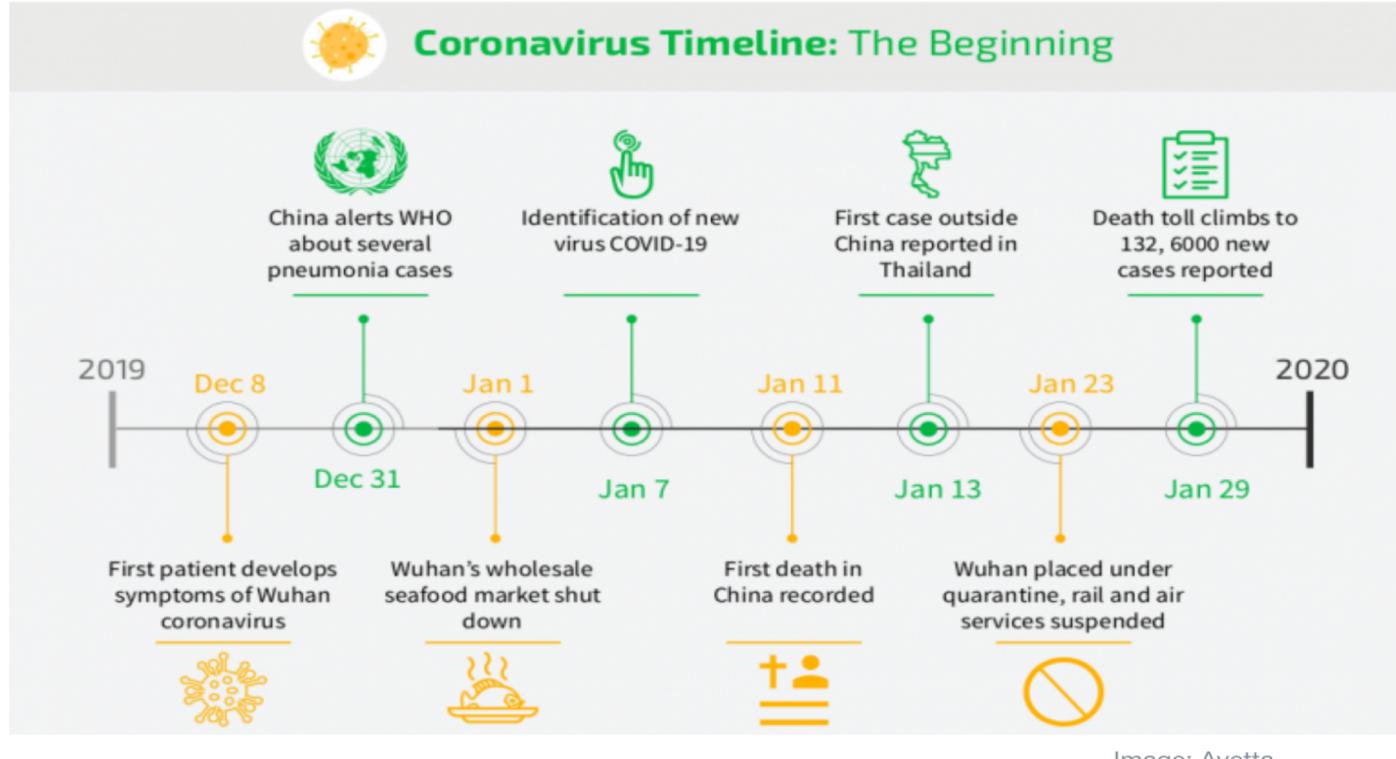


# Predictions of COVID-19 dynamics in the UK: short-term forecasting, analysis of lockdown relaxation strategies and impact of reopening schools

**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

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

# Modelling response: University of Warwick involvement

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- 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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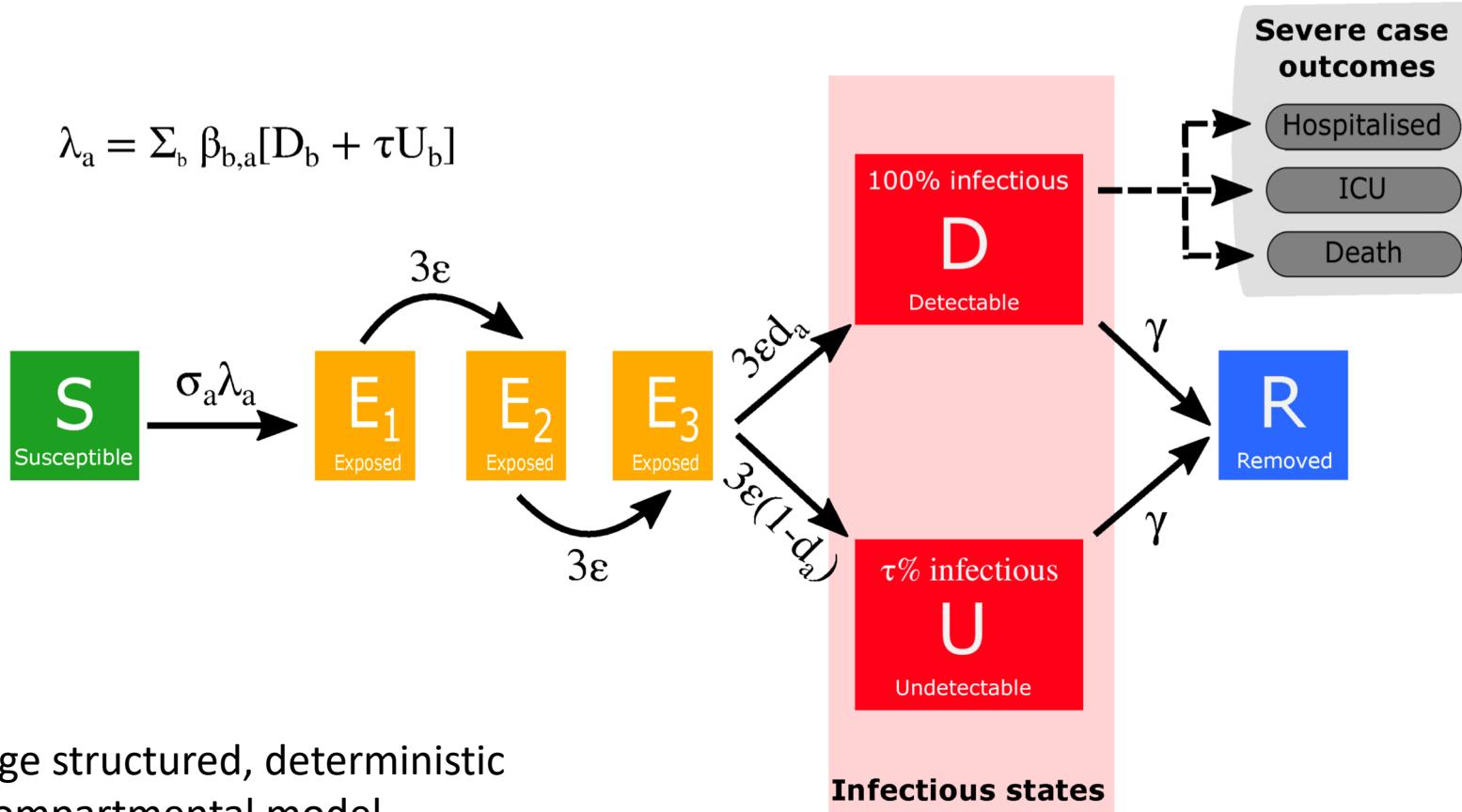
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# Modelling SARS-CoV-2 transmission: Disease state schematic

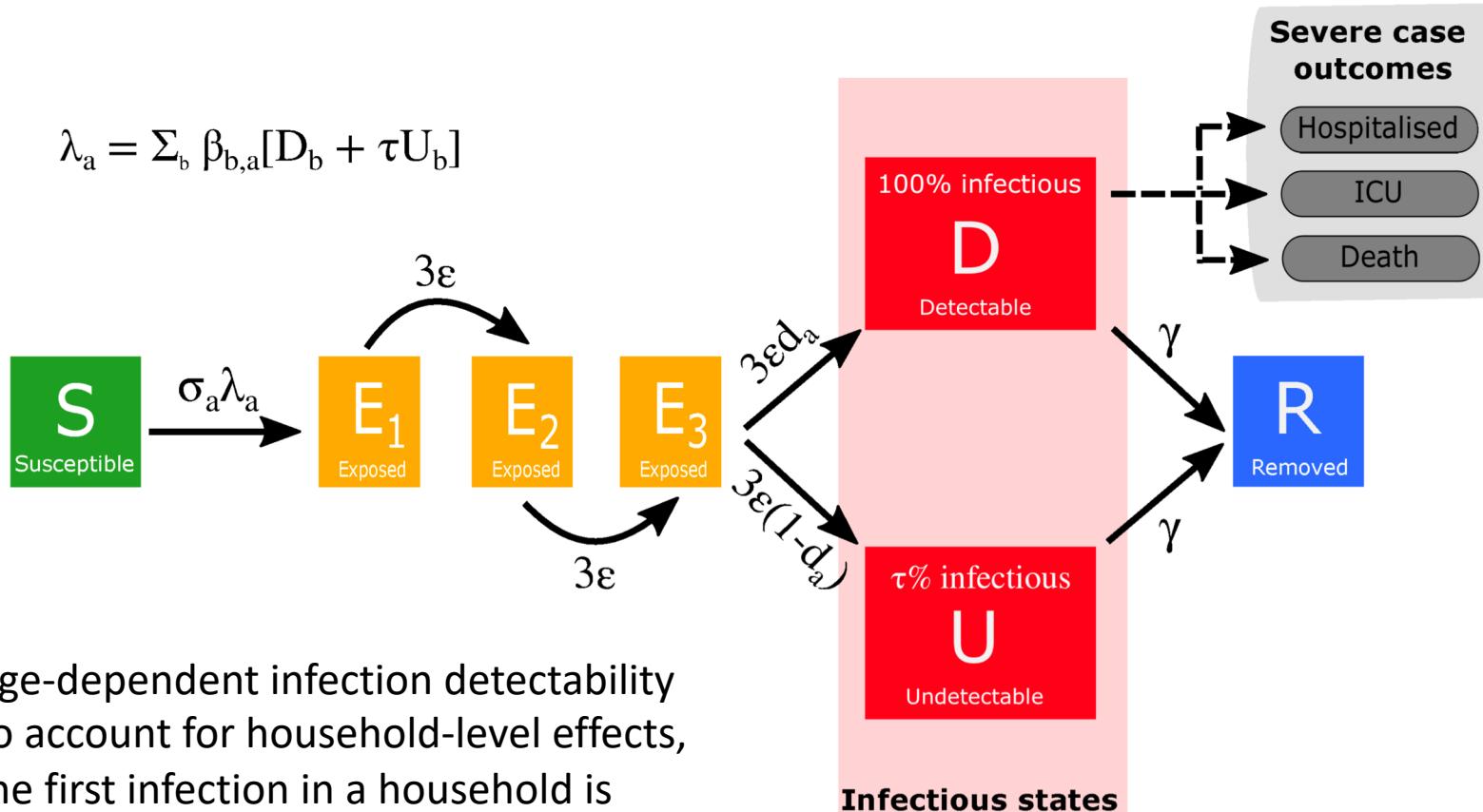
$$\lambda_a = \sum_b \beta_{b,a} [D_b + \tau U_b]$$



- Age structured, deterministic compartmental model

# Additional layers of complexity

$$\lambda_a = \sum_b \beta_{b,a} [D_b + \tau U_b]$$



- 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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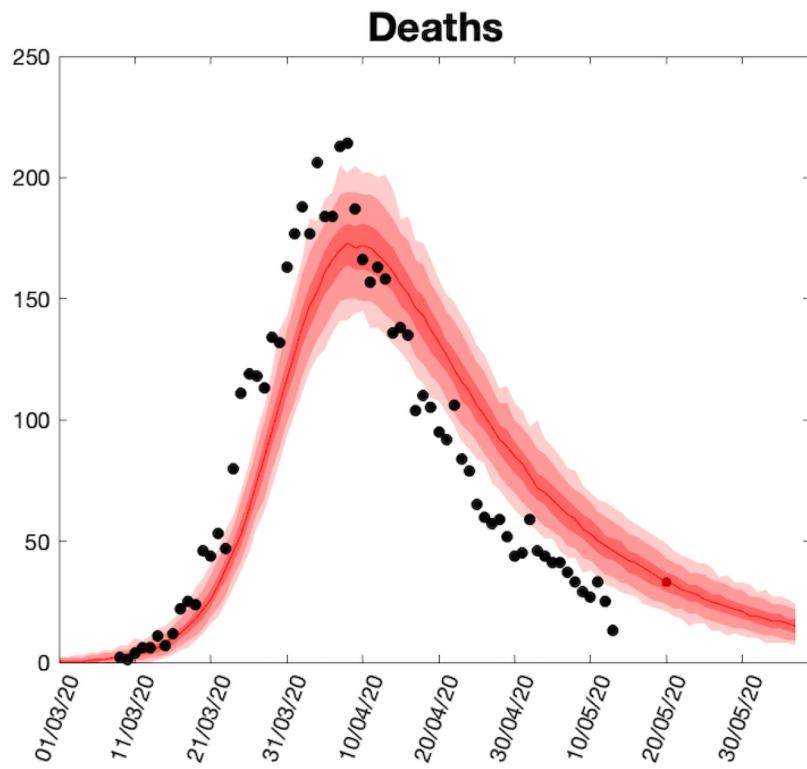
# The data & model parameterisation

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- 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).



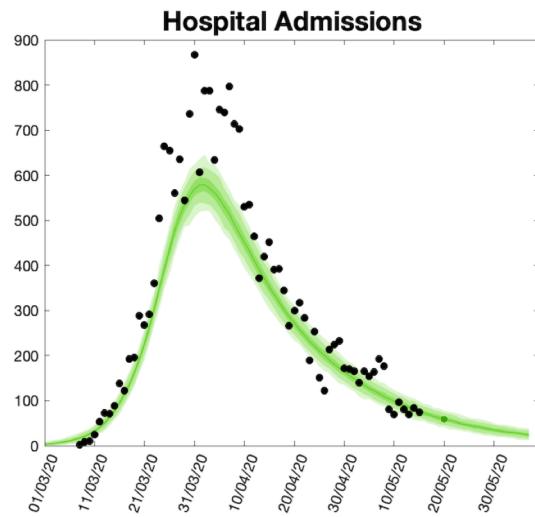
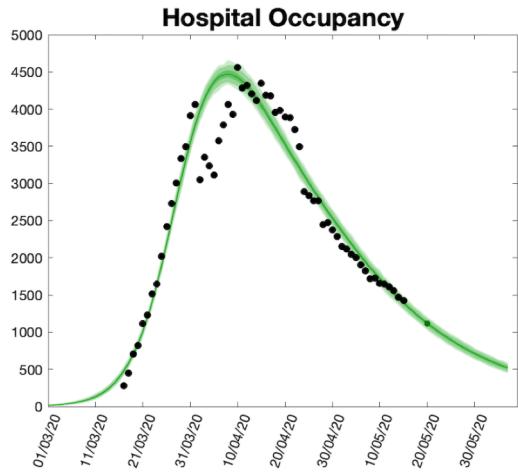
# What data is the model being fit to?



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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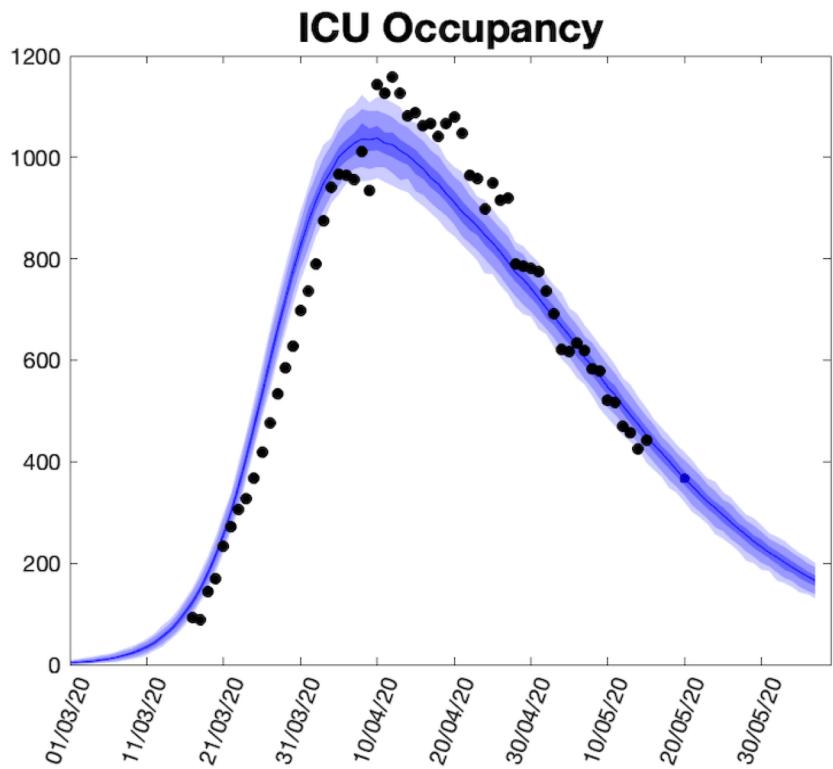


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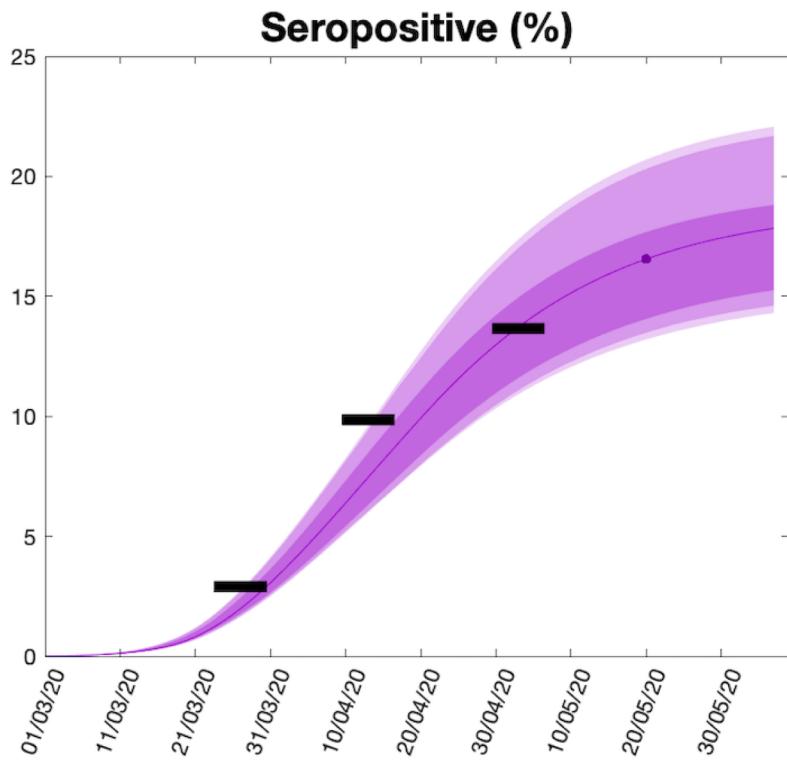
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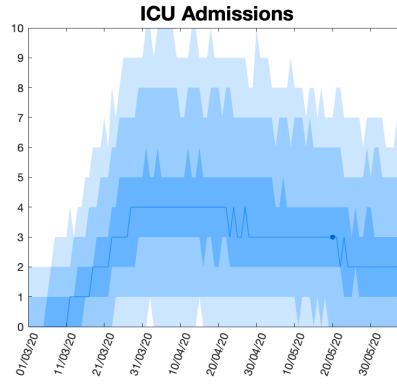
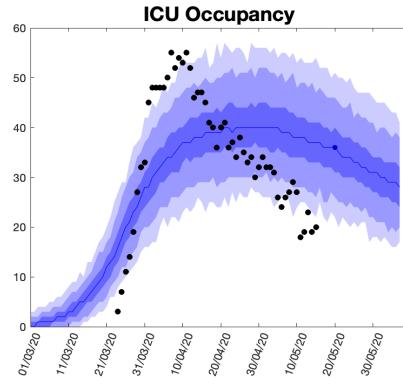
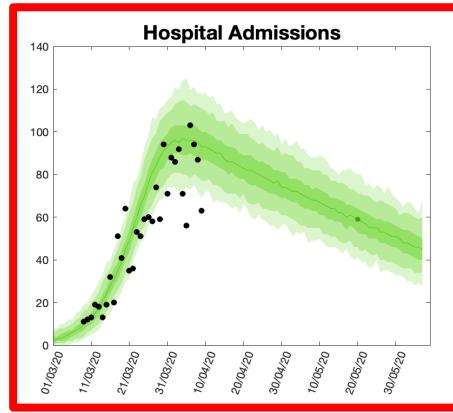
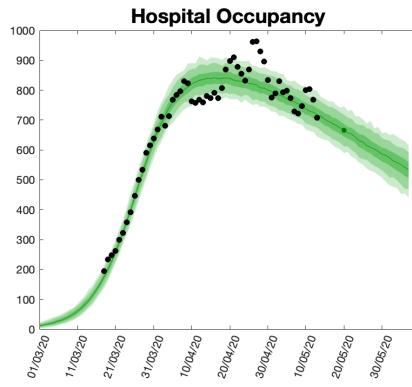
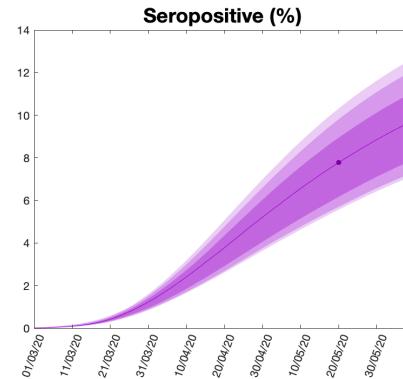
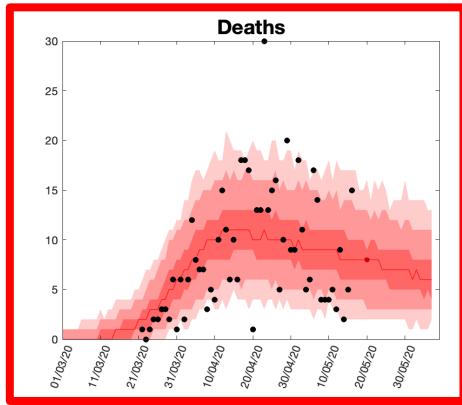
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# Epidemiological measures

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- 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



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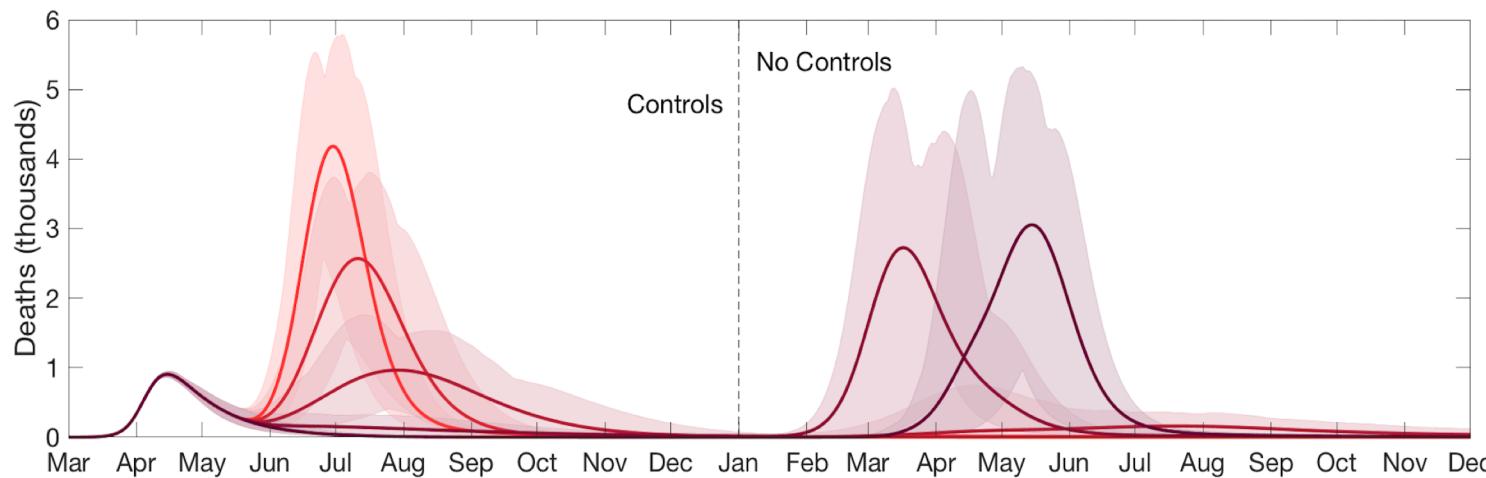
# Population-wide relaxation of lockdown measures

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- 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).

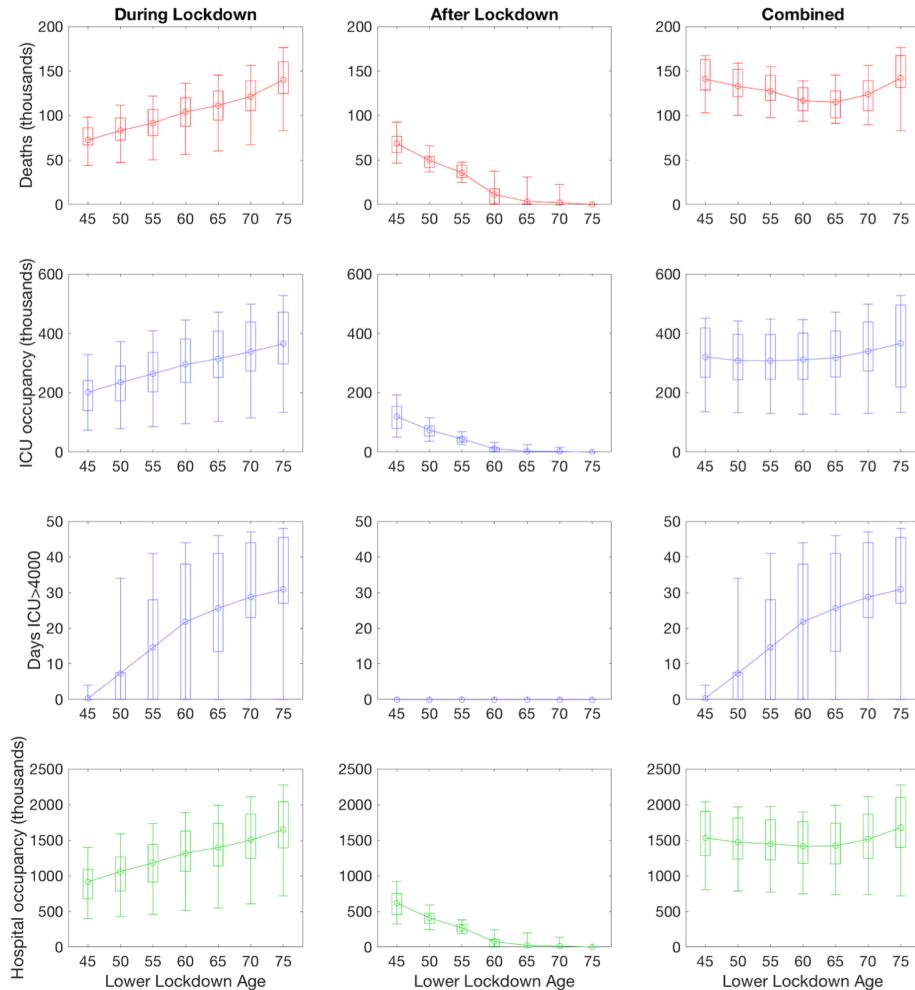
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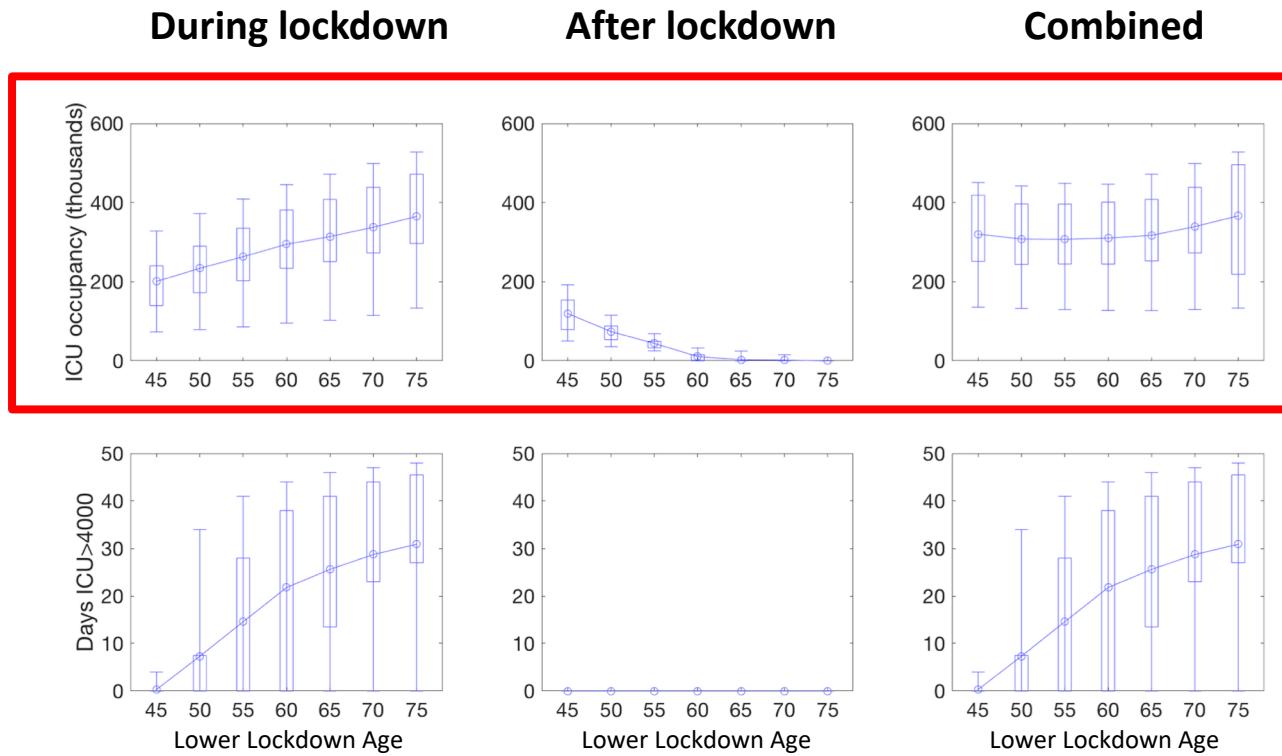
- Paler lines correspond to higher relaxation, which results in immediate resurgence.
- Minor change in relaxation suppresses the initial wave, though a second wave occurs during the “no control” phase.

# 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.

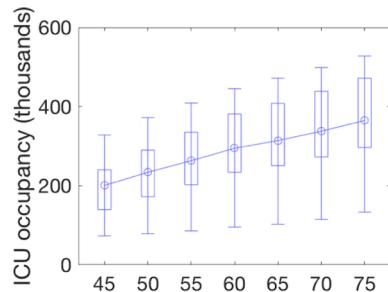
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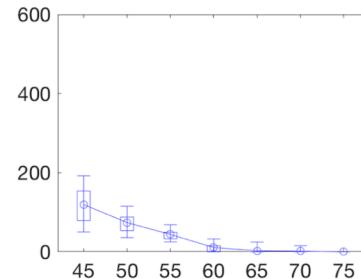
- When isolation is only in place for older age groups, a large initial wave of infection occurs during 2020, but a subsequent secondary wave is not observed.

# Age-based shielding strategies

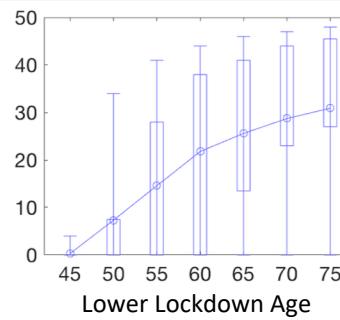
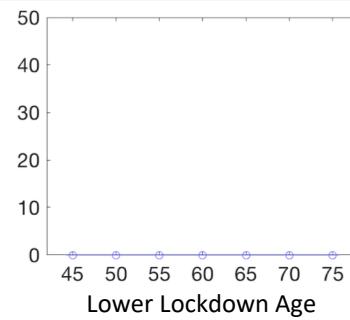
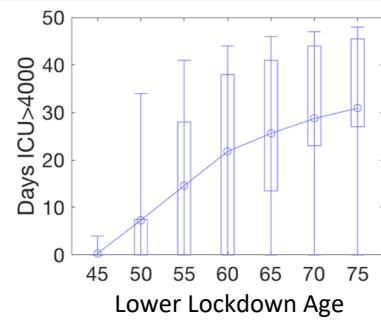
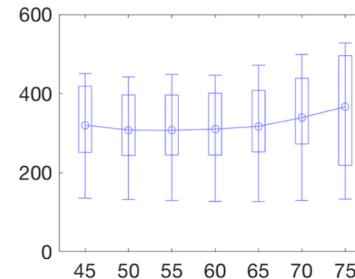
During lockdown



After lockdown

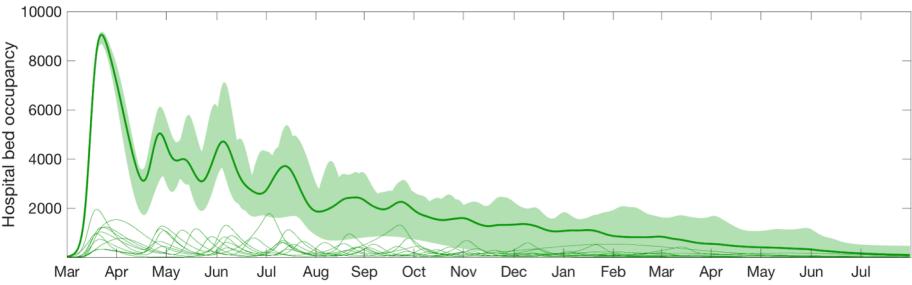
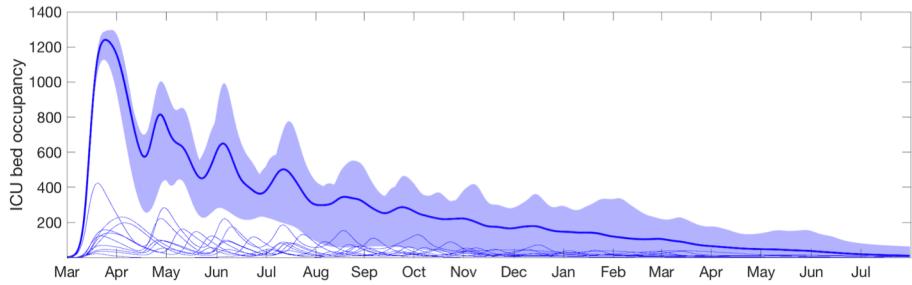
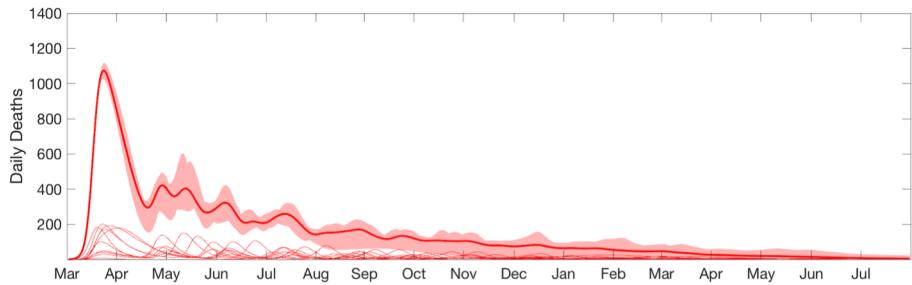


Combined



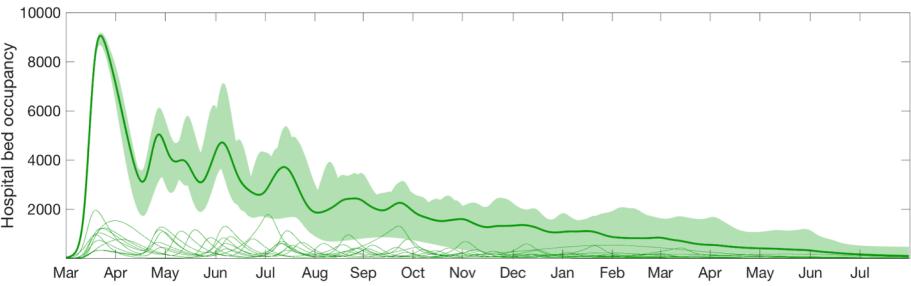
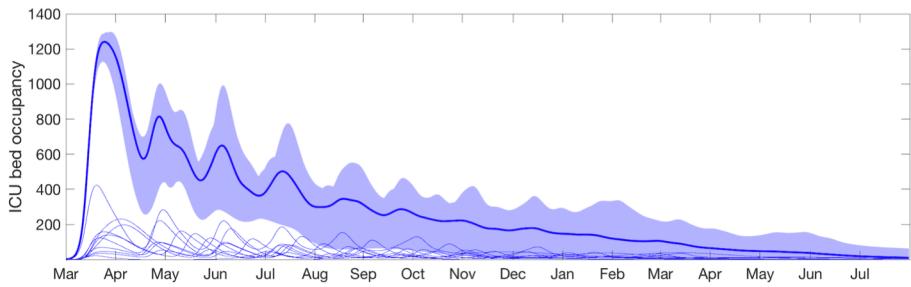
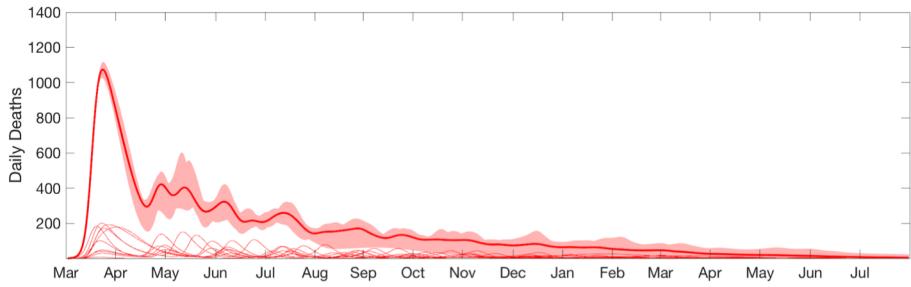
- As the age-threshold at which shielding is implemented increases, there is a **rise** in the total number of days for which ICU bed occupancy exceeds 4,000.

# 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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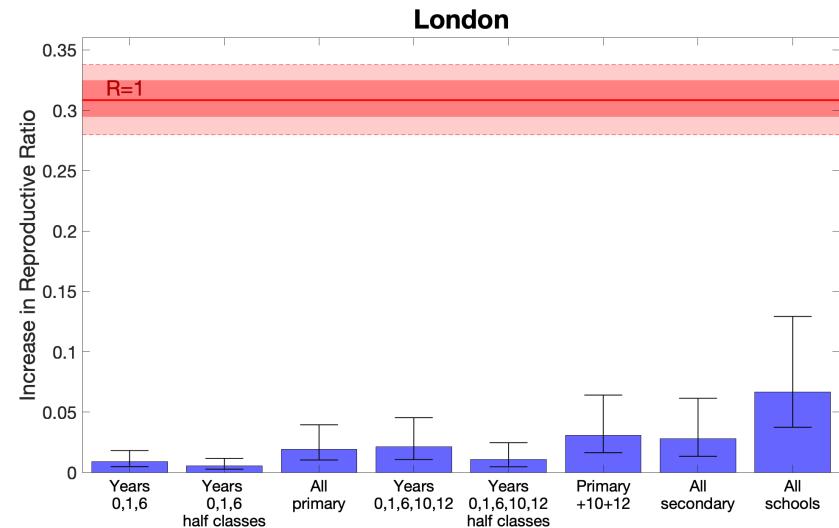
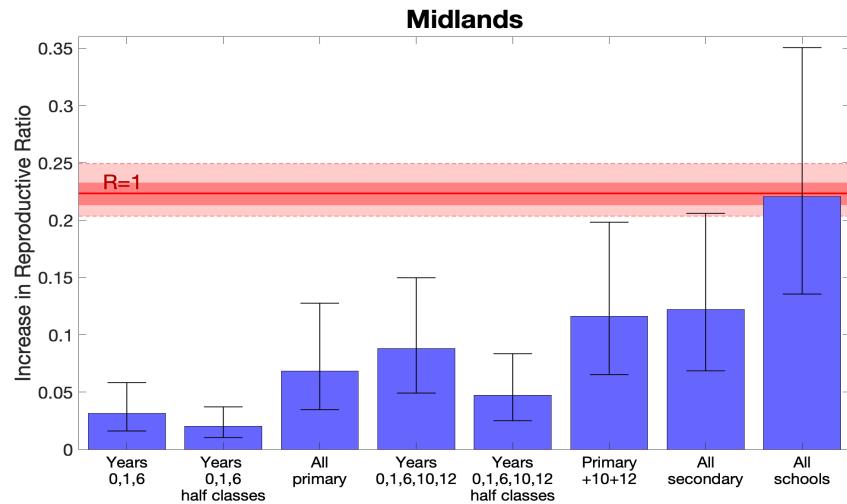
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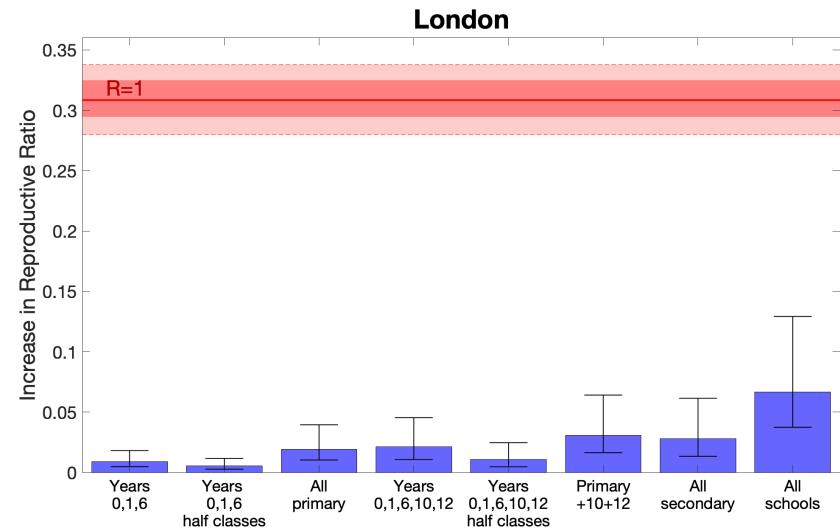
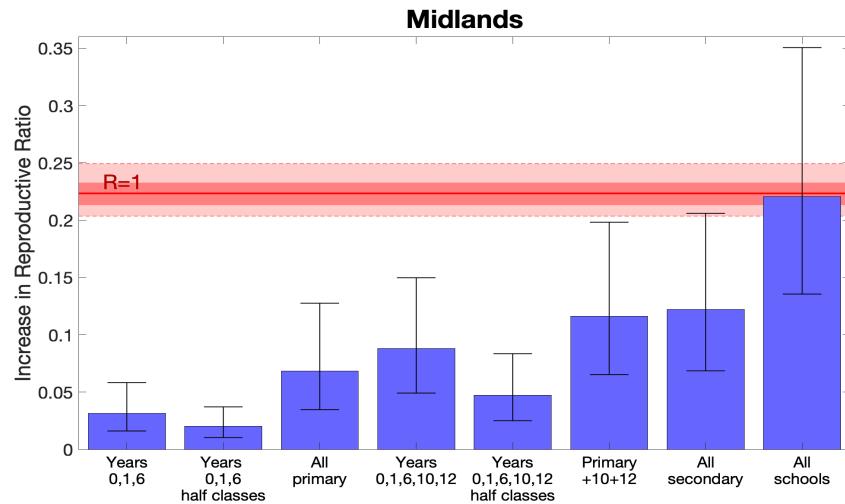
# Reopening schools

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



# 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

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- 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 parameterisation. 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://edmhhill.github.io>;

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

Preprint:



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