Dynamics of lockdown simulations and COVID-19 in Northern Ireland

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Compartmental modelling: SIR and SEIRD

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

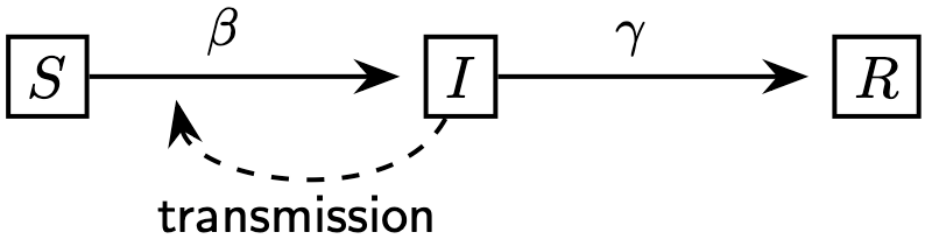


Figure 1: SIR model

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

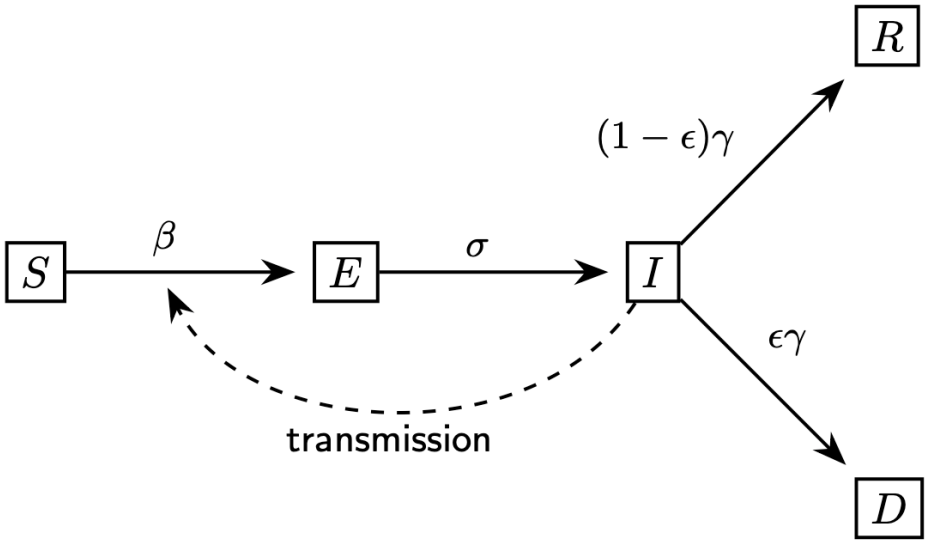


Figure 2: SEIRD model

Compartmental modelling: SEIIRD

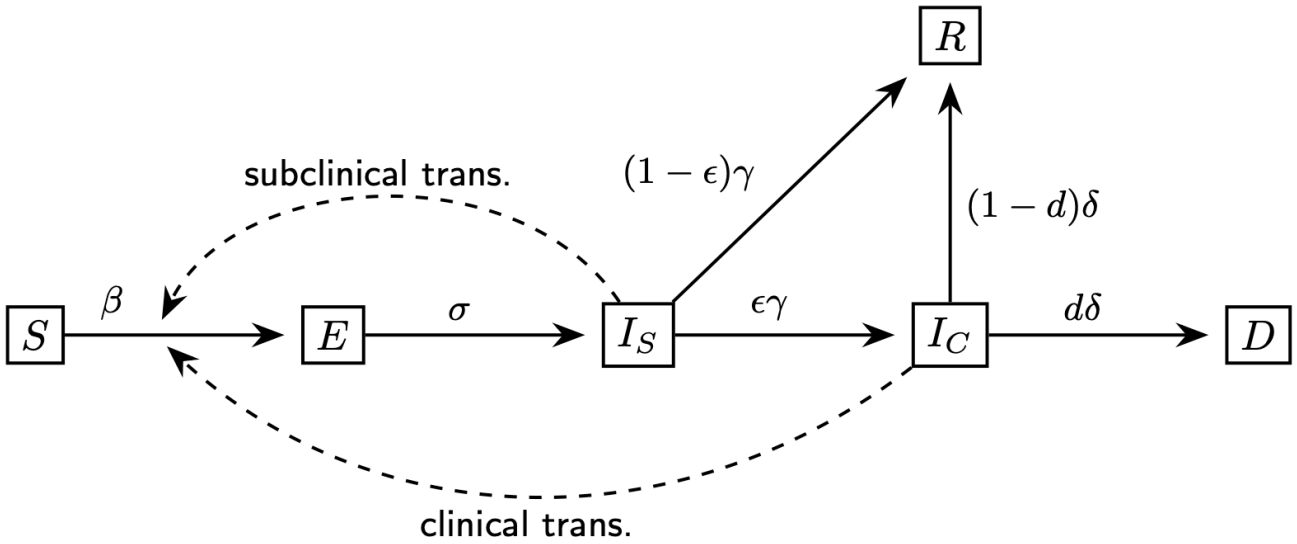


Figure 3: SEIIRD model

Cases can be separated by severity or visibility of symptoms:

- **Infectious (Subclinical)** show no symptoms but can still transmit with reduced rate. They may progress to . . .
- **Infectious (Clinical)**, who display symptoms, transmit, and may progress.

Compartmental modelling: SEIIRD with hospitalisation

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

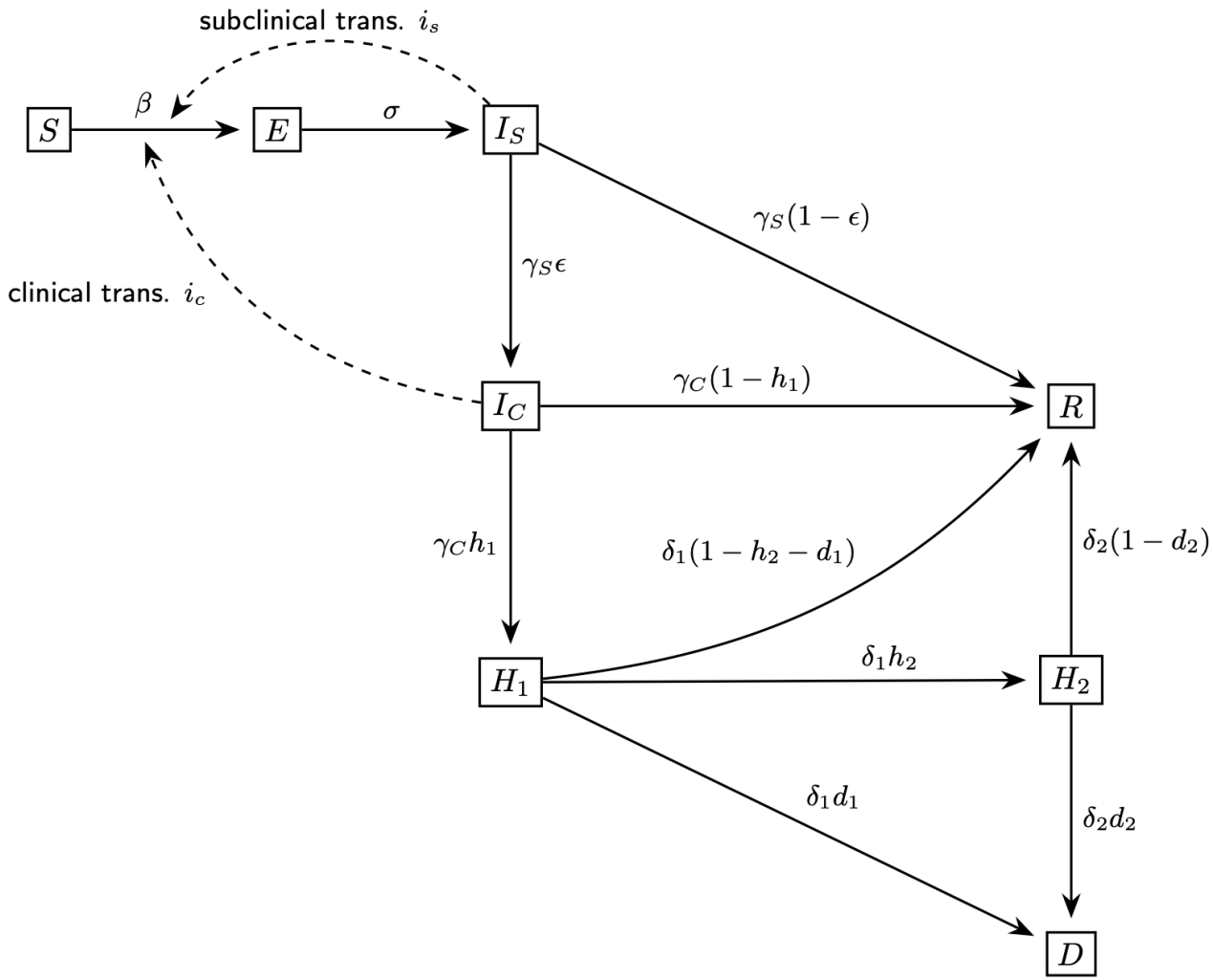


Figure 4: SEIIRD model with hospitalisation

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.

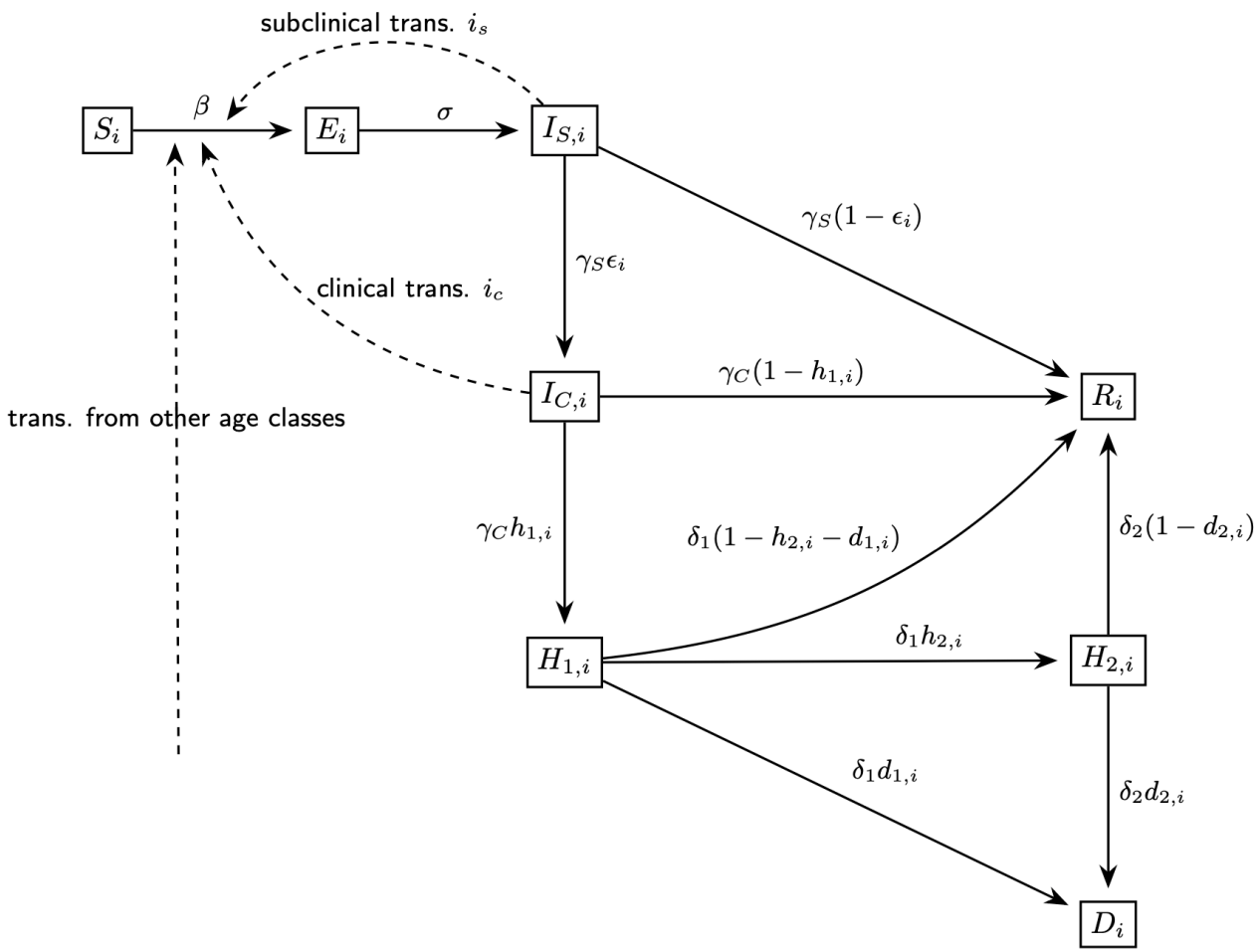
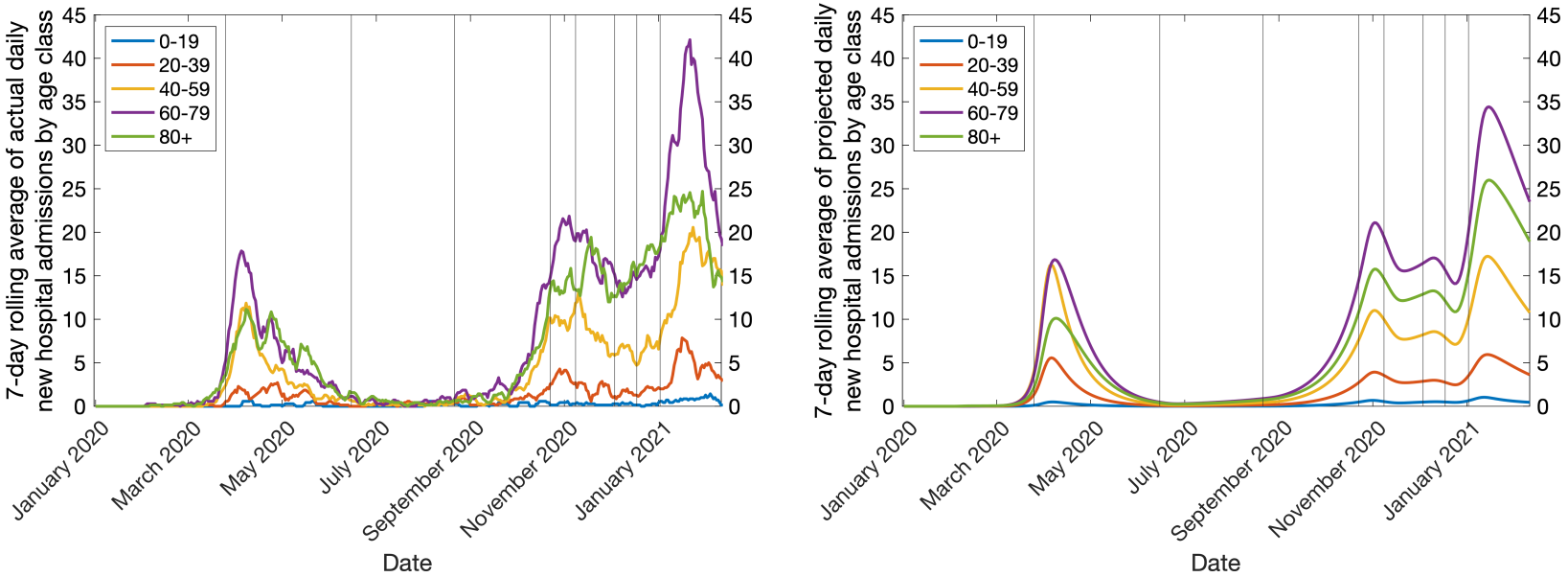


Figure 5: SEIIRD model with hospitalisation and age-structure

Parameterising for the Northern Ireland population

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

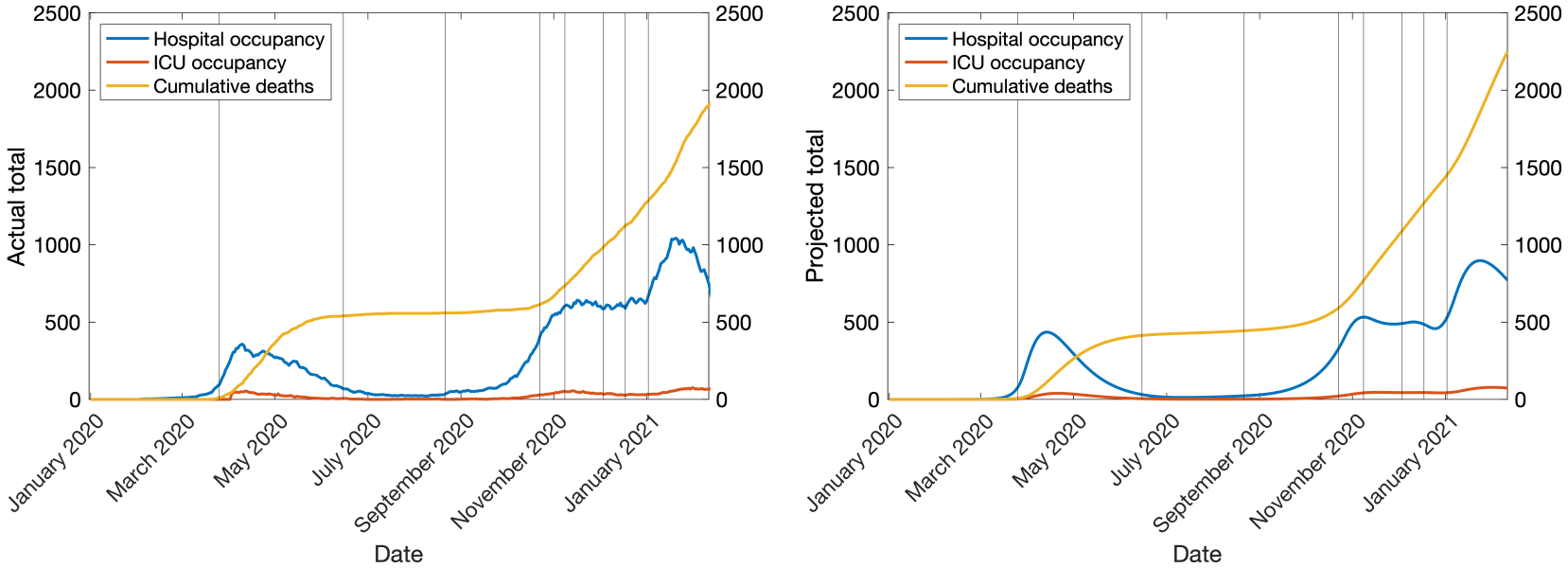


(a) Empirical (b) Fitted

Figure 6: 7-day rolling average hospital admissions

Fit β 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

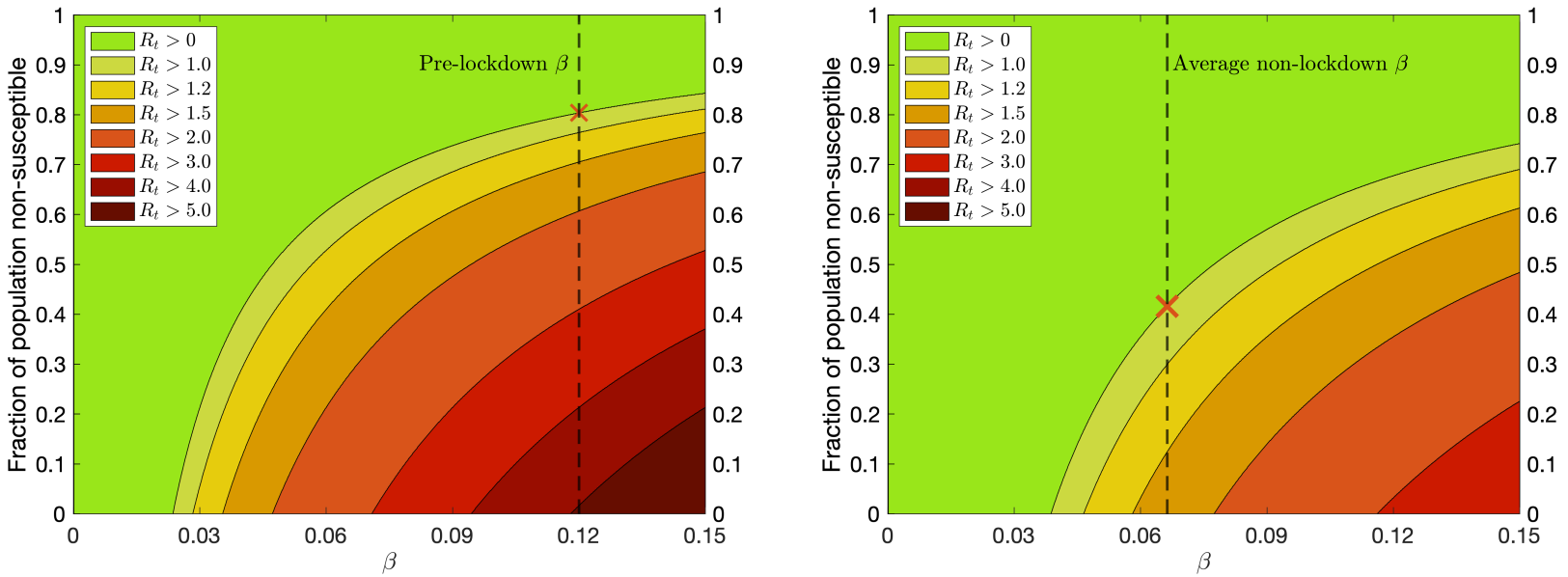


(a) Empirical (b) Projected

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

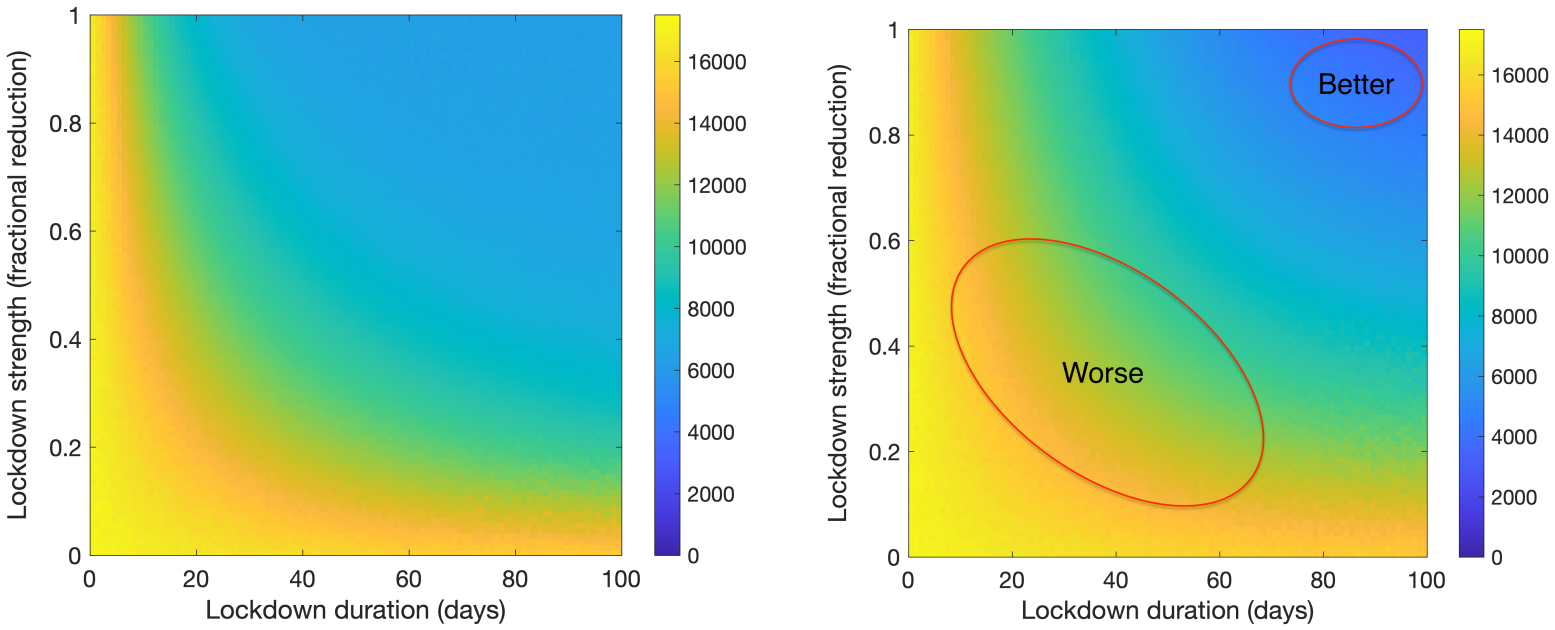


(a) Pre-pandemic 2020 conditions (b) Early 2021 non-lockdown conditions

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?

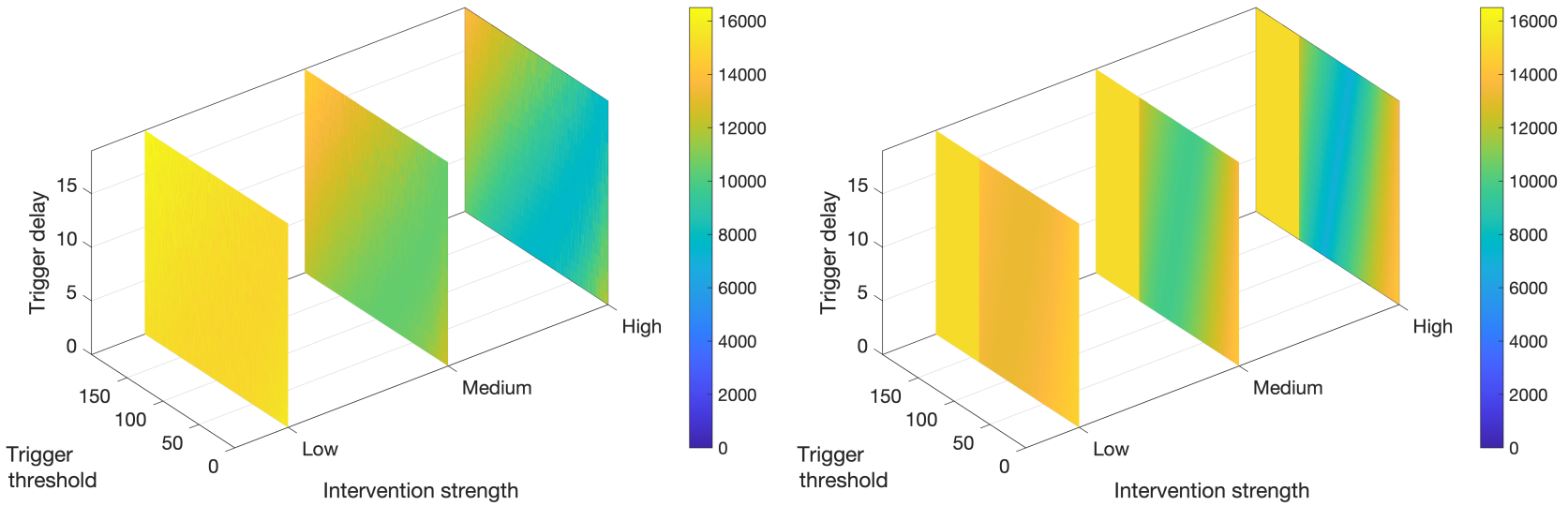
Simulate lockdowns activated by an observable trigger:

- Treating NI as a closed system, or with constant inflow (daily adding one new case of random age).
- Either one or infinitely-many 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.

Challenge: selecting the "right" model configuration and identifying common patterns!

Lockdowns mechanistically-triggered by hospital occupancy

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

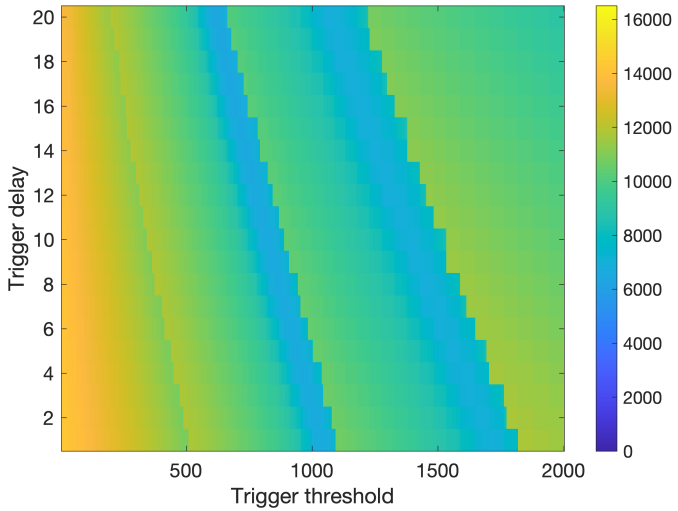
(b) Closed system model

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

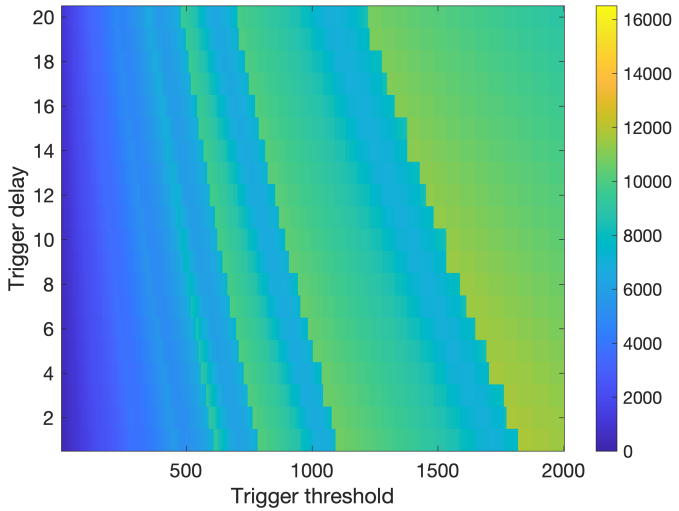
- Strongest lockdown, intermediate delay (zero impact if too late).
- Act sooner to minimise peak inpatients/ICU instead.
- **Closed systems:** greater danger from too-low thresholds. Why?

Peculiarities of a closed system model

In a closed system, the strongest 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 result in a resurgence when restrictions are lifted, with a greater number of deaths than if it was allowed to spread first.
- Earlier interventions better reduce peak healthcare demands, while later interventions are more effective at reducing deaths.

References

- 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).

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