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

Swapnil Mishra, Seth Flaxman, Axel Gandy, H Juliette T Unwin, Helen Coupland, Thomas A Mellan, Harrison Zhu, Tresnia Berah, Jeffrey W Eaton, Pablo N P Guzman, Nora Schmit, Lucia Callizo, Imperial College COVID-19 Response Team, Azra Ghani, Christl A. Donnelly, Steven Riley, Lucy C Okell, Michaela A C Vollmer, Neil M. Ferguson, Samir Bhatt

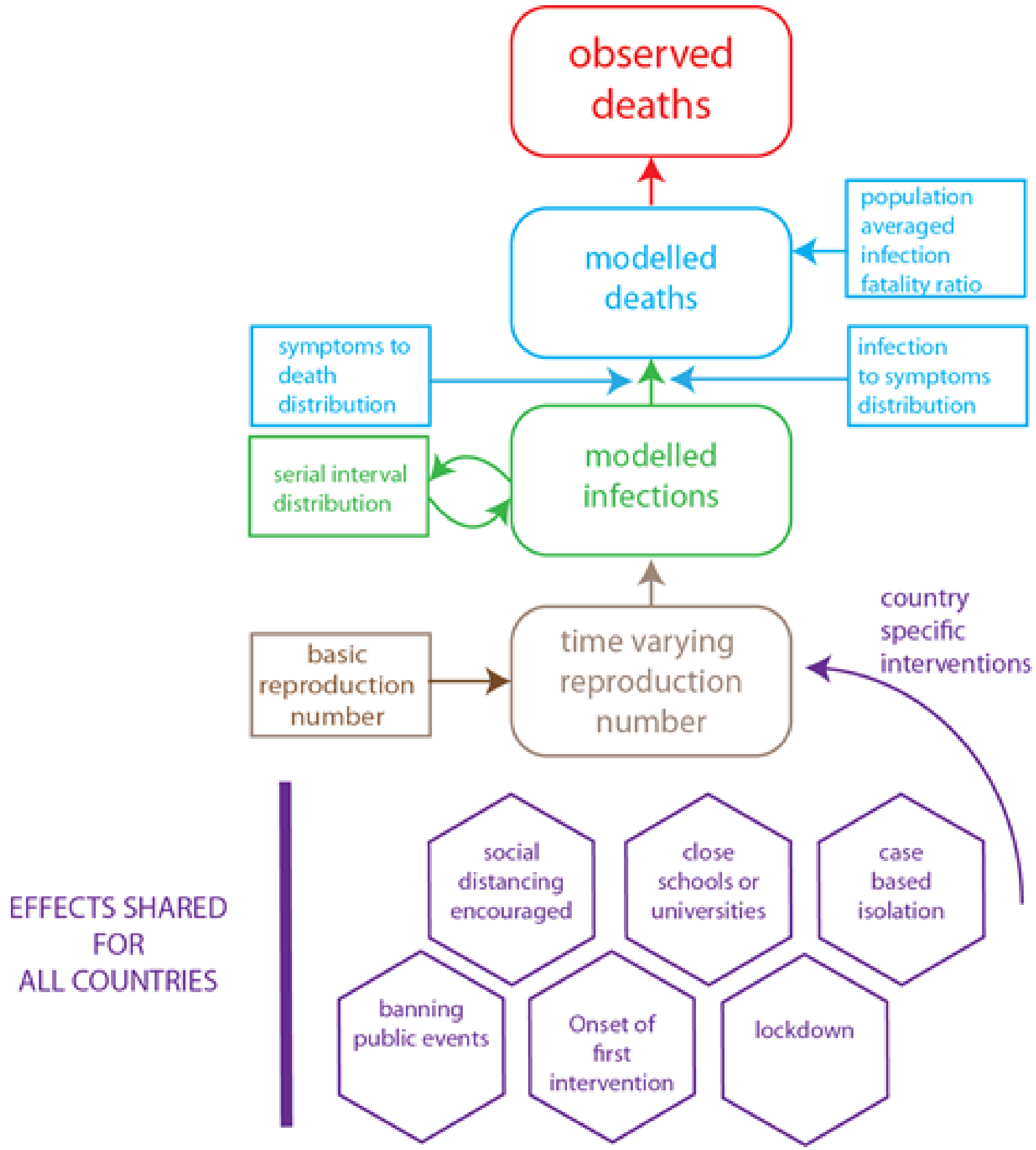
ECMI'2020-math4covid

Imperial College London

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 observed deaths, and use it to back-calculate the infections. Hence, the reproduction numbers.

Model Components



Bayesian Semi Mechanistic Model: Death Model

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

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

$$ifr_m^* \sim ifr_m \cdot N(1, 0.1)$$

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

$$d_{t,m} = ifr_m^* \sum_{\tau=0}^{t-1} c_{\tau,m} \pi_{t-\tau}$$

Bayesian Semi Mechanistic Model: Infection Model

Renewal equation

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

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

$$g \sim \mathrm{Gamma}(6.5, 0.62)$$

Bayesian Semi Mechanistic Model: Reproduction Number

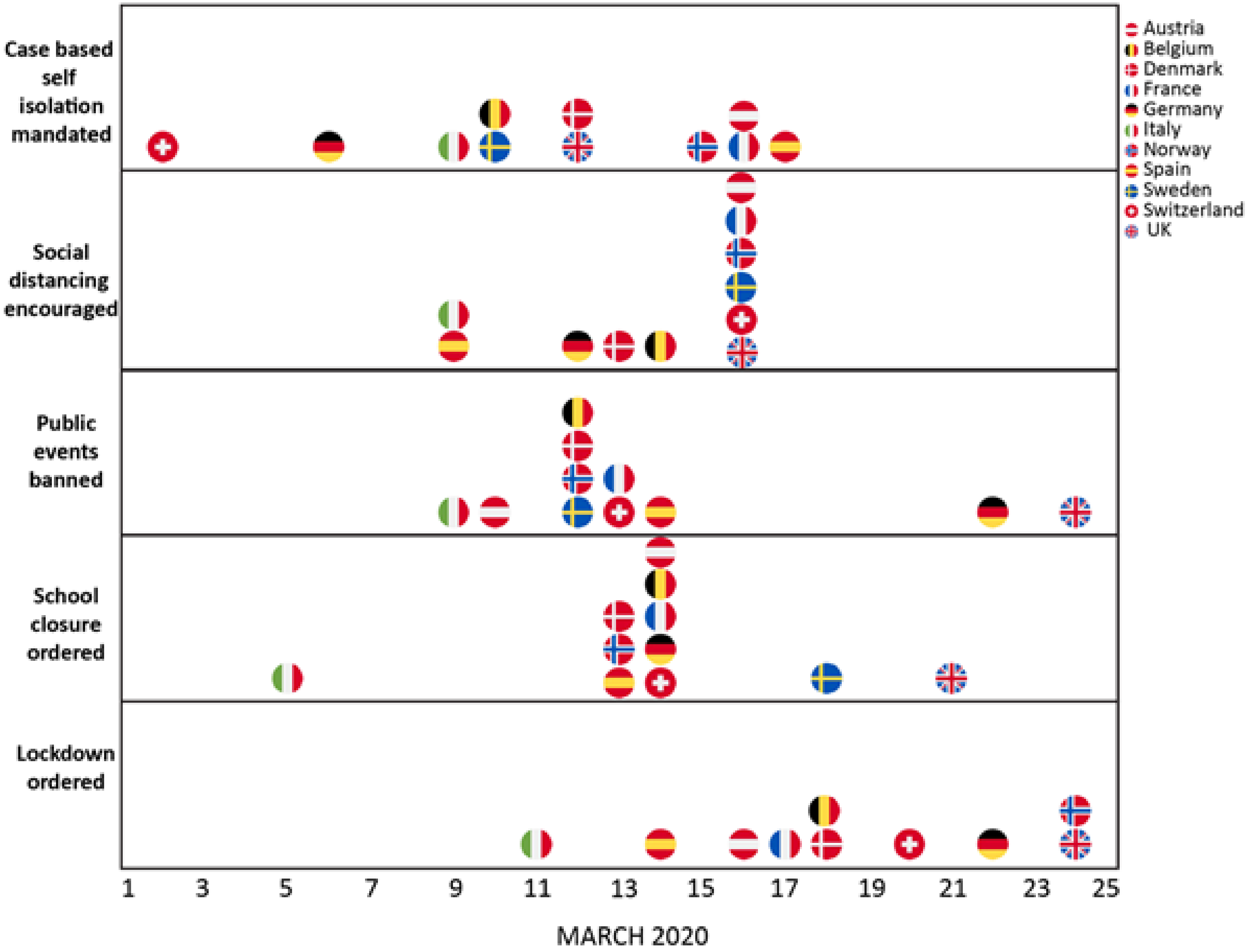
$$R_{t,m} = R_{0,m} e^{-\sum_{k=1}^{6} \alpha_k I_{k,t,m} - \beta_m I_{5,t,m}}$$

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

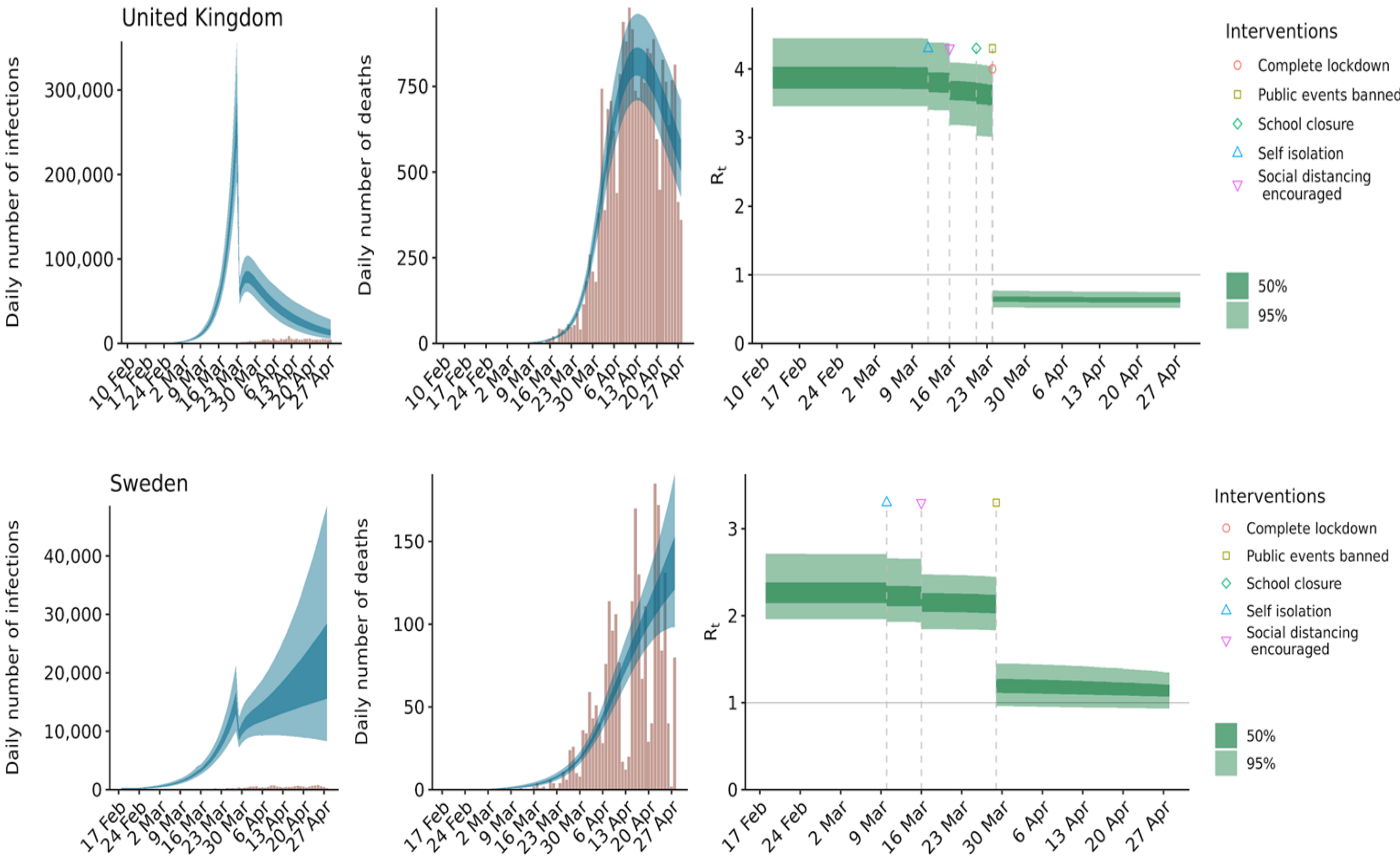
$$\alpha_k \sim \text{Gamma}(1/6, 1) - \frac{\log(1.05)}{6}$$

$$\beta_1, \ldots, \beta_M \sim N\left(0, \gamma\right) \text{ where } \gamma \sim N^{+}\left(0, .2\right)$$

Interventions



Results

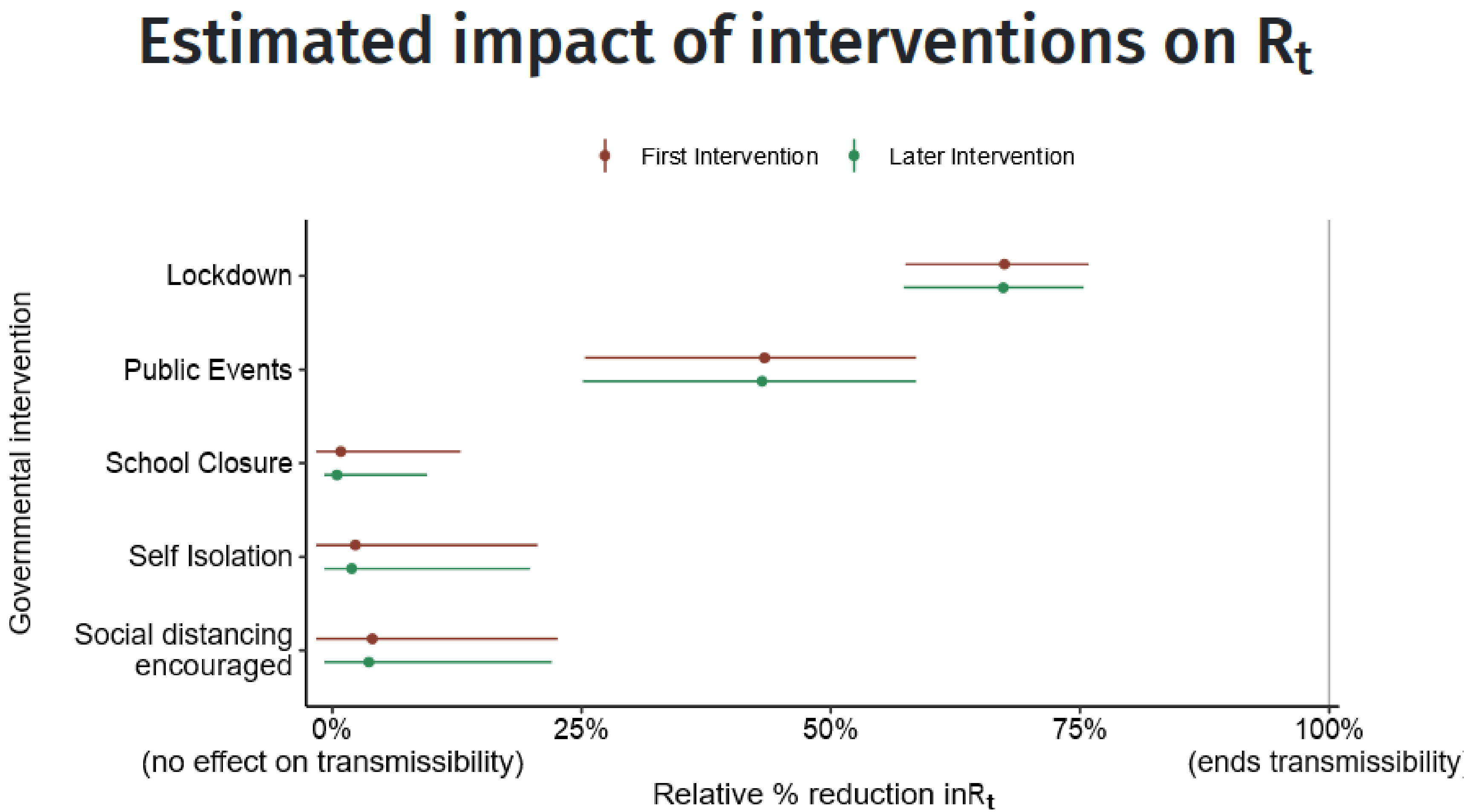

United Kingdom
Daily number of infections
300,000
200,000
100,000
0
10 Feb
17 Feb
24 Feb
2 Mar
9 Mar
16 Mar
23 Mar
30 Mar
6 Apr
13 Apr
20 Apr
27 Apr
Daily number of deaths
750
500
250
0
R_t
4
3
2
1
0
Interventions
Complete lockdown
Public events banned
School closure
Self isolation
Social distancing encouraged
50%
95%
Sweden
Daily number of infections
40,000
30,000
20,000
10,000
0
17 Feb
24 Feb
2 Mar
9 Mar
16 Mar
23 Mar
30 Mar
6 Apr
13 Apr
20 Apr
27 Apr
Daily number of deaths
150
100
50
0
R_t
3
2
1
0
Interventions
Complete lockdown
Public events banned
School closure
Self isolation
Social distancing encouraged
50%
95%

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%]

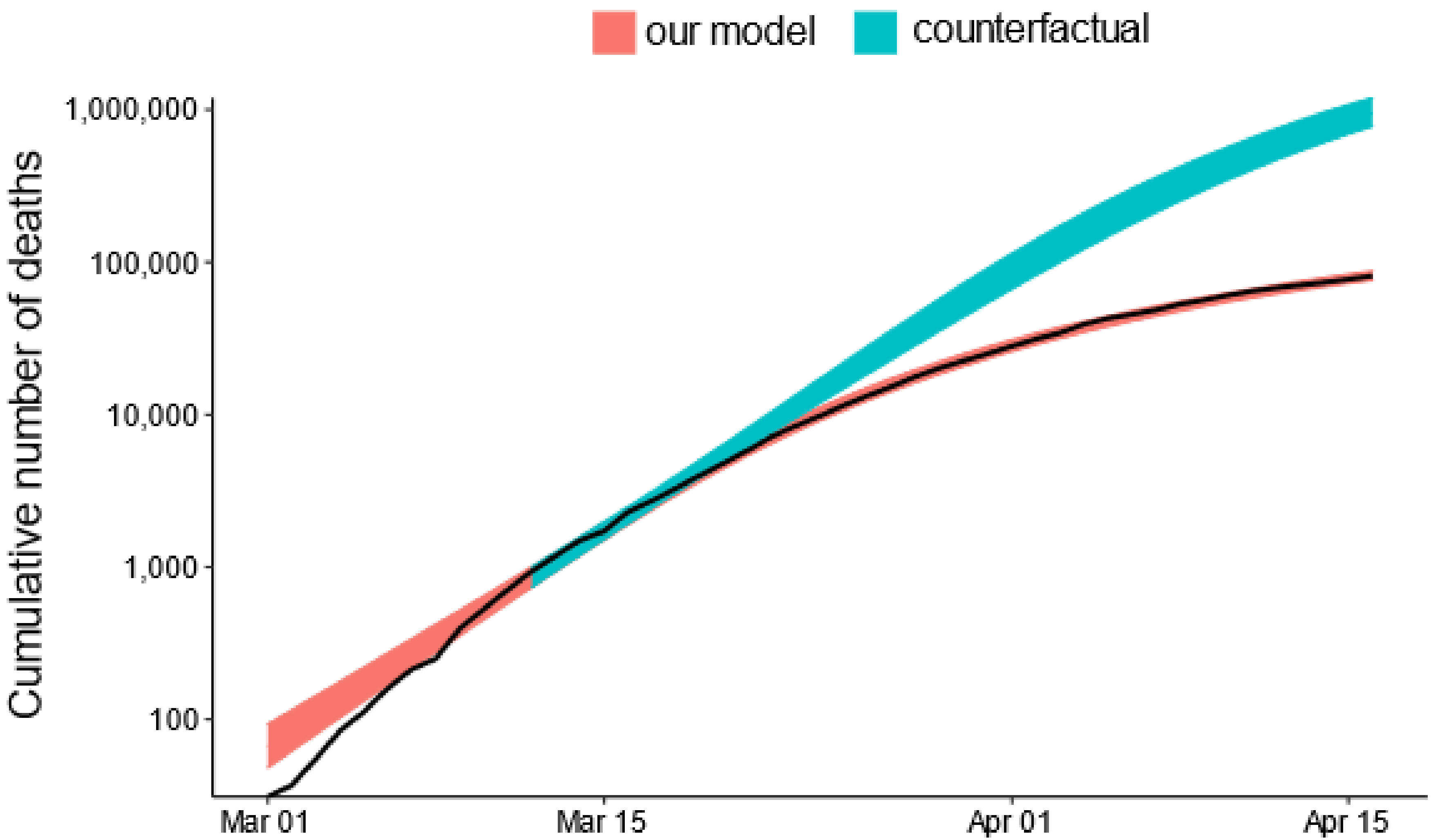
Posterior model estimates of percentage of total population infected over the course of the pandemic. Estimates as of 2020-04-28.

Results: Effectiveness of Interventions



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



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:

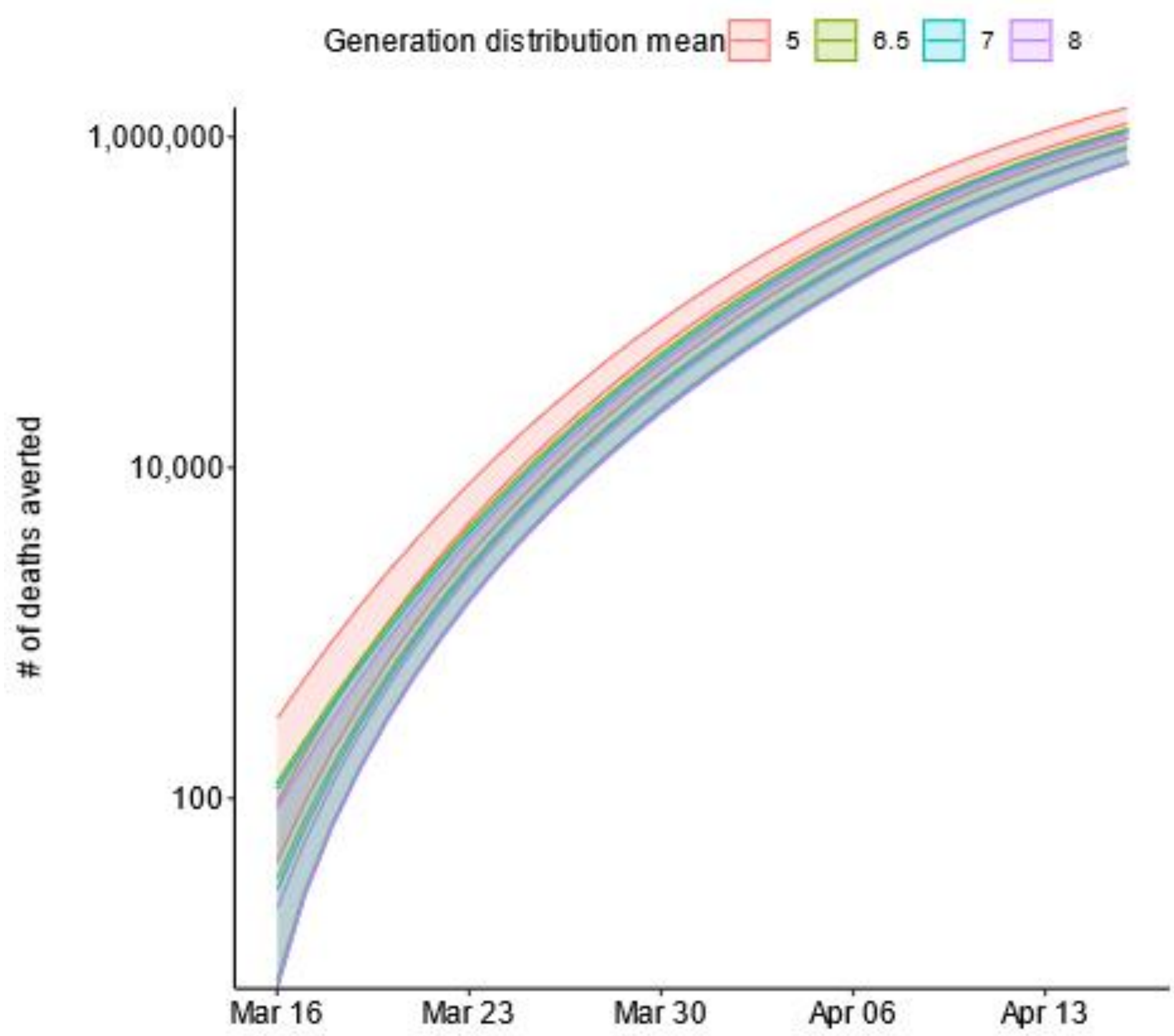
https://arxiv.org/abs/2004.11342

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

Code:

https://github.com/ImperialCollegeLondon/covid19model

Sensitivity on Generation Distribution



Sensitivity on Onset To Death Distribution