An Age Structured SEIR Model to Evaluate Public Health Interventions on Irish Covid-19 Incidence

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Objectives

The main idea is to measure the effect of lockdowns on the number of COVID-19 cases.

- Forecast future cases under different lockdown scenarios.
- Economic component - how much does each lockdown cost?
Confirmed Cases in Ireland

Daily new confirmed COVID-19 cases per million people
Shown is the rolling 7-day average. The number of confirmed cases is lower than the number of actual cases; the main reason for that is limited testing.
We want to try put a number on the lockdown effect.

We use a *compartmental model*; specifically, a *SEIR* model.

A SEIR model is a system of ODEs.
\[
\begin{align*}
\frac{dS_i}{dt} &= -\beta S_i \sum_j (C_{ij} I^p_j + \alpha C_{ij} I^a_j + k C_{ij} I^k_j + C_{ij} I^{t1}_j + m C_{ij} I^{t2}_j + C_{ij} I^n_j) / N_i \\
\frac{dE_i}{dt} &= \beta S_i \sum_j (C_{ij} I^p_j + \alpha C_{ij} I^a_j + k C_{ij} I^k_j + C_{ij} I^{t1}_j + m C_{ij} I^{t2}_j + C_{ij} I^n_j) / N_i - \frac{1}{\tau_L} E_i \\
\frac{dl^p_i}{dt} &= \frac{(1 - f_a)}{\tau_L} E_i - \frac{1}{\tau_C - \tau_L} l^p_i \\
\frac{dl^a_i}{dt} &= \frac{f_a}{\tau_L} E_i - \frac{1}{\tau_D} l^a_i \\
\frac{dl^k_i}{dt} &= \frac{f_k}{\tau_C - \tau_L} l^p_i - \frac{1}{\tau_D - \tau_C + \tau_L} l^k_i \\
\frac{dl^{t1}_i}{dt} &= \frac{f_t}{\tau_C - \tau_L} l^p_i - \frac{1}{\tau_C} l^{t1}_i \\
\frac{dl^{t2}_i}{dt} &= \frac{1}{\tau_C} l^{t1}_i - \frac{1}{\tau_D - \tau_C + \tau_L - \tau_t} l^{t2}_i \\
\frac{dl^n_i}{dt} &= \frac{1 - f_k - f_t}{\tau_C - \tau_L} l^p_i - \frac{1}{\tau_D - \tau_C + \tau_L} l^n_i \\
\frac{dR_i}{dt} &= \frac{1}{\tau_D} l^a_i + \frac{1}{\tau_D - \tau_C + \tau_L} l^k_i + \frac{1}{\tau_D - \tau_C + \tau_L - \tau_t} l^{t2}_i + \frac{1}{\tau_D - \tau_C + \tau_L} l^n_i
\end{align*}
\]
SEIR Model Graph (taken from IEMAG)

- **Latent period** $L$
- **Incubation period** $C$
- **Infectious period** $D$

### Infected
- **Latent**: $E$
- **Not infectious**: $I_p$
- **Presymptomatic**: $I_n$
- **Immediate isolation**: $I_t$
- **Await test results**: $I_t1$
- **Isolation**: $I_t2$

- **Transmission rate**: $\beta h$
- **Infect susceptibles**: $S$

#### Asymptomatic
Infected, possibly lower level ($h \leq 1$)

**Infectious [throughout natural infectious period]**

- **Transmission rate**: $\beta i$

#### Not quarantining
- **Transmission rate**: $\beta$

- **Test result wait period**: $T$

- **New daily confirmed cases**

- **All infected classes contribute to force of infection (with weightings)**
- **Infected individuals move from the infected classes to Removed (not shown)**
Contact Matrices

Mean number of contacts per day

A: All
B: Home
C: Work
D: School
E: Other locations

Age of contact (years)
Age of individual (years)
The purpose of lockdowns are to reduce social contact.

So a reasonable proxy for lockdown effect can be a scalar applied to the contact matrices.

We can fit these scales to the data using the following relationship with the case count:

$$\frac{dX_i}{dt} = \frac{1}{T} I_{t1}^i$$
Uncertainty Measurement

Two major sources of uncertainty:

The fitted contact matrix scalars.
  - Use parametric bootstrapping.

The “fixed” SEIR parameters.
  - Re-fit model to a number of parameter values selected by controlled design.
Central Composite Design (CCD)

Points for the SEIR parameters are selected by inscribing a cube inside a sphere in parameter space.
Project Outcomes

1. Breakdown of lockdown strategy for next (say) 2 months (ideally with some estimate of economic costing for each).

2. A Shiny app that can visualise SEIR output.