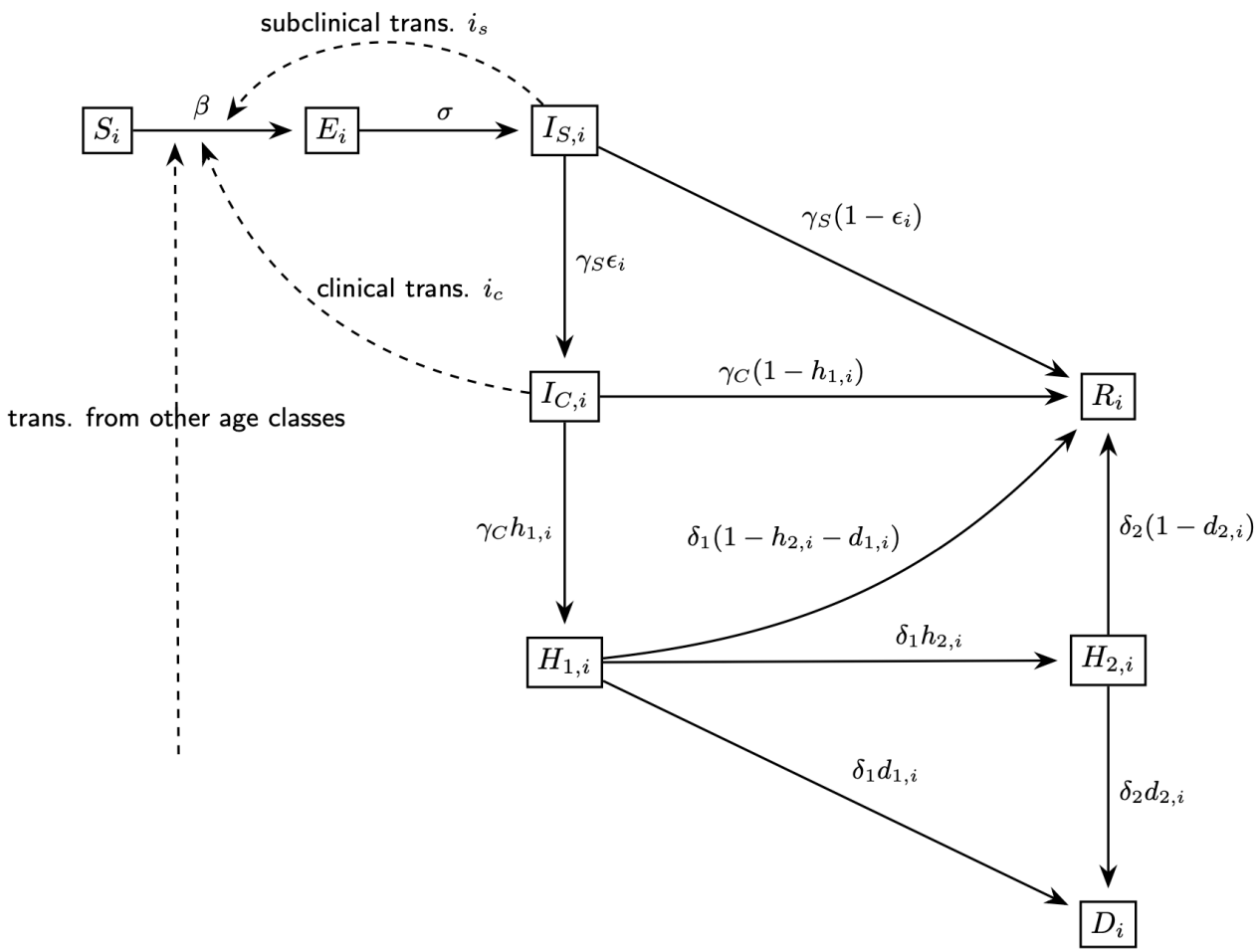
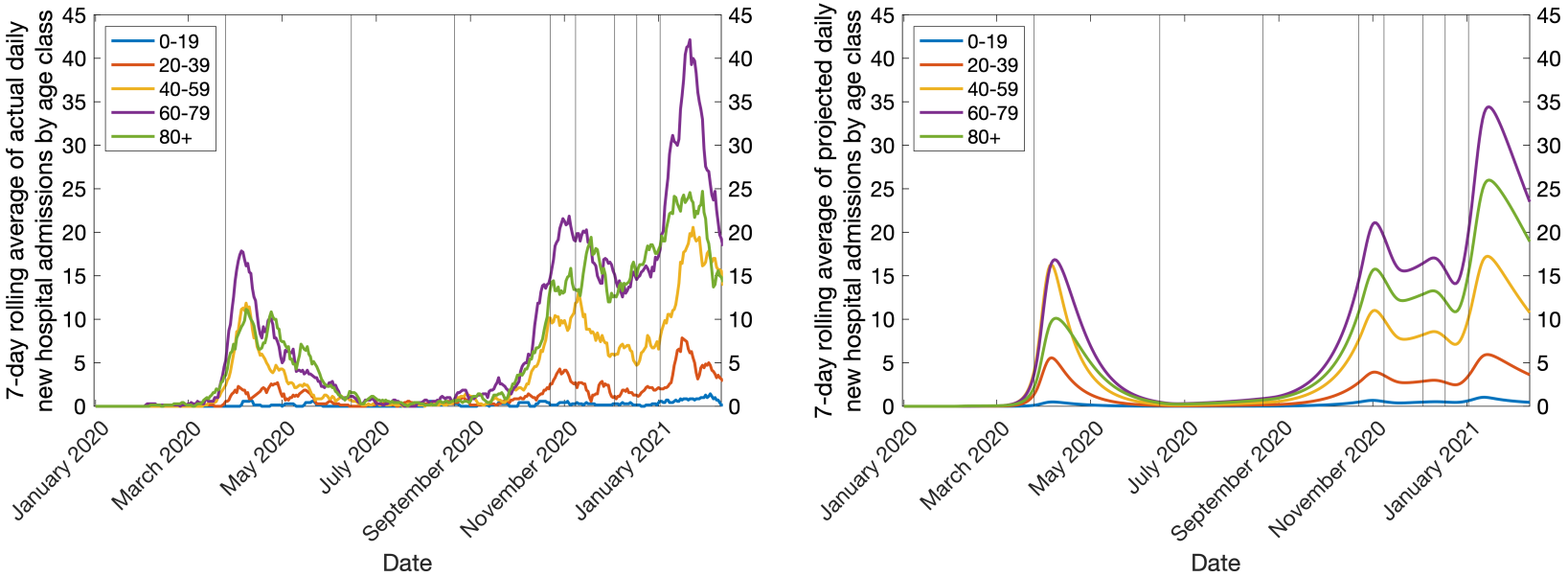



Figure 5: SEIIRD model with hospitalisation and age-structure

# Parameterising for the Northern Ireland population

Most parameters can be determined from existing literature, but transmission rate $\beta$ may vary during lockdowns, social distancing.

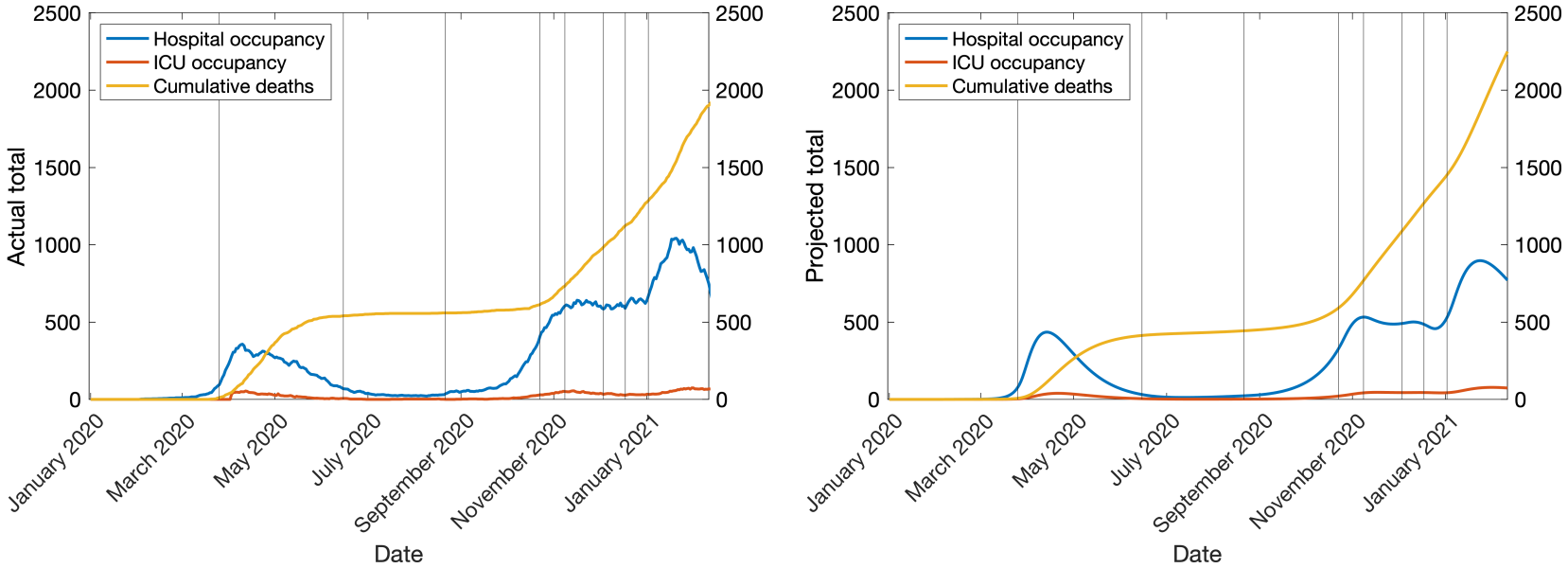



(a) Empirical (b) Fitted

Figure 6: 7-day rolling average hospital admissions

Fit $\beta$ in intervals (based on gov. policies) using the 7-day rolling average of daily hospital admissions for each age class from DoH.

# Cumulative deaths and healthcare demand

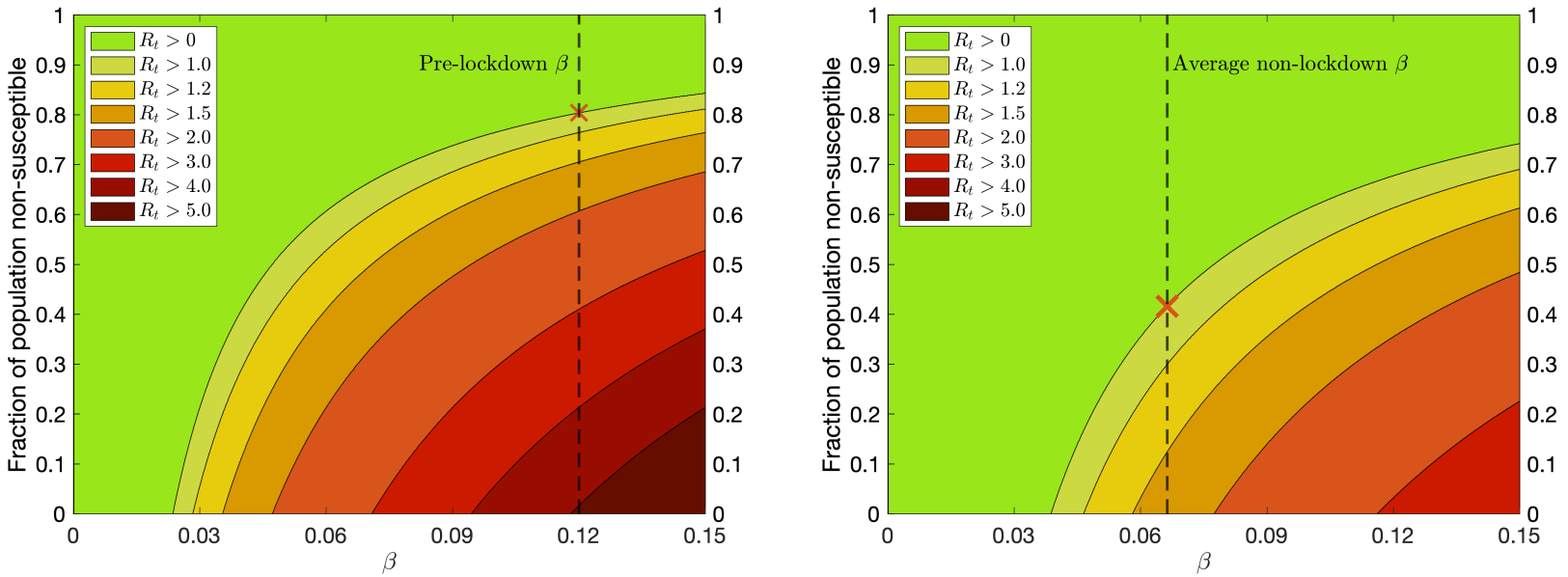



(a) Empirical (b) Projected

Figure 7: Hospital and ICU occupancy and cumulative deaths

- 9.5% had contracted COVID-19 by February 2021.
- Winter "circuit breaks" less effective than March lockdown.

# Effective reproductive number $R_t$

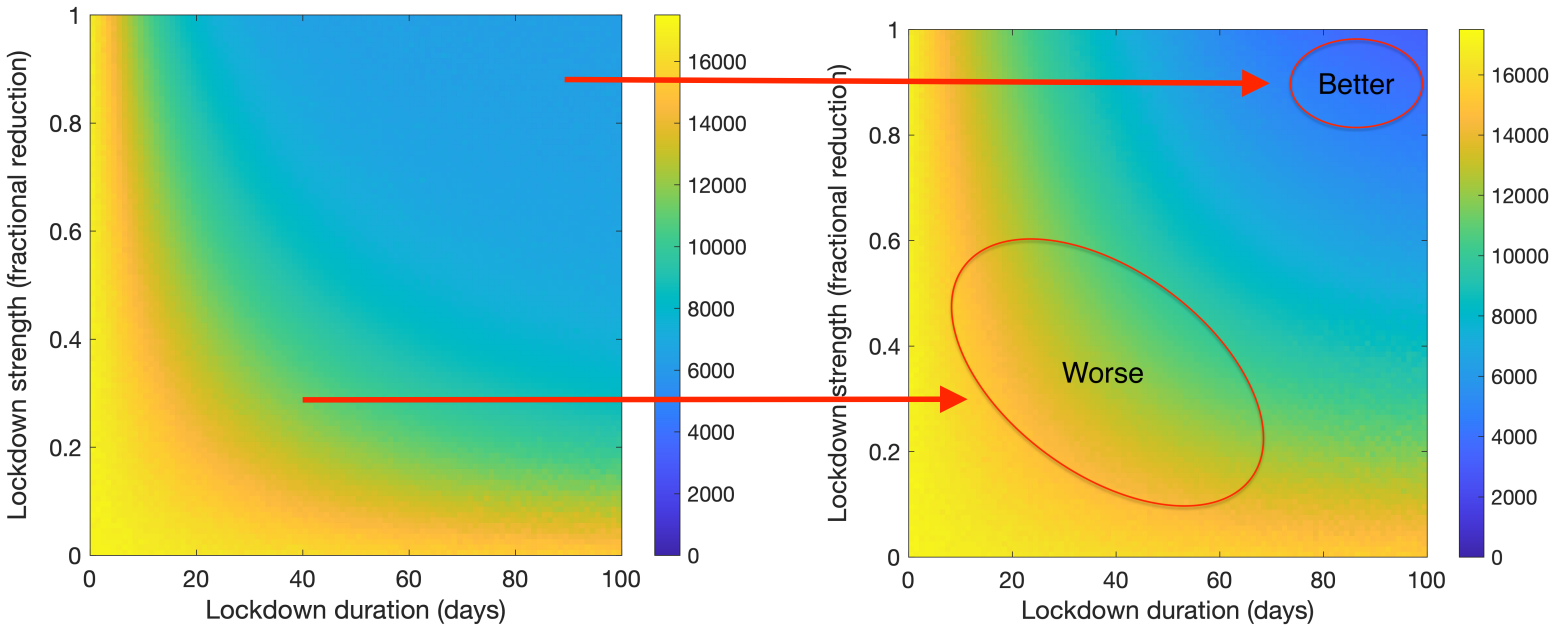



(a) Pre-pandemic 2020 conditions (b) Early 2021 non-lockdown conditions

Figure 8: Dependence of $R_t$ on immune fraction of the population

From average transmission rates in Spring 2020 (Fig. 8(a)) and Autumn 2020 - Spring 2021 outside of lockdowns (Fig. 8(b)), 80.4% or 42% must be immune to prevent spread ($R_t < 1$).

# Effectiveness of a single lockdown by strength and duration




(a) Whole population (b) Over 60's only

Figure 9: Cumulative deaths with optimally-timed single lockdown

- Shielding only the most vulnerable may be more effective than locking down the whole population.
- But *only* if it is strong enough and lasts past peak incidence.

# Lockdowns mechanistically-triggered by hospital occupancy

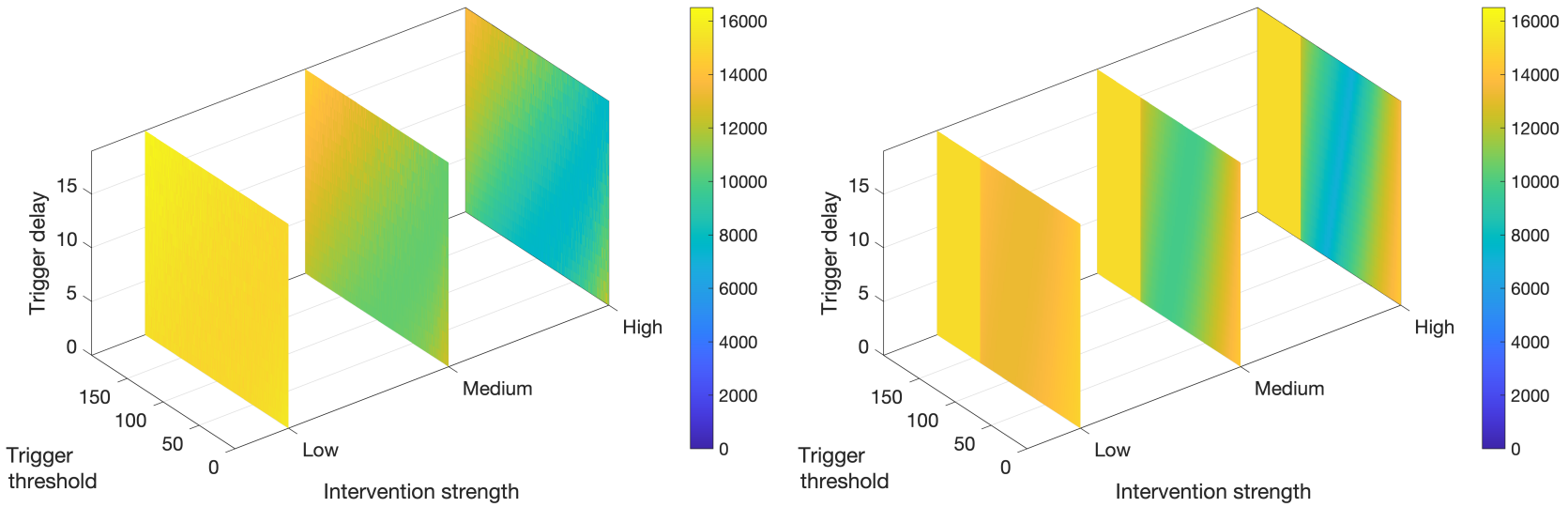
How can we use simulations to inform future pandemic response?

Simulate lockdowns activated by an observable trigger:

- Treating NI as a closed system, or daily adding one new case.
- Either one or multiple lockdowns permitted.
- Three strengths and durations of lockdown.
- Trigger: current hospital occupants or new daily deaths.
- Parameter space: how many inpatients (0-2000) or deaths (0-200) trigger lockdown; how many days (0-20) of delay.

# Mechanistically-triggered lockdowns

Without vaccination, herd immunity is the exit strategy. Time the lockdown to minimise excess spread over the threshold (40-45%).




(a) Constant inflow of cases

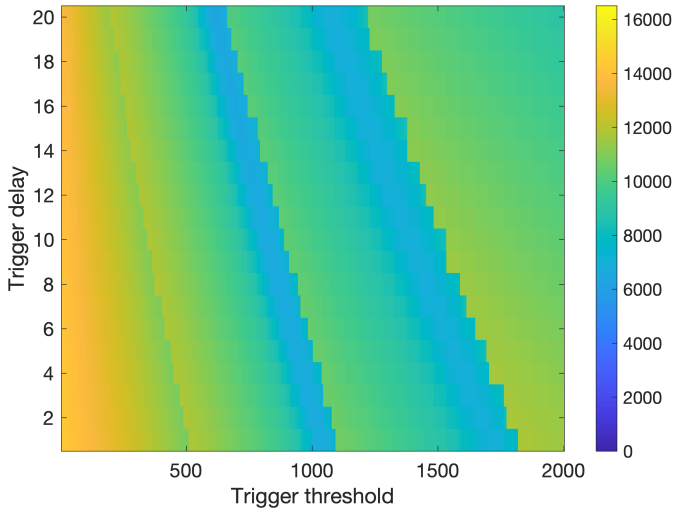
(b) Closed system model

Figure 10: Cumulative deaths with one lockdown triggered by daily deaths

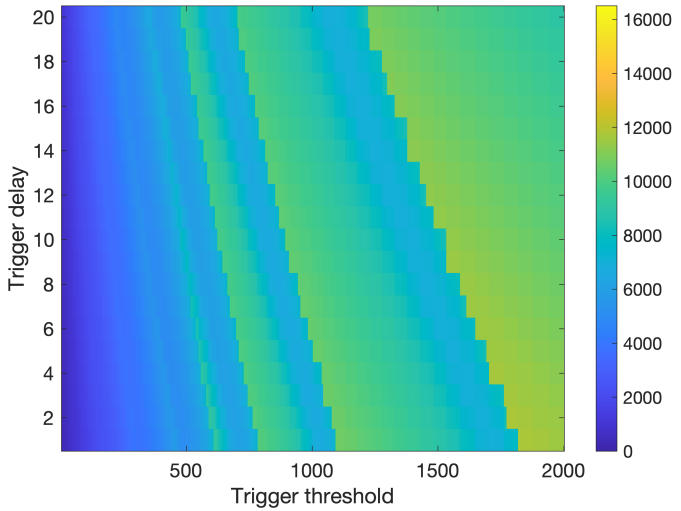
- Strongest lockdown, intermediate delay (zero impact if too late).
- Act sooner to minimise peak inpatients/ICU instead.
- **Closed systems:** greater danger from too-low thresholds. Why?

# Peculiarities of a closed system model

In a closed system, the strongest and fastest lockdowns *appear* optimal until the simulation fully "plays out" with a resurgence:




(a) Lockdowns in days 30-1000




(b) Lockdowns in days 30-2000

Figure 11: Cumulative deaths recorded after 2000 days with multiple lockdowns triggered by number of hospital inpatients

With a vaccination programme, the exit strategy shifts - it becomes truly best to maximally lockdown as fast as possible.

# Summary

- Single-lockdown restrictions targeting the more vulnerable may be more effective, but only if sufficient that the virus spreads then dissipates in the remaining population.
- Without a vaccine exit strategy, locking down too strong and too early in an isolated community can lead to resurgence when restrictions are lifted, with worse overall outcomes.
- Earlier interventions better reduce peak healthcare demands, while later interventions are more effective at reducing deaths.

# References and Acknowledgements

Abernethy, Gavin M., and David H. Glass. "Optimal COVID-19 lockdown strategies in an age-structured SEIR model of Northern Ireland." *Journal of the Royal Society Interface*, 19:188 (2022). DOI: 10.1098/rsif.2021.0896

Department of Health (NI) Covid-19 data:
`https://www.health-ni.gov.uk/articles/covid-19-dashboard-updates`

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