Understanding the effectiveness of government interventions in Europe's second wave of COVID-19

Abstract

Aim

Update estimates of the relative effectiveness of NPIs based on data from Europe's second wave (a joint collaboration between the Brauner and flaxman teams).

Methods

- Collect a large dataset of NPI implementations (114 subnational areas in 7 countries)
- Estimate the effectiveness of 17 NPIs from case and deaths data using a hierarchical regression model with the renewal equation and convolutions from infection to report as novel link functions.
- Address limitations in modeling from previous studies

Results

- Similar to previous findings.
- Targeted closure of business worked well.
- Reduced impact from school closures

Summary

- A well conducted study that draws on a large team to conduct novel work in a robust framework.
- Major improvement is in the quality of the data rather than the method.
- The nature of the observational data is highly complex and many of these issues have been insufficiently dealt with.

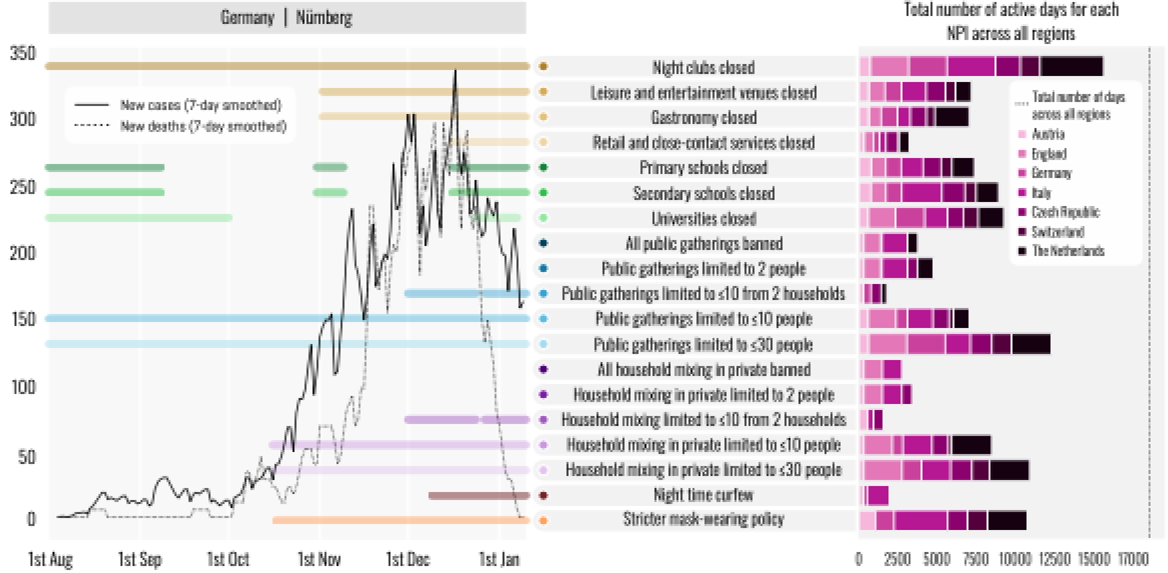
Introduction

Previous work

- Earlier studies used data based on NPI introductions in a very short time window in March 2020.
- Nearly all countries and regions imposed the same NPIs in the same order.
- Numerous data quality issues and varying testing/reporting regimes in the first wave.
- Lack of subnational data may have induced ecological fallacies.

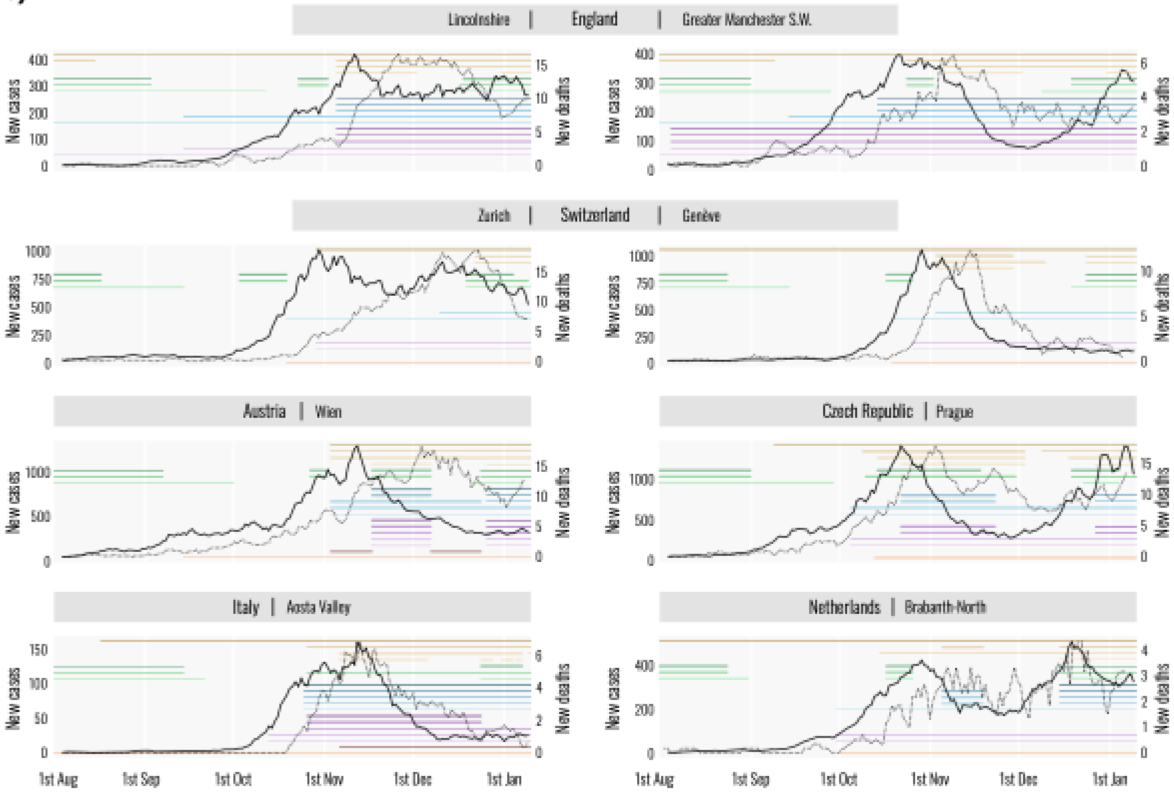
This work

- Bespoke data categorisation
- Latent stochastic infection model (fancy regression)
- Robust evaluation of assumptions
- 1st August to 9th January 2021
- 7 countries with 114 regions of analysis



Germany | Nürnberg
New cases (7-day smoothed)
New deaths (7-day smoothed)
350
300
250
200
150
100
50
0
1st Aug
1st Sep
1st Oct
1st Nov
1st Dec
1st Jan
Total number of active days for each NPI across all regions
Night clubs closed
Leisure and entertainment venues closed
Gastronomy closed
Retail and close-contact services closed
Primary schools closed
Secondary schools closed
Universities closed
All public gatherings banned
Public gatherings limited to 2 people
Public gatherings limited to ≤10 from 2 households
Public gatherings limited to ≤10 people
Public gatherings limited to ≤30 people
All household mixing in private banned
Household mixing in private limited to 2 people
Household mixing limited to ≤10 from 2 households
Household mixing in private limited to ≤10 people
Household mixing in private limited to ≤30 people
Night time curfew
Stricter mask-wearing policy
Total number of days across all regions
Austria
England
Germany
Italy
Czech Republic
Switzerland
The Netherlands
0
2500
5000
7500
10000
12500
15000
17000

C)



Lincolnshire | England | Greater Manchester S.W.
Zurich | Switzerland | Genève
Austria | Wien
Czech Republic | Prague
Italy | Aosta Valley
Netherlands | Brabanth-North
New cases
New deaths
1st Aug
1st Sep
1st Oct
1st Nov
1st Dec
1st Jan

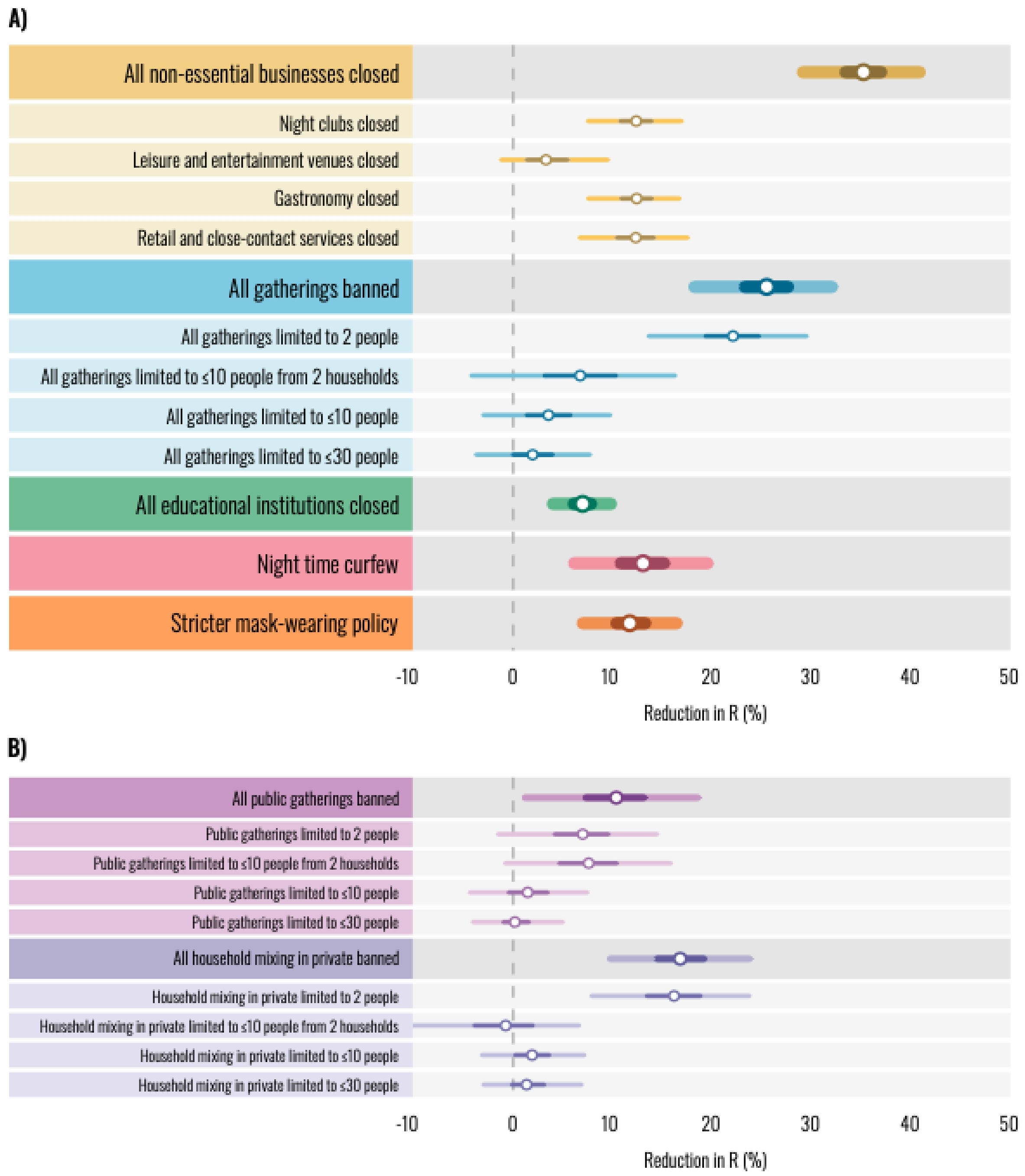
Results

First vs second wave

- Pairwise 6969 days on average with on NPI and not the other with minimum of 635 region days
- NPIs reduced Rt by 66% [95% CI: 61%-69%] vs 77%-82%
- The most stringent set reduced Rt by 56% [95% CI: 40%-64%] vs 76%-82%

Effect estimates

- Lockdown effect: 52% [95% CI: 47-56%]
- Stricter mask-wearing policy (mandatory in most or all shared/public spaces) and a night time curfew had moderate, but statistically significant effects [12%, 95% CI: 7-17%] and [13%, 6-20%])



A)
All non-essential businesses closed
Night clubs closed
Leisure and entertainment venues closed
Gastronomy closed
Retail and close-contact services closed
All gatherings banned
All gatherings limited to 2 people
All gatherings limited to ≤10 people from 2 households
All gatherings limited to ≤10 people
All gatherings limited to ≤30 people
All educational institutions closed
Night time curfew
Stricter mask-wearing policy
-10
0
10
20
30
40
50
Reduction in R (%)
B)
All public gatherings banned
Public gatherings limited to 2 people
Public gatherings limited to ≤10 people from 2 households
Public gatherings limited to ≤10 people
Public gatherings limited to ≤30 people
All household mixing in private banned
Household mixing in private limited to 2 people
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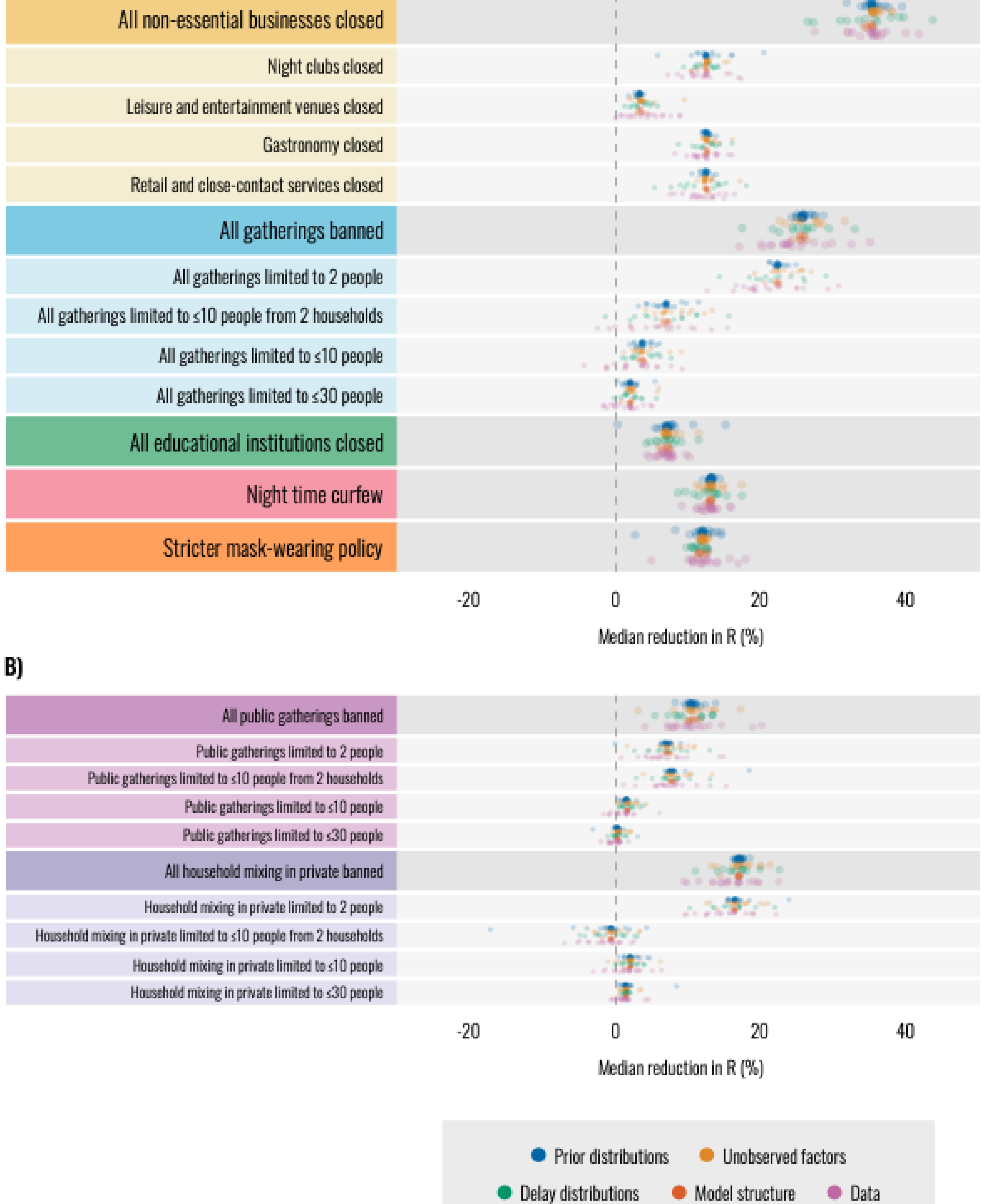
-10
0
10
20
30
40
50
Reduction in R (%)

Estimate of robustness

- 17 sensitivity analyses
- Stability of unobserved effects (unrecorded NPIs, changes to ascertainment and fatality rates)
- Sensitivity analysis in SI is made up of lots of graphs, investigate in your own time.



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Median reduction in R (%)
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0
20
40
Median reduction in R (%)
Prior distributions
Unobserved factors
Delay distributions
Model structure
Data

Conclusions

Summary

- Estimates can be used to inform reopening
- First such estimates

Limitations

- We don't know the impact of voluntary safety measures or variants
- No effectiveness estimate can apply to all regions.

Methods

Summary

- Lots of details about NPI collection - looks robust.
- Model: Nothing, all in supplement.

Code

https://github.com/MrinankSharma/COVID19NPISecondWave

TLDR: it is pretty nice python

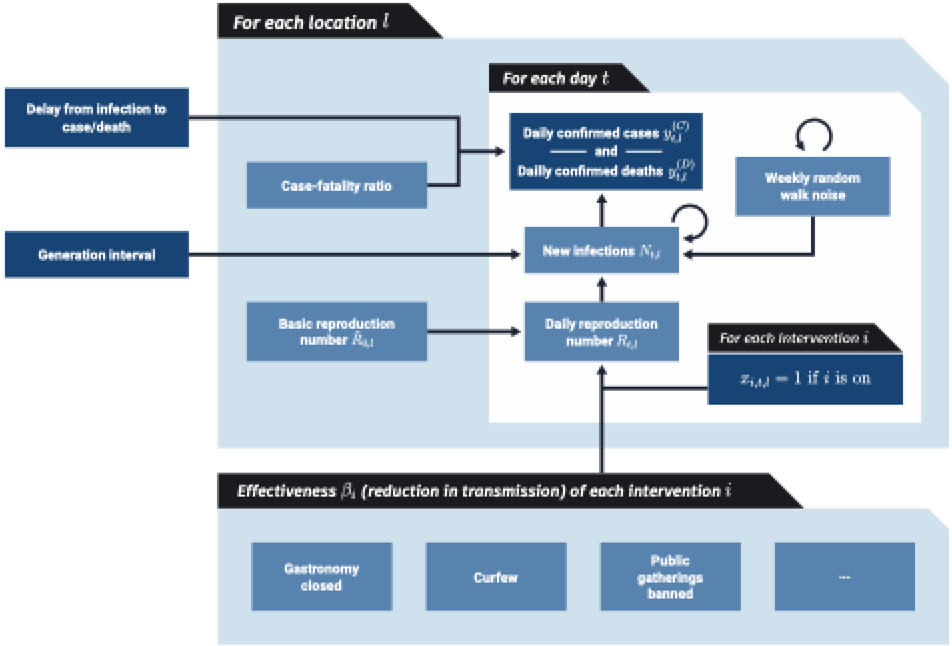
Model

Summary

- Fixed effects NPI regression model with a 14 day random walk.
- Fixed generation time renewal equation based model to estimate infections
- Fixed delays to death and report
- IFR fit by location but fixed in time (explored UK varying IRFs taken from the imperial dashboard as a sensitivity)

Summary

- Country specific overdispersion in the negative binomial observation model.
- Implemented in NumPyro using NUTS MCMC.
- McAloon incubation period
- Linelist data from Austria, Germany, and UK for report delay.



For each location l
For each day t
Delay from infection to case/death
Case-fatality ratio
Daily confirmed cases $y_{t,l}^{(C)}$ and Daily confirmed deaths $y_{t,l}^{(D)}$
Weekly random walk noise
Generation interval
New infections $N_{t,l}$
Basic reproduction number $\bar{R}_{0,l}$
Daily reproduction number $R_{t,l}$
For each intervention i
$z_{i,t,l} = 1$ if i is on
Effectiveness β_i (reduction in transmission) of each intervention i
Gastronomy closed
Curfew
Public gatherings banned
...

(weekly) random walk. The random walk term allows $R_{t,l}$ to change from one week to the next. Precisely, $R_{t,l}$ follows:

$$R_{t,l} = \underbrace{\tilde{R}_{0,l}}_{\substack{R \text{ at } t=0 \text{ if no} \\ \text{NPIs active}}} \overbrace{\left(\prod_{i=1}^{I} \exp\left(-\beta_i \, x_{i,t,l}\right)\right)}^{\text{effect due to active NPIs}} \underbrace{\exp(z_{t,l})}_{\substack{\text{latent random} \\ \text{walk}}} , \tag{1}$$

where $x_{i,t,l} = 1$ means NPI i is active in location l on day t ($x_{i,t,l} = 0$ otherwise), and I is the number of NPIs. We now explain each of these terms in more detail.

We place a prior distribution over $\tilde{R}_{0,l}$, the reproduction number (in the absence of NPIs) on August 1st 2020. In fact, many locations had some recorded interventions active at $t = 0$. Therefore, we chose the mean of the prior on $\tilde{R}_{0,l}$ carefully. We ensured the prior on $R_{0,l}$ matched published estimates[a] of R_t for the first week of August from (3) and (4). For clarity, $\tilde{R}_{0,l}$ is the reproduction number that *would* have been observed in location l at $t = 0$ had no NPIs been active. The prior over $\tilde{R}_{0,l}$ follows:

$$\tilde{R}_{0,l} \sim \text{Truncated Normal}(1.35, 0.3^2), \tag{2}$$

where trunction prevents values of $\tilde{R}_{0,l}$ less than 0.1.

We parameterise the effect of NPI i with the effect parameter β_i. This parameter is independent of time and shared across all locations, i.e., the effectiveness of a particular NPI is assumed to be identical across regions (though the random walk described below can account for differences). We place an Asymmetric Laplace prior over the effect parameter β_i, with scale parameter 30, asymmetry parameter 0.5, and location parameter 0. This prior has mean 0.05 and standard deviation 0.07. The prior allows for (unbounded) positive and

[a] The prior over $R_{0,l}$ depends on $\tilde{R}_{0,l}$, the interventions active at $t = 0$ in location l and the prior on the effectiveness of NPIs. We fixed the intervention prior first and then chose the prior on $\tilde{R}_{0,l}$

negative effects as we cannot exclude the possibility that an NPI increases transmission. However, our prior places 80% of its mass on positive effects, reflecting a belief that NPIs are more likely to reduce transmission than to increase it. Furthermore, this is a shrinkage prior–it places more than 80% of its mass on "small" effectiveness (less than 10% change in $R_{t,l}$).

noise terms follow:

$$z_{t,l} = \begin{cases} 0 & t \leq 13 \\ z_{t-1,l} + \varepsilon_{\lfloor (t-14)/7 \rfloor, l} & \text{if } t \bmod 7 = 0\,, \\ z_{t-1,l} & \text{otherwise} \end{cases} \tag{3}$$

where $\lfloor \cdot \rfloor$ denotes the floor operation and $\epsilon_{i,l} \sim \text{Normal}(0, \sigma_R^2)$. In words, $z_{t,l}$ is set to 0 for the first two weeks, meaning that $R_{t,l}$ depends only on $\tilde{R}_{0,l}$ and the active interventions for the first two weeks. Then, every week, the value of $z_{t,l}$ may increase or decrease depending on the noise variable $\epsilon_{i,l}$. If we observe that transmission increased in a particular week, then we may infer $\epsilon_{i,l}$>0 and vice versa.

The random walk addresses an important limitation–we cannot include all possible factors that affect transmission. We can attempt to attribute effect sizes to NPIs at a time t, but we need to agnostically account for other unobserved factors that could have changed transmission (e.g. behaviour, adherence). By using a random walk, we include a latent stochastic process that agnostically models unobserved trends and residual structural correlations.

walk prior appears to be shared in time and space

$$\bar{N}_{t,l} = R_{t,l} \sum_{\tau=1}^{32} \left(\bar{N}_{t-\tau,l} \cdot \pi_{GI}[\tau] \right). \tag{4}$$

Renewal processes have a strong relationship to Hawkes processes and arise naturally from a Bellman Harris branching process (6,5). The renewal equation has also been shown to be equivalent to a susceptible-exposed-infected-recovered Erlang model. The renewal equation therefore specifies an epidemilogically motivated function class. One issue with the renewal equation is that it specifies a deterministic expectation for the number of new infections. This is generally suitable as infections become large, but in low incidence settings, estimation of $R_{t,l}$ can be sensitive to random fluctations and noise. Therefore, we include an additive noise term, reflecting a belief that changes in the number of infections at low infection counts provide limited evidence to ascertain $R_{t,l}$, and must be treated with caution. Thus, the actual number of infections follows:

$$N_{t,l} = \mathrm{softplus}(\bar{N}_{t,l} + \epsilon_{t,l}), \tag{5}$$

where $\epsilon^{(N)}_{t,l} \sim \mathrm{Normal}(0, 5^2)$ (sensitivity analysis in Fig. S9). We use the softplus$(\cdot)$ rectifier to ensure that $N_{t,l} \geq 0$.

We seed the model with one week of unobserved initial infections[b].

$$N_{-t,l} = \mathrm{Lognormal}(\tilde{\mu} = 0, \tilde{\sigma} = 3), \qquad \text{for } 1 \leq t \leq 7. \tag{6}$$

Table 1: Table of epidemiological parameters, their distributional forms and their source.

Delay	Distributional form of delay	Source
Generation interval	Gamma(mean=4.83, sd = 1.73)	Meta-analysis (*14*)
Incubation period	Gamma(mean=5.53, sd = 4.73)	Meta-analysis (*14*)
Onset to reported death	Gamma(mean=18.61, sd = 13.62)	Linelist (Sec. 1.2)
Onset to case confirmation	Gamma(mean=5.28, sd = 3.75)	Linelist (Sec. 1.2)