Estimating the number of infections and the impact of non-pharmaceutical interventions on COVID-19

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Motivation

- COVID-19 emerged in Europe, from January or latter.
- Various governments have implemented various control measures to stop the spread.
- Need to estimate the effectiveness of interventions.
- Estimation of time varying reproduction is challenging, due to:
  - High proportion of infections not detected by health systems.
  - Regular change in testing policies.
  - Most health systems have capacity to test only ‘high risk’ cases.
- Estimation based on reported cases is systematically biased.
- Use a more reliable source of observed deaths, and use it to back-calculate the infections. Hence, the reproduction numbers.
Model Components
Bayesian Semi Mechanistic Model: Death Model

\[ D_{t,m} \sim \text{Negative Binomial} \left( d_{t,m}, d_{t,m} + \frac{d_{t,m}^2}{\psi} \right) \]

\[ \psi \sim \mathcal{N}^+(0, 5) \]

\[ ifr^*_m \sim ifr_m \cdot \mathcal{N}(1, 0.1) \]

\[ \pi \sim \text{Gamma}(5.1, 0.86) + \text{Gamma}(17.8, 0.45) \]

\[ d_{t,m} = ifr_m^* \sum_{\tau=0}^{t-1} c_{\tau,m} \pi^{t-\tau} \]
Bayesian Semi Mechanistic Model: Infection Model

Renewal equation

\[ c_{t,m} = S_{t,m} R_{t,m} \sum_{\tau=0}^{t-1} c_{\tau,m} g_{t-\tau} \]

\[ S_{t,m} = 1 - \sum_{i=1}^{t-1} \frac{c_{i,m}}{N_m} \]

\[ g \sim \text{Gamma}(6.5, 0.62) \]
Bayesian Semi Mechanistic Model: Reproduction Number

\[ R_{t,m} = R_{0,m} e^{- \sum_{k=1}^{6} \alpha_k I_{k,t,m} - \beta_m I_{5,t,m}} \]

\[ R_{0,m} \sim \mathcal{N}^+(3.28, |\kappa|) \]

\[ \alpha_k \sim \text{Gamma}(1/6, 1) - \frac{\log(1.05)}{6} \]

\[ \beta_1, \ldots, \beta_M \sim \mathcal{N}(0, \gamma) \text{ where } \gamma \sim \mathcal{N}^+(0, .2) \]
## Interventions

| Intervention                               | Countries     |
|-------------------------------------------|---------------|
| Case based self isolation mandated        | Austria, Belgium, Denmark, France, Germany, Italy, Norway, Spain, Sweden, Switzerland, UK |
| Social distancing encouraged              | Austria, Belgium, Denmark, France, Germany, Italy, Norway, Spain, Sweden, Switzerland, UK |
| Public events banned                      | Austria, Belgium, Denmark, France, Germany, Italy, Norway, Spain, Sweden, Switzerland, UK |
| School closure ordered                    | Austria, Belgium, Denmark, France, Germany, Italy, Norway, Spain, Sweden, Switzerland, UK |
| Lockdown ordered                          | Austria, Belgium, Denmark, France, Germany, Italy, Norway, Spain, Sweden, Switzerland, UK |

**MARCH 2020**
Results

United Kingdom

Daily number of infections

Daily number of deaths

\[ R_t \]

Interventions
- Complete lockdown
- Public events banned
- School closure
- Self isolation
- Social distancing encouraged

Sweden

Daily number of infections

Daily number of deaths

\[ R_t \]

Interventions
- Complete lockdown
- Public events banned
- School closure
- Self isolation
- Social distancing encouraged
## Results: Percentage Infected

| Country    | % of total population infected (mean [95% credible interval]) |
|------------|---------------------------------------------------------------|
| Austria    | 0.81% [0.62%-1.07%]                                          |
| Belgium    | 10.97% [7.85%-15.17%]                                         |
| Denmark    | 0.93% [0.69%-1.24%]                                           |
| France     | 3.87% [2.94%-5.05%]                                           |
| Germany    | 0.84% [0.63%-1.09%]                                           |
| Greece     | 0.13% [0.10%-0.17%]                                           |
| Italy      | 4.38% [3.52%-5.47%]                                           |
| Netherlands| 3.27% [2.53%-4.24%]                                           |
| Norway     | 0.52% [0.38%-0.71%]                                           |
| Portugal   | 1.11% [0.85%-1.49%]                                           |
| Spain      | 5.34% [4.19%-6.86%]                                           |
| Sweden     | 6.44% [3.95%-9.95%]                                           |
| Switzerland| 1.92% [1.47%-2.48%]                                           |
| United Kingdom | 4.10% [3.12%-5.39%]                                      |

Posterior model estimates of percentage of total population infected over the course of the pandemic. Estimates as of 2020-04-28.
Results: Effectiveness of Interventions

**Estimated impact of interventions on $R_t$**

- **Lockdown**: No effect on transmissibility to 75% reduction in $R_t$.
- **Public Events**: No effect on transmissibility to 50% reduction in $R_t$.
- **School Closure**: No effect on transmissibility to 25% reduction in $R_t$.
- **Self Isolation**: No effect on transmissibility to 25% reduction in $R_t$.
- **Social distancing encouraged**: No effect on transmissibility to 25% reduction in $R_t$.

Mean relative percentage reduction in $R_t$ is shown with 95% posterior credible intervals. If 100% reduction is achieved, $R_t = 0$ and there is no more transmission of COVID-19.
Results: Effectiveness of Interventions

The graph shows the cumulative number of deaths over time from March 1 to April 15. Two lines are depicted:
- The red line labeled "our model" shows a lower trajectory compared to the turquoise line labeled "counterfactual".
- The "counterfactual" line indicates a higher number of deaths compared to the "our model" line.

The "our model" line suggests a more effective intervention, leading to fewer deaths. The "counterfactual" line represents a scenario without interventions, indicating a higher number of deaths over the same period.
Summary

- Semi-mechanistic Bayesian hierarchical model to attempt to infer the impact of these interventions across 11 European countries.
- We estimate that countries have managed to reduce their reproduction number substantially.
- The proportion of the population infected to date – the attack rate - is estimated to be highest in Sweden and Belgium and lowest in Norway, Austria and Germany.
- Major non-pharmaceutical interventions and lockdown in particular have had a large effect on reducing transmission.
- Given the counterfactual we present it is critical that the current interventions remain in place and trends in cases and deaths are closely monitored in the coming days and weeks to provide reassurance that transmission of SARS-Cov-2 is under control.
Limitations and Assumptions

- Changes in the reproductive number – a measure of transmission - are an immediate response to interventions.

- Each intervention has the same effect on the reproduction number across countries and over time, excluding the lockdown intervention.

- For lockdown, we now estimate a global effect and a country specific effect.

- The interventions that we consider have different implementation details across countries, which we do not take into account.

- We make various further assumptions that our model results are contingent on (e.g. about the time between infections, about being able to observe all COVID-related deaths (we do have under-reporting parameter work in progress), about the time between infection and death and about the infection-fatality-ratio).
Thanks!

Report: https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/report-13-europe-npi-impact/

Technical Report:
https://arxiv.org/abs/2004.11342

Website: https://mrc-ide.github.io/covid19estimates/#/

Code: https://github.com/ImperialCollegeLondon/covid19model
Sensitivity on Generation Distribution

The diagram shows the generation distribution mean over time, with four different mean values: 5, 6.5, 7, and 8. The y-axis represents the number of deaths averted, ranging from 1 to 1,000,000. The x-axis represents dates from March 16 to April 13.

The trends indicate a significant increase in the number of deaths averted as the generation distribution mean increases, with higher means resulting in more deaths averted over time.
Sensitivity on Onset To Death Distribution

Onset to death mean
- 13
- 15
- 17.8

# of deaths averted

Mar 16  Mar 23  Mar 30  Apr 06  Apr 13