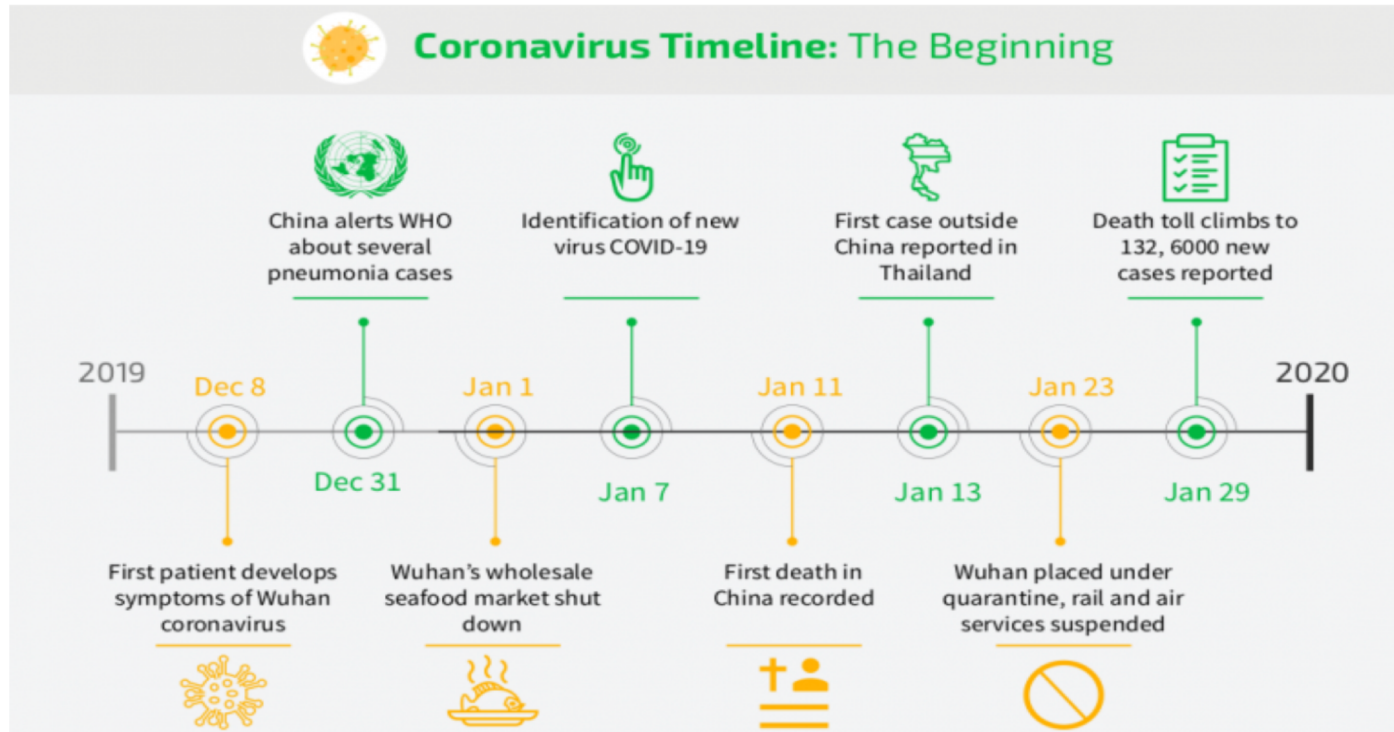


Predictions of COVID-19 dynamics in the UK: short-term forecasting, analysis of lockdown relaxation strategies and impact of reopening schools

**Ed Hill, Louise Dyson, Matt Keeling, Mike Tildesley,
& SBIDER COVID-19 Modelling Team.**

Zeeman Institute: Systems Biology & Infectious Disease Epidemiology Research
(SBIDER), University of Warwick, UK.

Background: Events in the UK



The coronavirus timeline.

Image: Avetta

- **31st January:** The first cases in the UK were reported.
- **12th March:** The “delay” phase was enacted, during which individuals with a cough or fever were advised to self-isolate for seven days
- **20th March:** All restaurants, pubs and cafes ordered to close.
- **23rd March:** Full lockdown began.
- **May onwards:** Easement of lockdown in phases. Usage of localised measures.

Modelling response: University of Warwick involvement

- University of Warwick researchers have been involved in the UK government response at many levels, as well as the response in other countries.
- Four of the research group (Matt Keeling, Mike Tildesley, Louise Dyson, Ed Hill) are currently members of **Scientific Pandemic Influenza Group on Modelling (SPI-M)**.
- SPI-M report to the **Scientific Advisory Group for Emergencies (SAGE)**, which provides scientific and technical advice to support government decision makers.
- The Warwick model is used for:
 - determining the current levels of infection and short-term forecasting,
 - longer-term predictions and planning.

Talk outline

(1) Introducing the model

(2) Fitting to data & short-term forecasting

- Overview of data streams and usage in estimating epidemiological measures, such as R and growth rate.

(3) Assessing lockdown relaxation strategies (May 2020)

- Age-independent; Age-based shielding; Adaptive interventions.

(4) Impact of reopening schools from June 2020

- Consider set of partial and full reopening options across both primary schools (ages 4-11) and secondary schools (ages 11-16).

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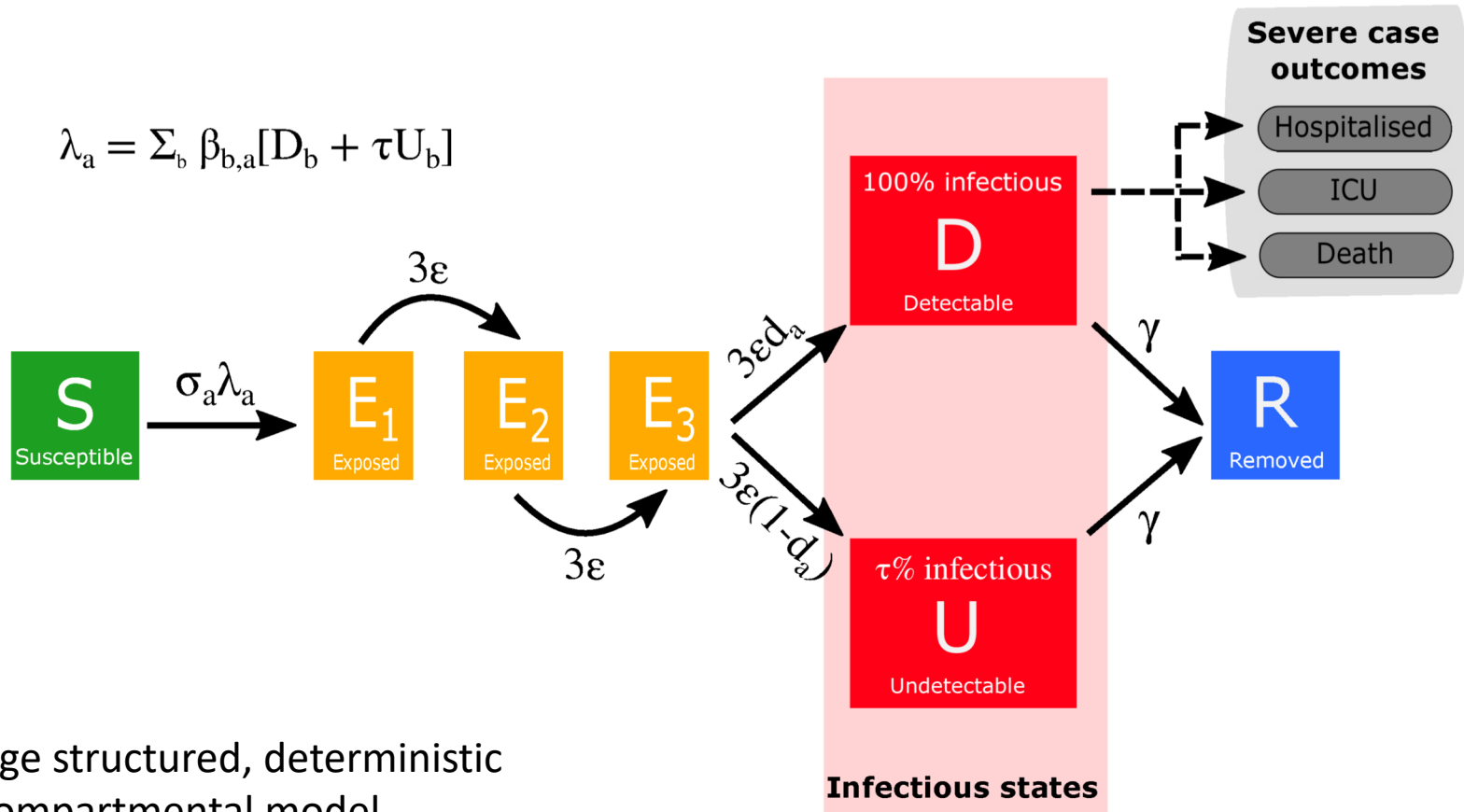
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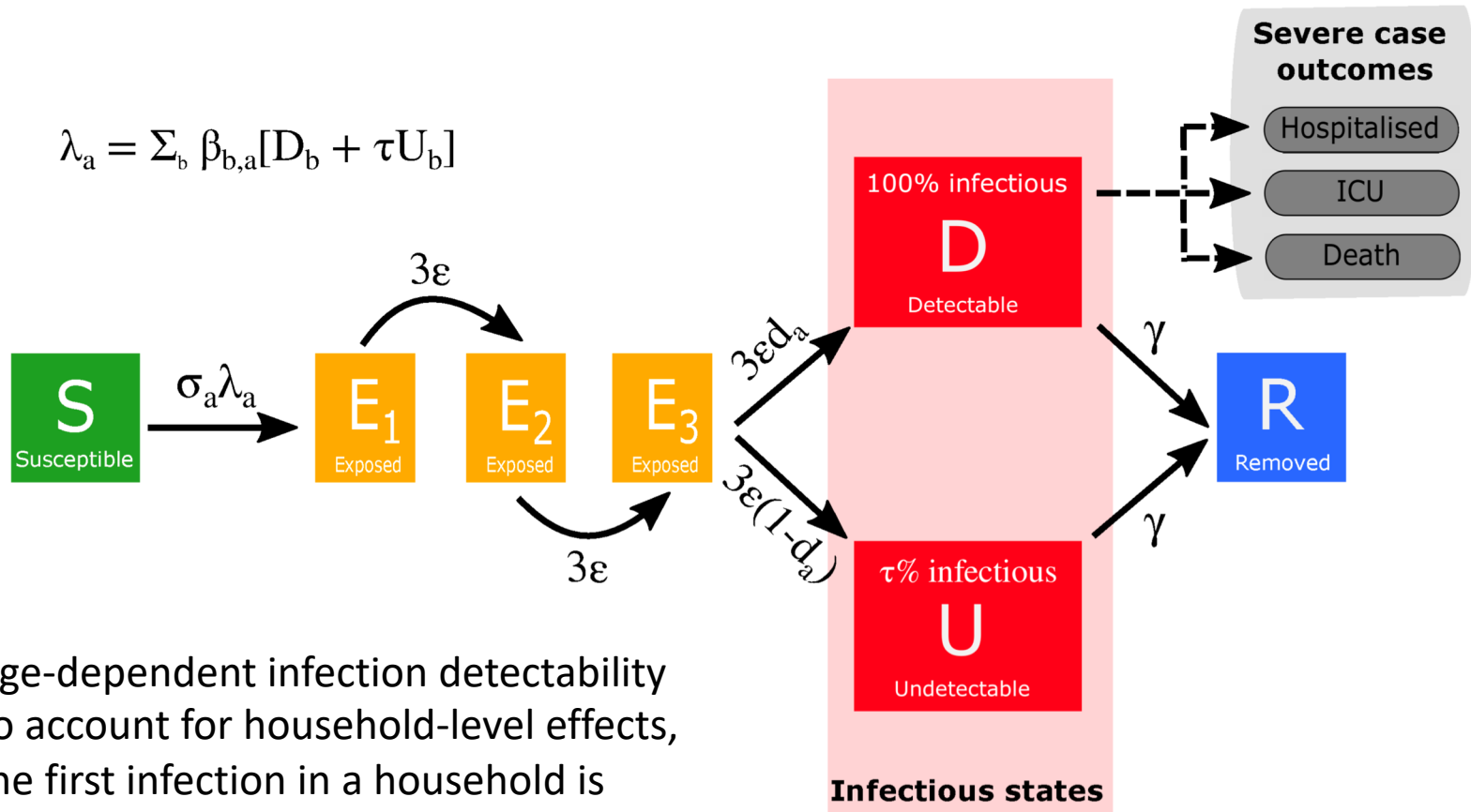
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Modelling SARS-CoV-2 transmission: Disease state schematic



Additional layers of complexity



- Age-dependent infection detectability
- To account for household-level effects, the first infection in a household is considered separately to subsequent infections.
- Includes household quarantine states

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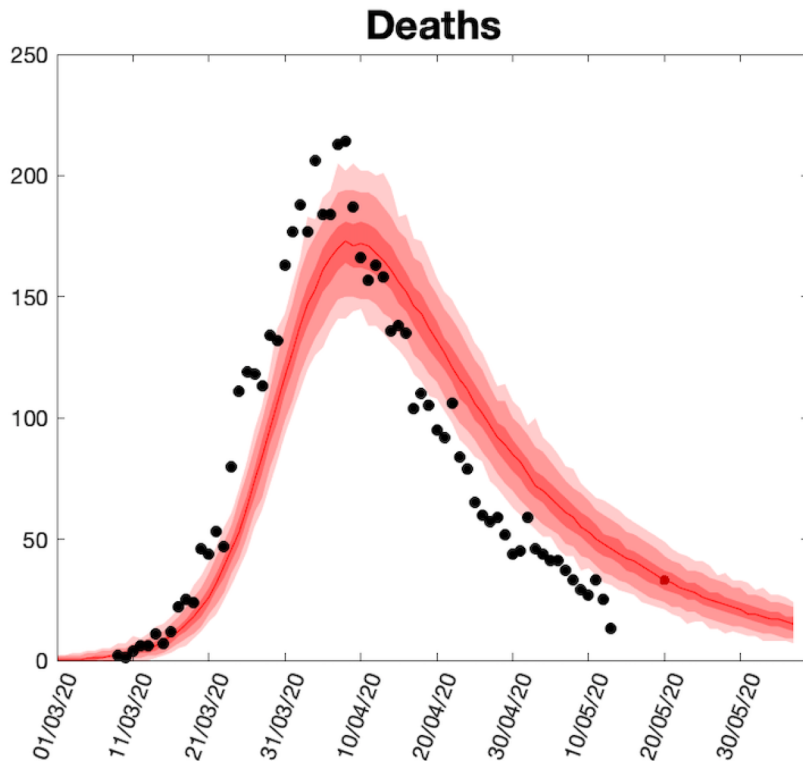
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The data & model parameterisation

- Regional basis, 10 in total:
 - Seven regions in England (London, Midlands, South East, South West, East of England, North East, North West)
 - Three devolved nations: Wales, Scotland, Northern Ireland
- Empirical data
 - Healthcare transition times (e.g. symptom onset to hospitalisation)
- Inferred distributions for the transmission model parameters by fitting to the available data using statistical methods (parameter inference).

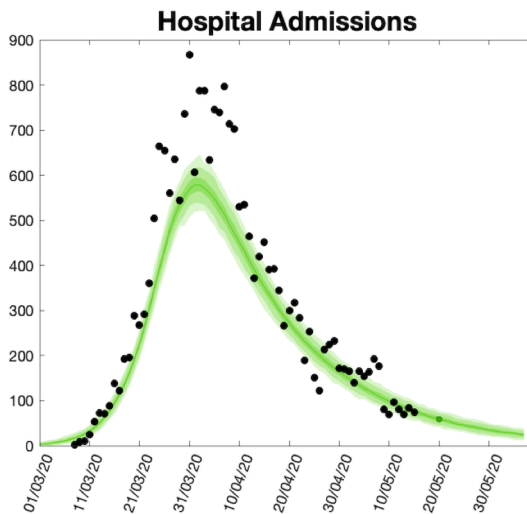
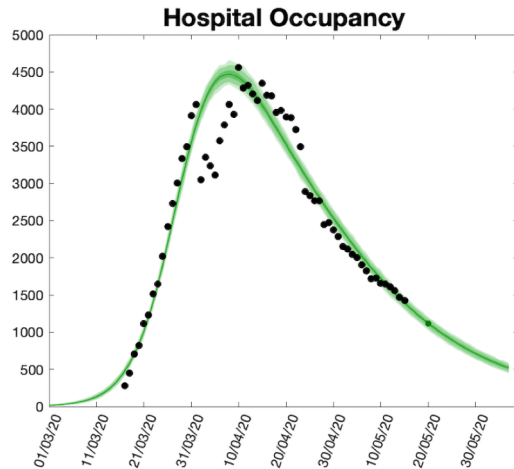
What data is the model being fit to?



Collectively fitting to up to four types of data (where available):

- Deaths
 - By date of death (ideally)
 - By date of reporting
- Hospital occupancy & new admissions
- ICU occupancy
- Serology

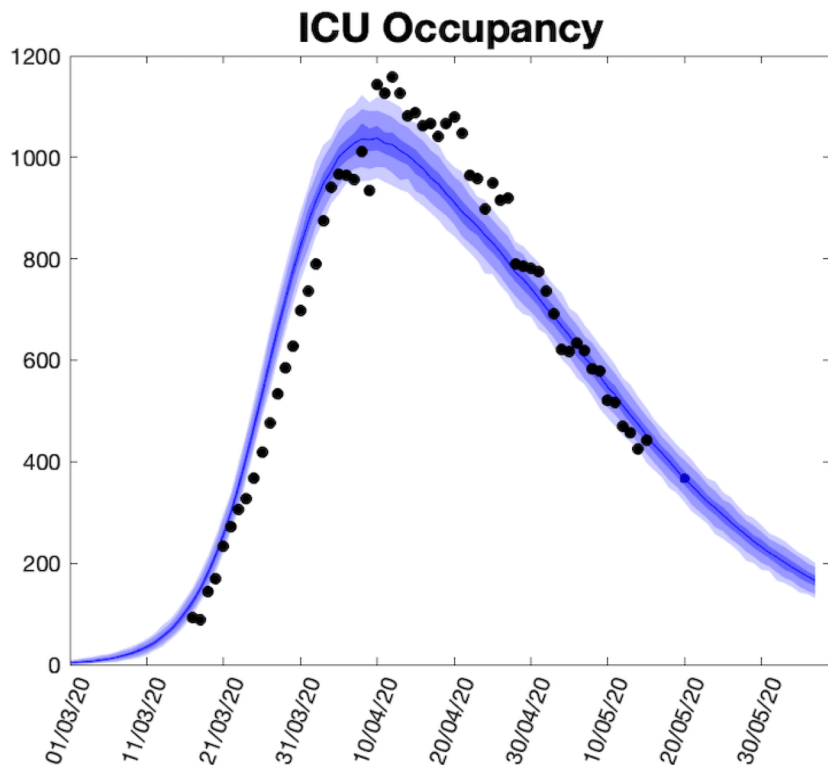
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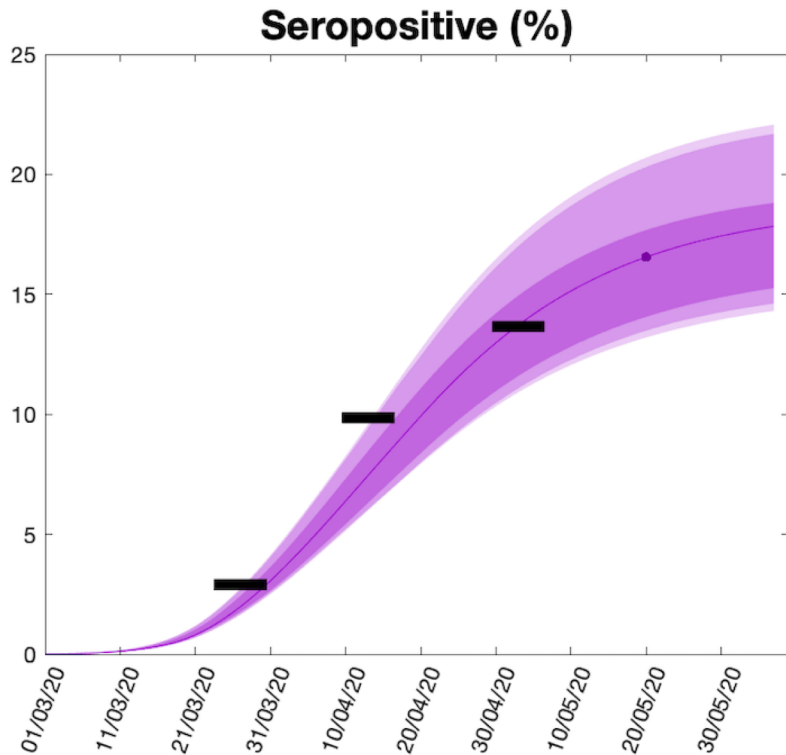
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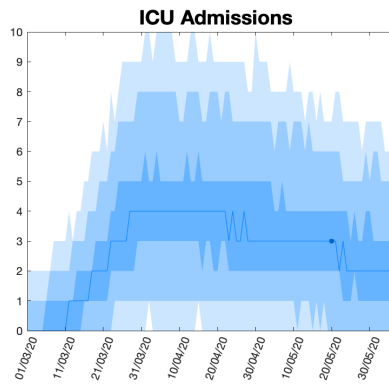
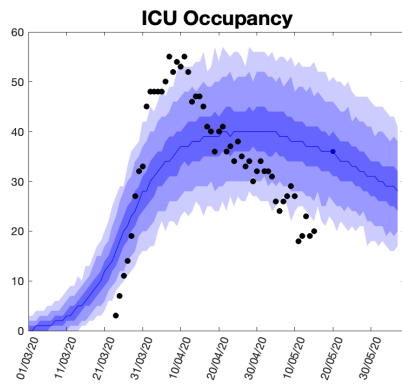
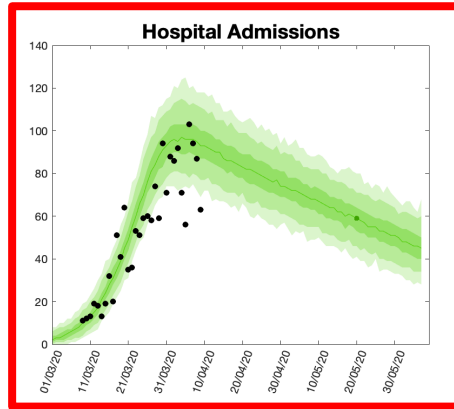
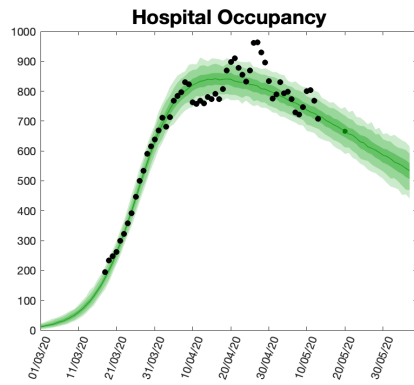
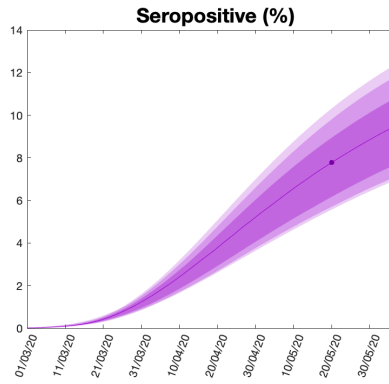
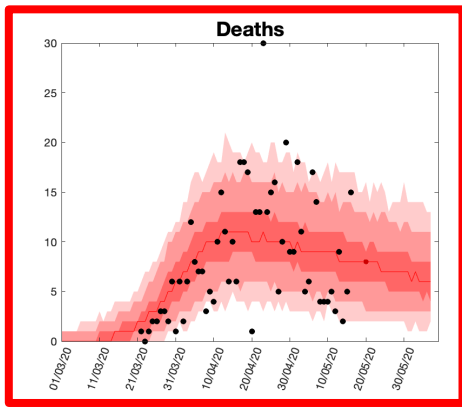
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Collectively fitting to up to four types of data (where available):

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Epidemiological measures

- We can use the transmission model to estimate, in each region:
 - Reproduction number (R);
 - Incidence;
 - Prevalence;
 - Growth rate;
 - Estimated occupancy of hospital beds.

- Note of caution: **The R number is only a single measure** and so cannot be used as a sole indicator of the current threat posed by an epidemic.
 - the rate of occurrence of new infections
 - the prevalence of infection across communities
 - the current burden faced by the healthcare system

Talk outline

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- Age-independent; Age-based shielding; Adaptive interventions.

(4) Impact of reopening schools from June 2020

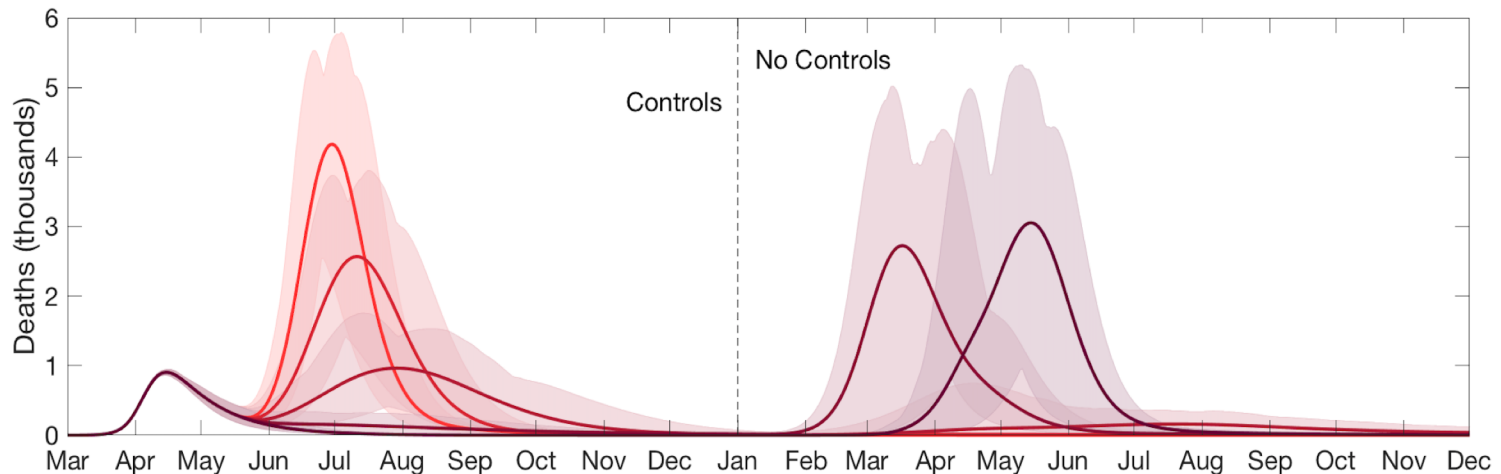
- Consider set of partial and full reopening options across both primary schools (ages 4-11) and secondary schools (ages 11-16).

Population-wide relaxation of lockdown measures

- Assumed social distancing measures were relaxed on 7th May for all individuals.
- At the start of 2021, all remaining social distancing measures are removed (the "no control" phase).

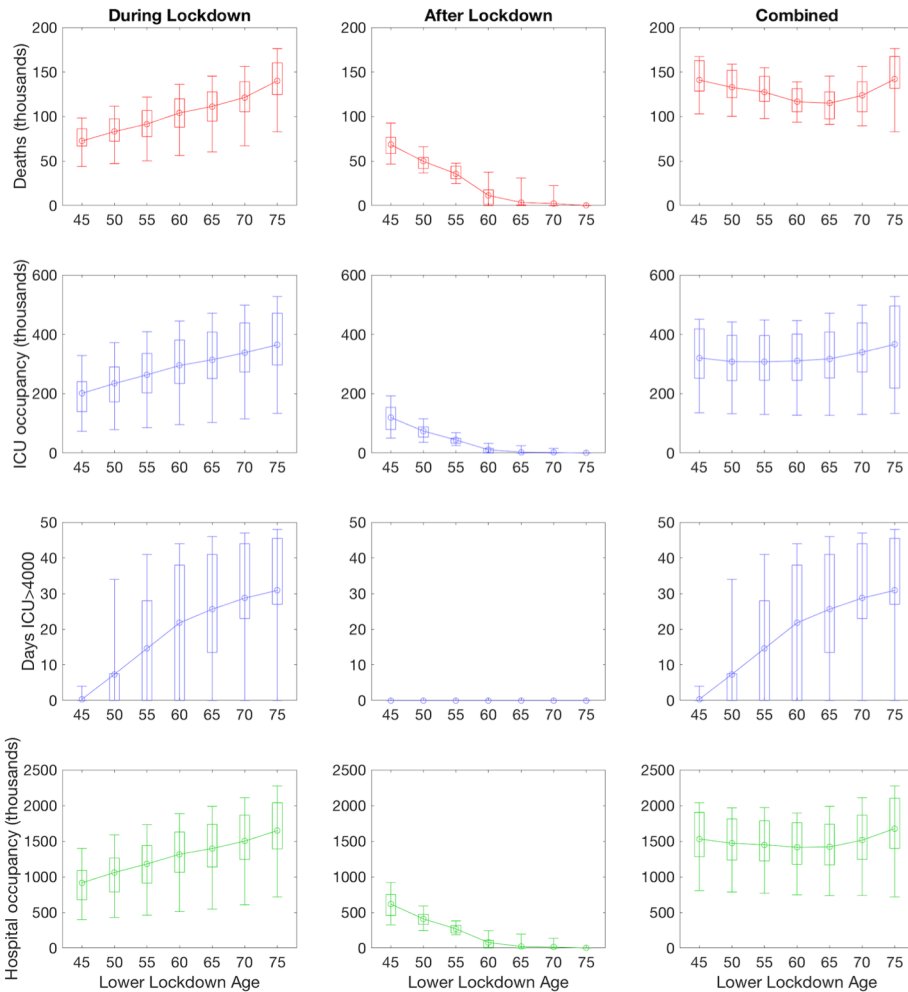
Population-wide relaxation of lockdown measures

- Assumed social distancing measures were relaxed on 7th May for all individuals.
- At the start of 2021, all remaining social distancing measures are removed (the "no control" phase).



- Paler lines correspond to higher relaxation, which results in immediate resurgence.
- Minor change in relaxation suppresses the initial wave, though a second wave occurs during the "no control" phase.

Age-based shielding strategies



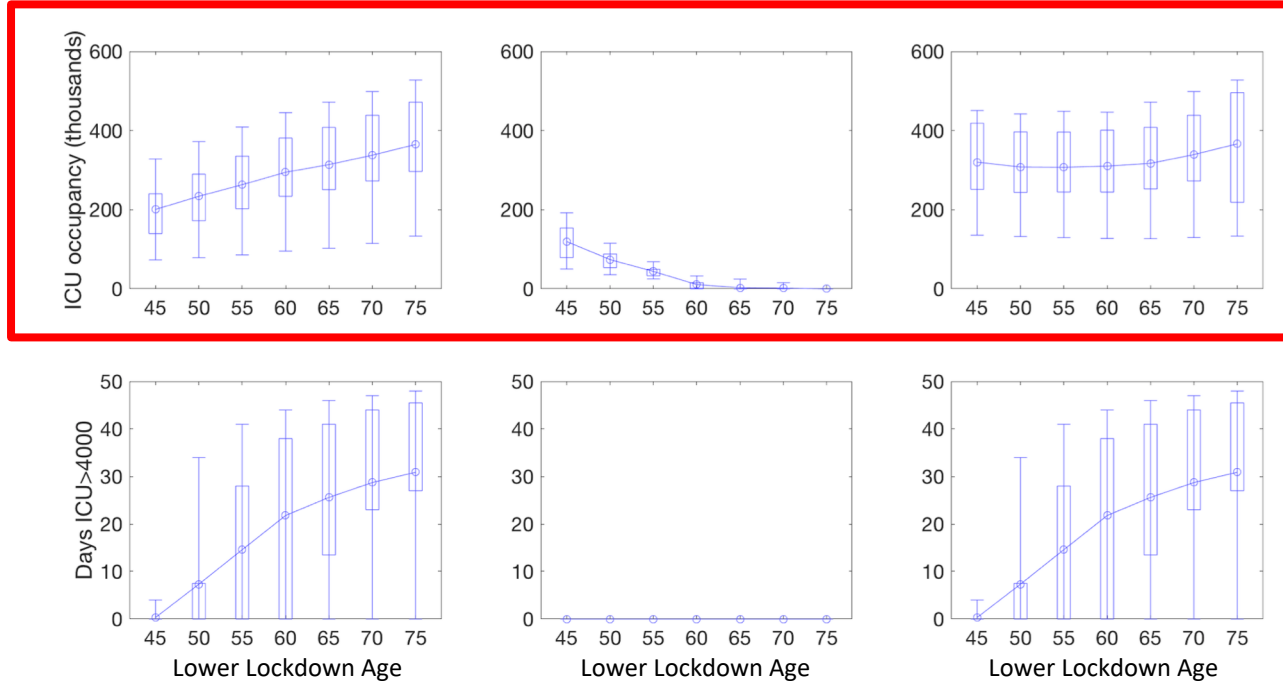
- Social distancing measures were lifted on 7th May for all individuals below an age threshold (x axis).
- Social distancing measures remain in place for the remainder of the population until the end of 2020.
- No interventions were applied post-lockdown release, with simulations continued until the end of 2022.

Age-based shielding strategies

During lockdown

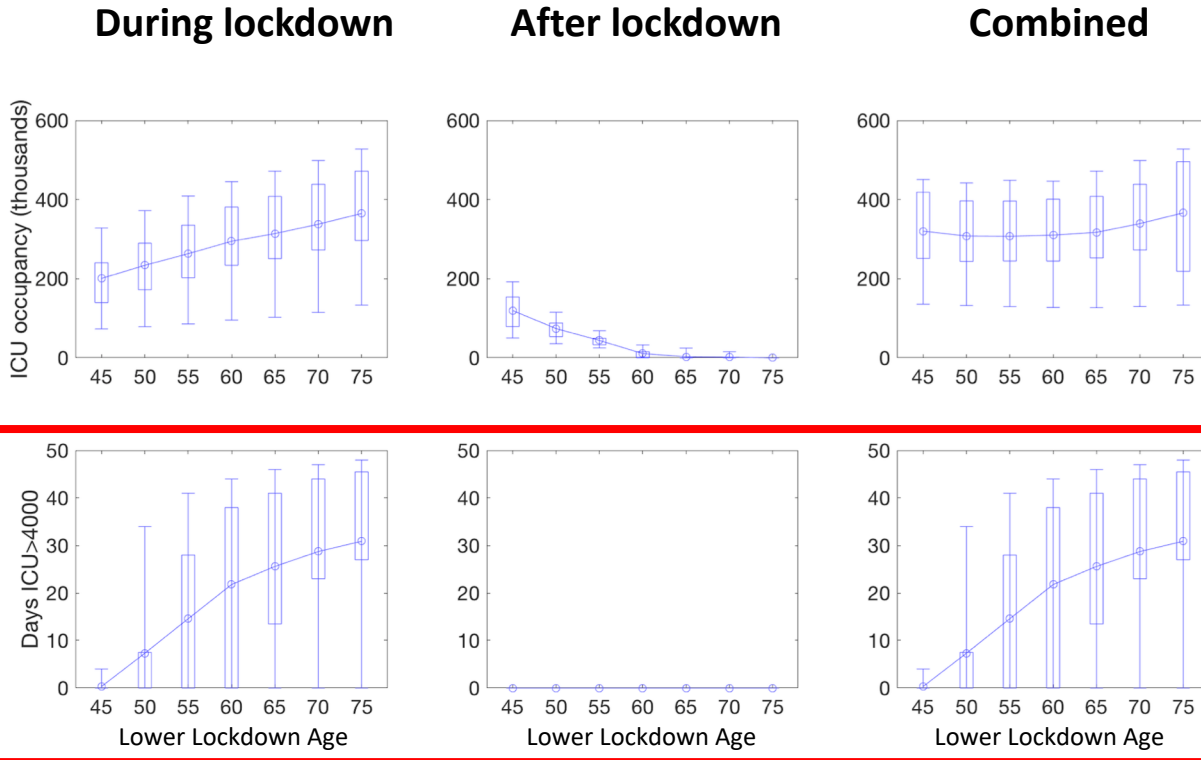
After lockdown

Combined



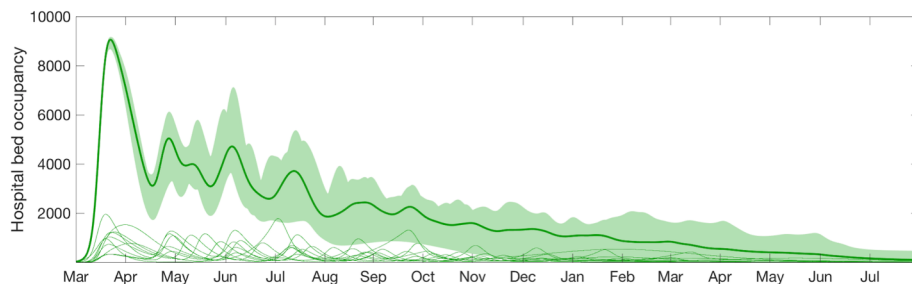
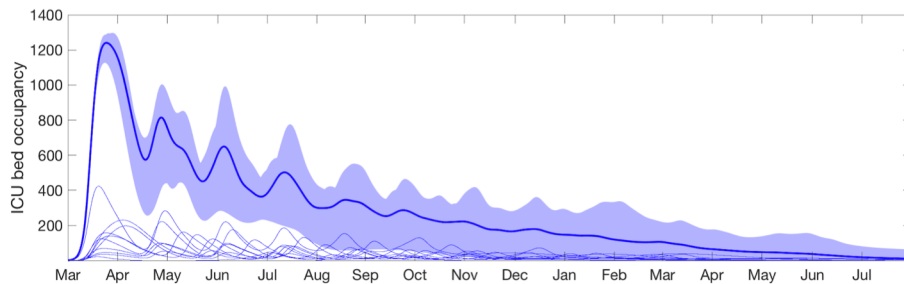
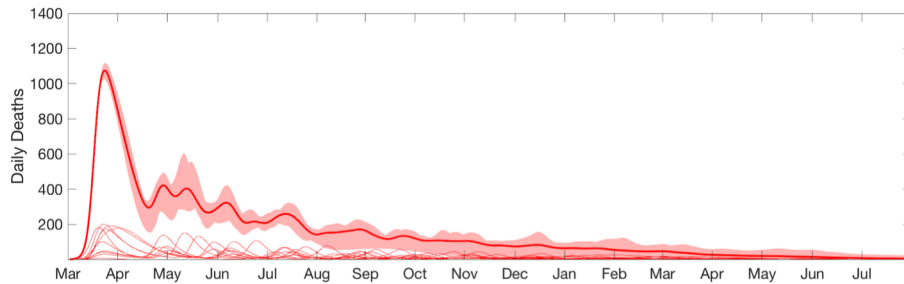
- When isolation is only in place for older age groups, a large initial wave of infection occurs during 2020, but a subsequent secondary wave is not observed.

Age-based shielding strategies



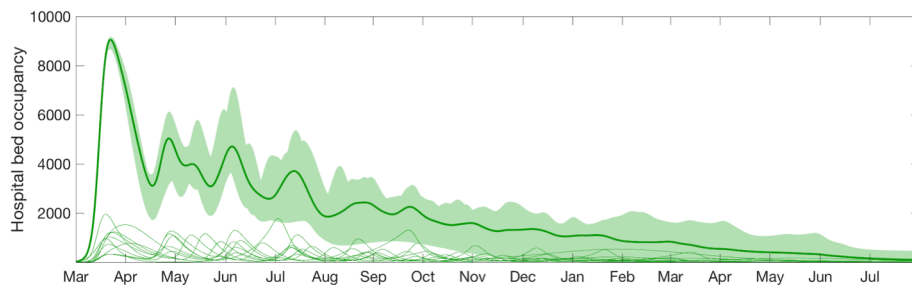
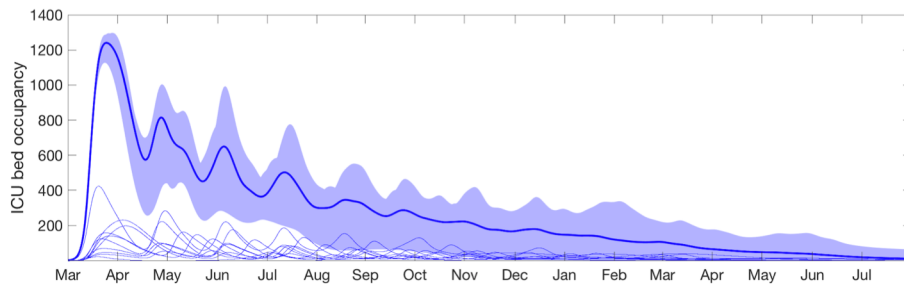
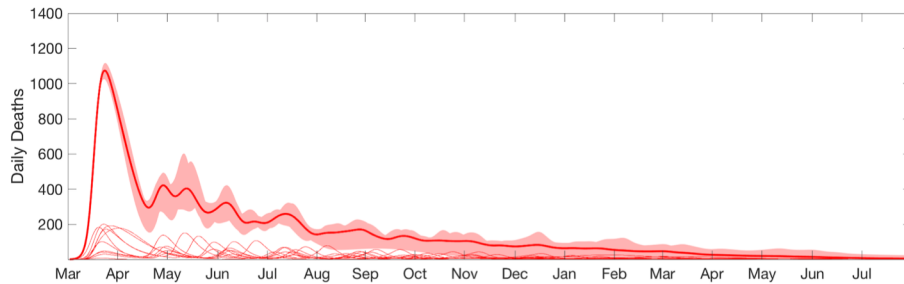
➤ As the age-threshold at which shielding is implemented increases, there is a **rise** in the total number of days for which ICU bed occupancy exceeds 4,000.

Adaptive interventions: ICU occupancy triggers



- Social distancing measures were relaxed on 7th May for all individuals
- Lockdown measures reintroduced at a regional level if ICU occupancy exceeds 45 ICU cases per million within the given region.

Adaptive interventions: ICU occupancy triggers



- Ensures healthcare system is not overwhelmed.
- Longer epidemic tail.

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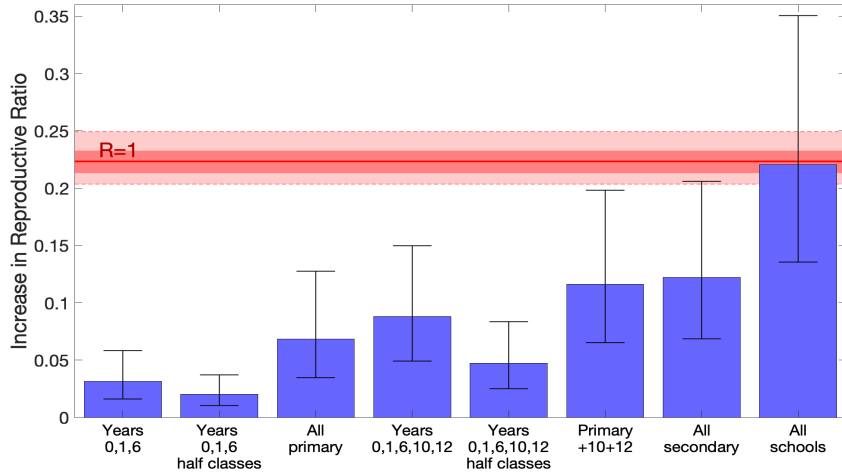
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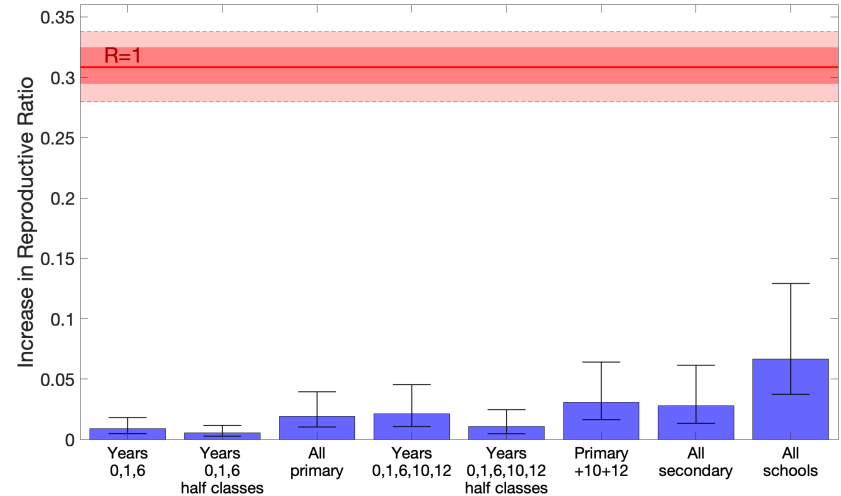
Reopening schools

Our model was used to determine the impact of school re-opening in June.

Midlands

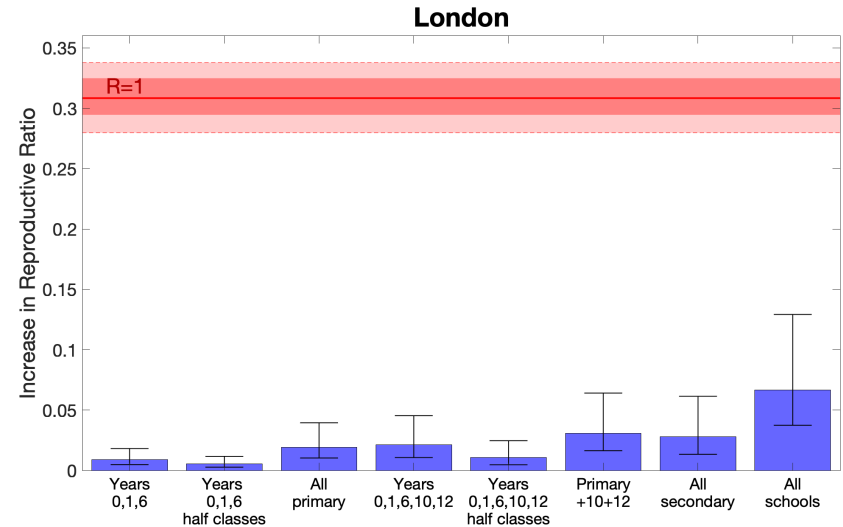
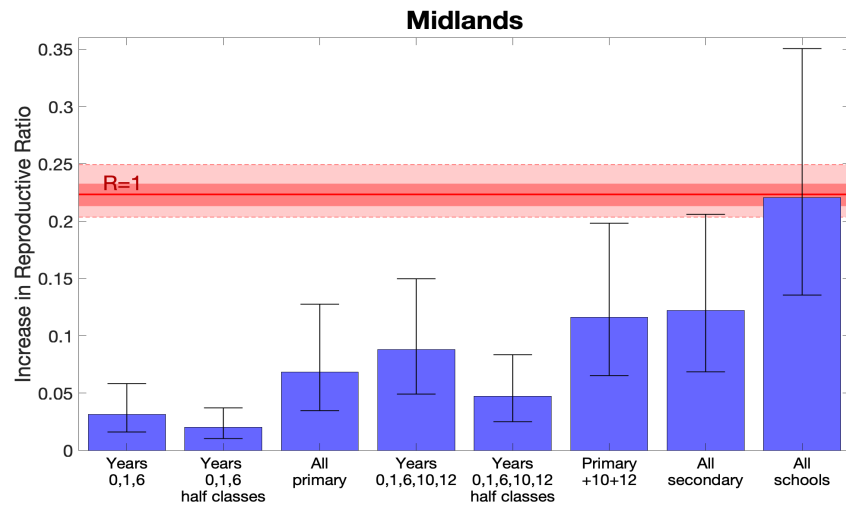


London



Reopening schools

Our model was used to determine the impact of school re-opening in June.



- Opening schools would cause R to rise.
- Median estimates for R remained below 1 in all regions.
 - Important to note these estimates did not take into account other changes to social distancing guidance.
- Small increase in R when year 0, 1 and 6 return to school.

Ongoing work

- Reopening higher education;
- Reacting to local spatial spread;
- Modelling to evaluate vaccination programmes;
- Adaptive management;
- ...

Summary

(1) Introducing the model

- Presented a deterministic, age-structured compartmental model framework used to model SARS-CoV-2 transmission in the UK.

(2) Fitting to data & short-term forecasting

- Critical care, mortality and serology data streams used for model paramterisation. Model used for regional estimates.

(3) Assessing lockdown relaxation strategies (May 2020)

- Care needed to identify strategies to “safely” exit lockdown and react in a timely fashion to increase in cases.

(4) Impact of reopening schools from June 2020

- At that time, reopening of schools (in isolation of other relaxation measures) unlikely to push R above 1.

Acknowledgements

- Data processing team

(Massimiliano Tamborrino, Glen Guyver-Fletcher, Alex Holmes)

- Literature team

(Bridget Penman, Erin Gorsich, Trystan Leng, Hector McKimm, Emma Southall)

- Public Health England & COVID-19 Hospitalisation in England Surveillance System (CHESS)

- Malcom Semple, ISARIC4C Investigators & the COVID-19 Clinical Information Network (CO-CIN)

Related research undertaken by the Zeeman Institute:
<https://tinyurl.com/warwickCOVID>

Emails:

Edward.Hill@warwick.ac.uk; L.Dyson@warwick.ac.uk.

Webpages:

<https://edmhill.github.io/>;

<https://warwick.ac.uk/fac/sci/math/people/staff/dyson/>

Preprint:



[Predictions of COVID-19 dynamics in the UK: short-term forecasting and analysis of potential exit strategies.](https://doi.org/10.1101/2020.05.10.20083683)
Keeling *et al.* (2020) *medRxiv*.
doi:[10.1101/2020.05.10.20083683](https://doi.org/10.1101/2020.05.10.20083683)

Preprint:

[Fitting models to the COVID-19 outbreak and estimating R](https://doi.org/10.1101/2020.08.04.20163782)
Keeling *et al.* (2020) *medRxiv*.
doi:[10.1101/2020.08.04.20163782](https://doi.org/10.1101/2020.08.04.20163782)



Preprint:



[The impact of school reopening on the spread of COVID-19 in England](https://doi.org/10.1101/2020.06.04.20121434)
Keeling *et al.* (2020) *medRxiv*.
doi:[10.1101/2020.06.04.20121434](https://doi.org/10.1101/2020.06.04.20121434)