Modelling scenarios for relaxation of lockdown in England

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Summary of results

Deaths and hospital beds occupied due to COVID-19 appear to have peaked in the UK. However, this trend is not equally apparent across all regions of the country. While London and the Midlands have shown rapid drops in deaths, new admissions, and beds occupied, in all other regions the decrease has been more gradual (**Fig. 1**).

Relative changes in behaviour may play a role: Google Mobility data and CoMix Behavioural tracking (https://cmmid.github.io/topics/covid19/comix-impact-of-physical-distance-measures-on-transmission-in-the-UK.html) suggests movement and contacts have decreased more in London than in other regions of the country. Seroprevalence studies also suggest that acquired immunity may also be contributing to the relatively steep decrease in COVID-19 cases in London. Other regions do not appear to have such levels of seroprevalence.

This raises the possibility that, while the reproduction number may be below 1 overall, measures to lift movement restrictions may have different effects in different regions. The model estimated reproductive numbers as of early May for each NHS region in England are given in **Table 1**. Note, however, that these estimates of the reproduction number do not take account of hospital acquired infection, and therefore likely over-estimate the level of community transmission (that is, the estimated reproduction number is probably biased upwards).

Projecting forward, the gradual lifting of restrictions is predicted to increase the basic reproduction number above 1 in all regions outside of London towards mid summer, particularly as more restrictions are lifted on August 15th (**Fig. 2**). Differences between the four scenarios considered are minor: having additional children in school for the month of June makes a relatively small difference, and tracing a maximum of 30 rather than 15 contacts per index case is predicted to have a relatively small impact on transmission. This is because our model assumes that individuals are making relatively few contacts per day (~4.5 during lockdown, rising to ~9 by the end of the year) and with a relatively short window of infectiousness prior to notification, most relevant contacts are assumed to be picked up by the 15-contact limit. So while raising this to 30 contacts increases the number of people isolated (**Fig. 3**), it is not twice as likely to identify individuals who have actually been infected. However, if a contact-tracing app is able to identify potentially-infected contacts significantly more accurately than individual recall, the additional number of contacts traced may have a greater impact than we were able to account for here.

The increase in *R* above 1 leads to a resurgence of cases in all regions outside London in our projections, with numbers of deaths and hospitalisations increasing, particular during September and October (**Fig. 4**). Note that in some regions, the increase in *R* also leads to a very long "tail" of cases prior to the second peak (see e.g. North East & Yorkshire). While cases are decreasing over this period, they still represent a substantial burden in terms of deaths.

Cumulative infections by region are shown in **Fig. 5**. Note that while London currently has the highest level of seropositivity, other regions would be projected to eventually overtake it as cases continue to accumulate and eventually increase.

Shortcomings of the model

It is difficult to estimate the impact of contact tracing, which fundamentally deals with actions being taken at an individual level, with a compartmental model such as the one we are using here. We are developing an individual-based model to improve these predictions.

The actual performance of a contact tracing app is unknown. We have had to make assumptions about the potential effectiveness of contact tracing, with both manual and app tracing assumed. A broader exploration of the impact of contact tracing on the basic reproduction number can be found in a recent report by Kucharski et al, "Effectiveness of isolation, testing, contact tracing and physical distancing on reducing transmission of SARS-CoV-2 in different settings" (https://cmmid.github.io/topics/covid19/reports/bbc_contact_tracing.pdf). As the performance of the app starts to be evaluated, such models could help assess the likely impact on transmission.

Our model fitting does not take account of hospital acquired infections, and so probably overestimates the current reproduction number. Estimates that try to take account of nosocomial transmission currently put the reproduction number at 0.6 (0.4 – 0.7) in London, and 0.7 (0.6 – 0.8) in the South West, for instance (https://epiforecasts.io/covid/). These lower estimates of the reproduction could allow slightly greater freedom to relax social distance measures than is apparent from our analyses.

Conclusions

The reproduction number is likely to be slightly overestimated here, because the model does not account for hospital transmission increasing the number of deaths and diagnoses of COVID-19 in hospital. Nonetheless, our results suggest that lifting of restrictions should be done carefully, and highlight that the overall picture of declining transmission across the country may mask important regional differences. Monitoring the impact of lifting restrictions should be done at a sub-national level in order to be sensitive to these differences and avoid a second wave of cases. Regions outside London and the Midlands may currently have the greatest potential for transmission, and accordingly these areas may be most vulnerable to loosened restrictions leading to a resurgence in cases. While the return of children to school does increase transmission, our model suggests that it is the increase in work, leisure, and retail-based contacts that has the greatest potential to lead to a resurgence in cases.

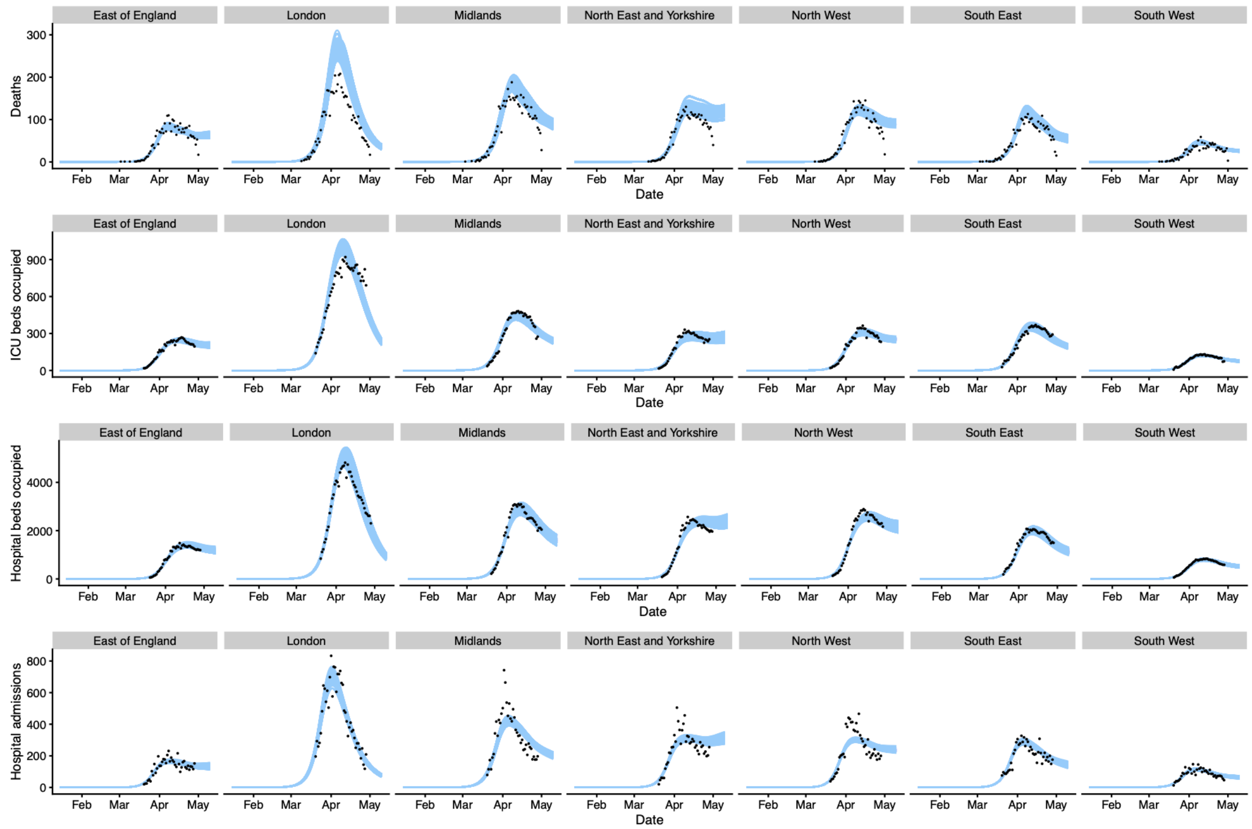


Fig. 1 Deaths in hospital, ICU beds occupied, all hospital beds occupied, and hospital admissions across the seven NHS England regions. Black dots show data, blue lines show model fit.

Table 1. Model-estimated reproduction number across the seven NHS England regions. Note that R is currently lower in London and the Midlands than in other regions.

Region	**Mean R_e (95% HDI)**
East of England	1.00 (0.93-1.11)
London	0.72 (0.67-0.82)
Midlands	0.88 (0.85-0.92)
North East and Yorkshire	1.01 (0.97-1.06)
North West	0.97 (0.93-1.02)
South East	0.92 (0.88-1.01)
South West	0.95 (0.91-1.01)

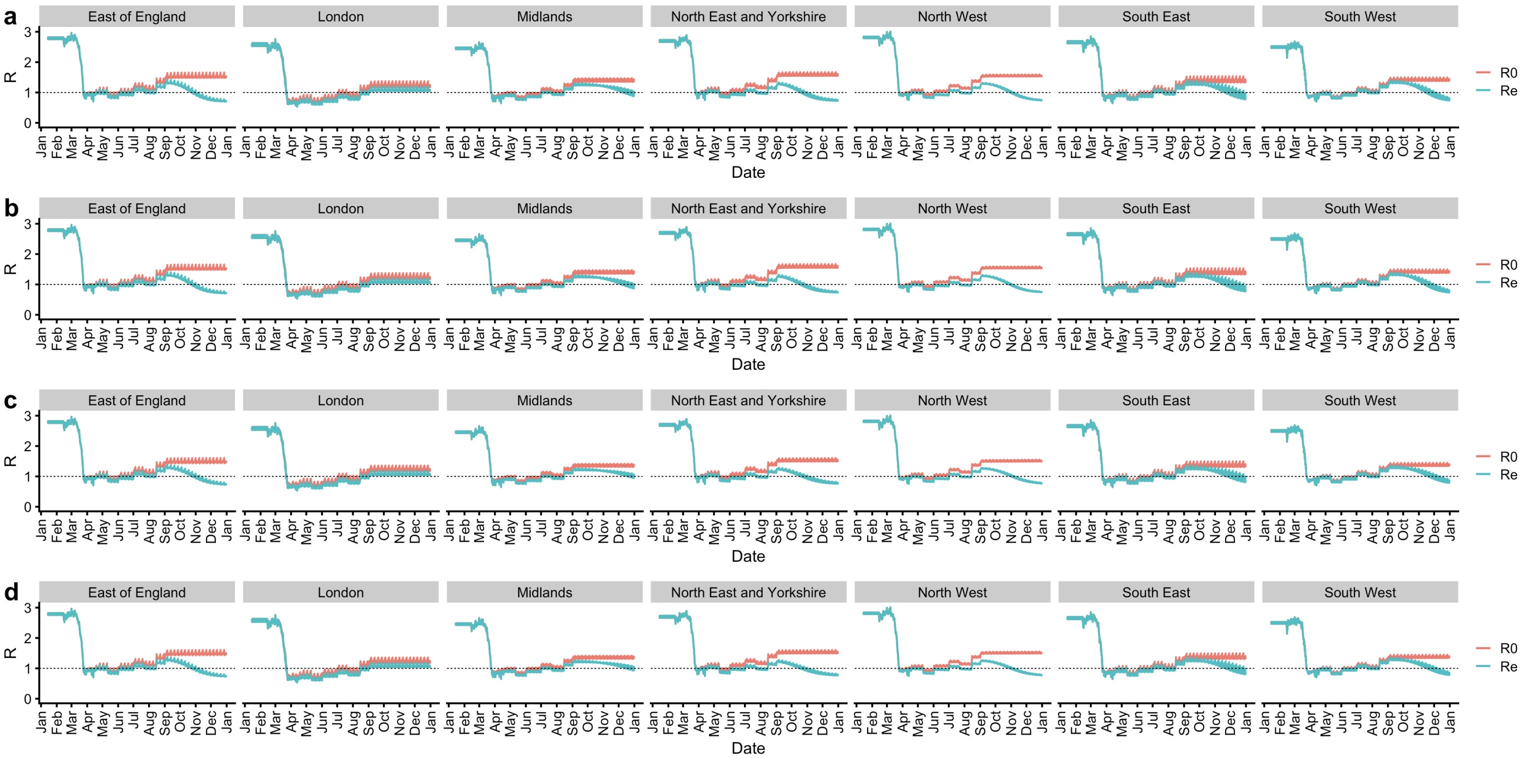


Fig. 2. Model predicted changes to R_0 and R_e under **(a)** scenario 1, **(b)** scenario 2, **(c)** scenario 3, and **(d)** scenario 4, with the introduction of contact tracing. All regions show a potential resurgence of cases; for London and the Midlands, this risk is less immediate, but for other regions of the country, slight relaxing of restrictions brings R_e close to or greater than 1.

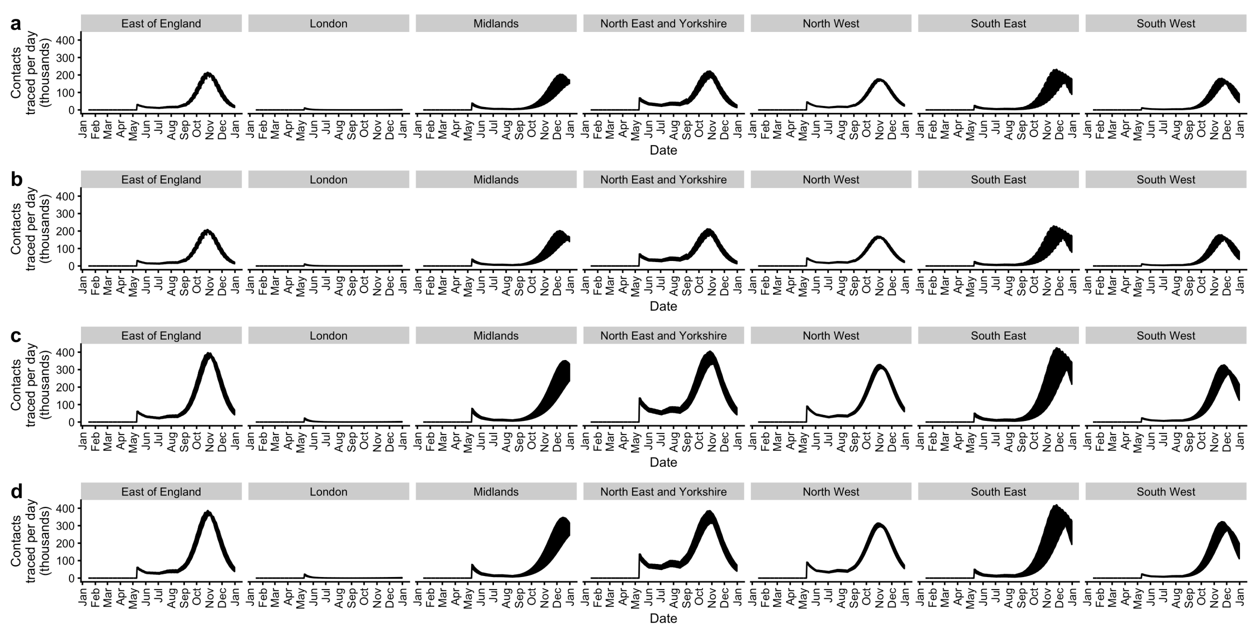
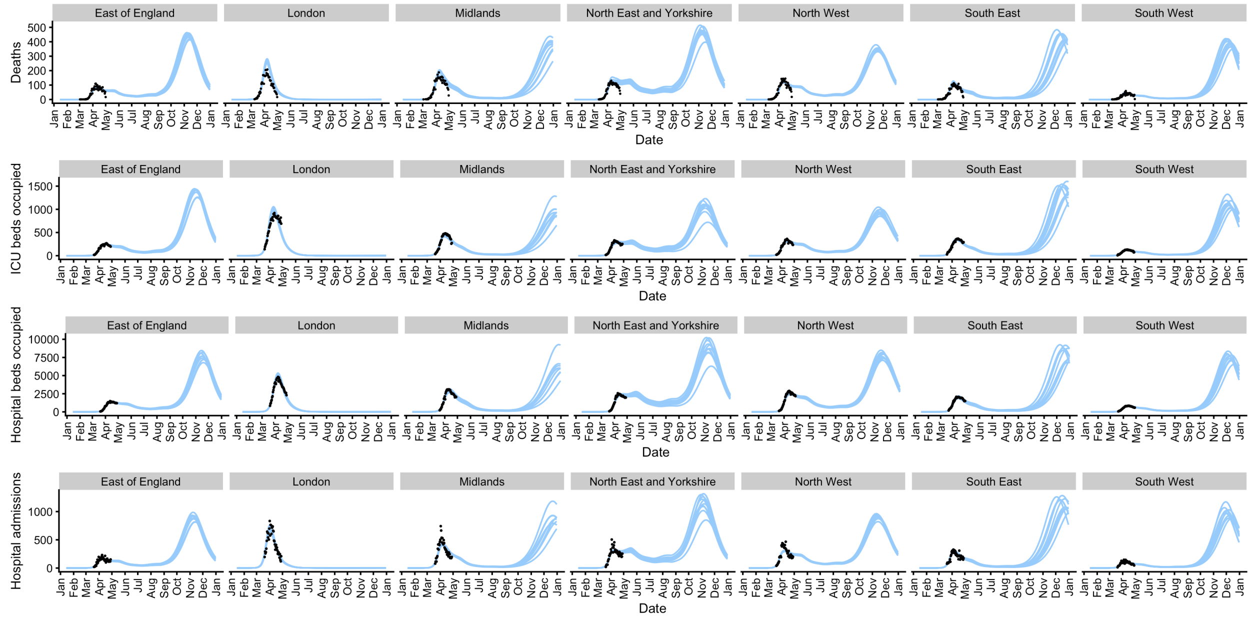


Fig. 3. Contacts traced per day **(a)** scenario 1, **(b)** scenario 2, **(c)** scenario 3, **(d)** scenario 4.

(a)



(b)

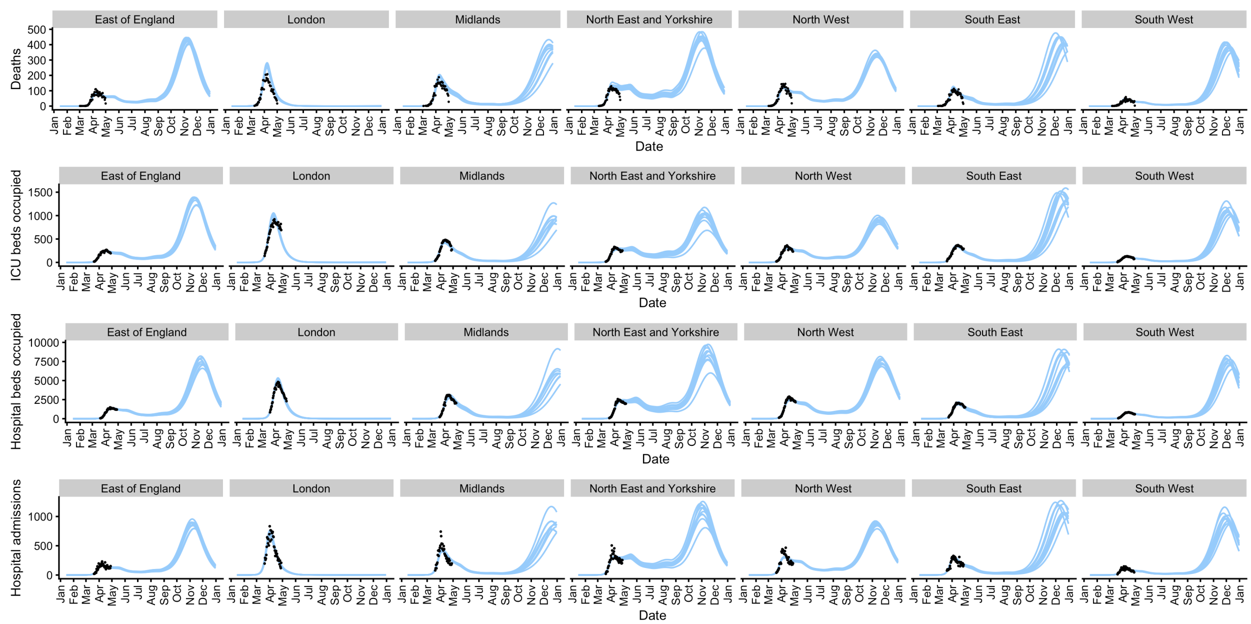
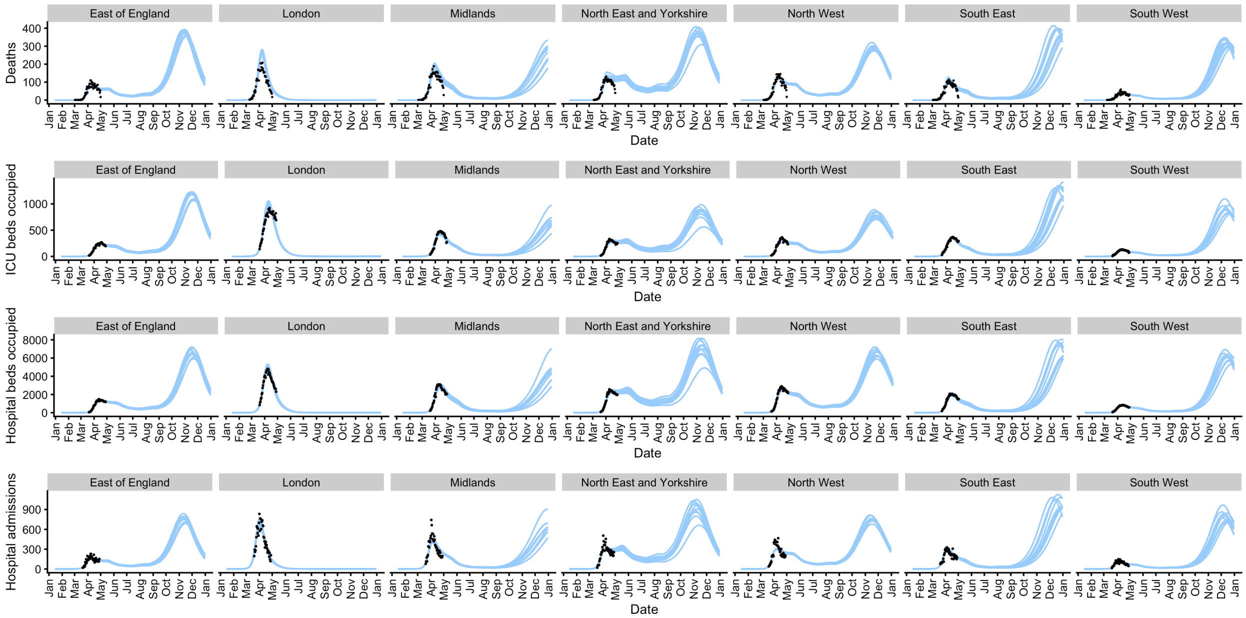


Fig. 4. (also see next page) Potential for resurgence as measured by deaths in hospital, ICU and total hospital beds occupied, and hospital admissions under **(a)** scenario 1, **(b)** scenario 2, **(c)** scenario 3, **(d)** scenario 4. Note, this assumes that restrictions will be lifted as specified with no additional restrictions enacted.

(c)



(d)

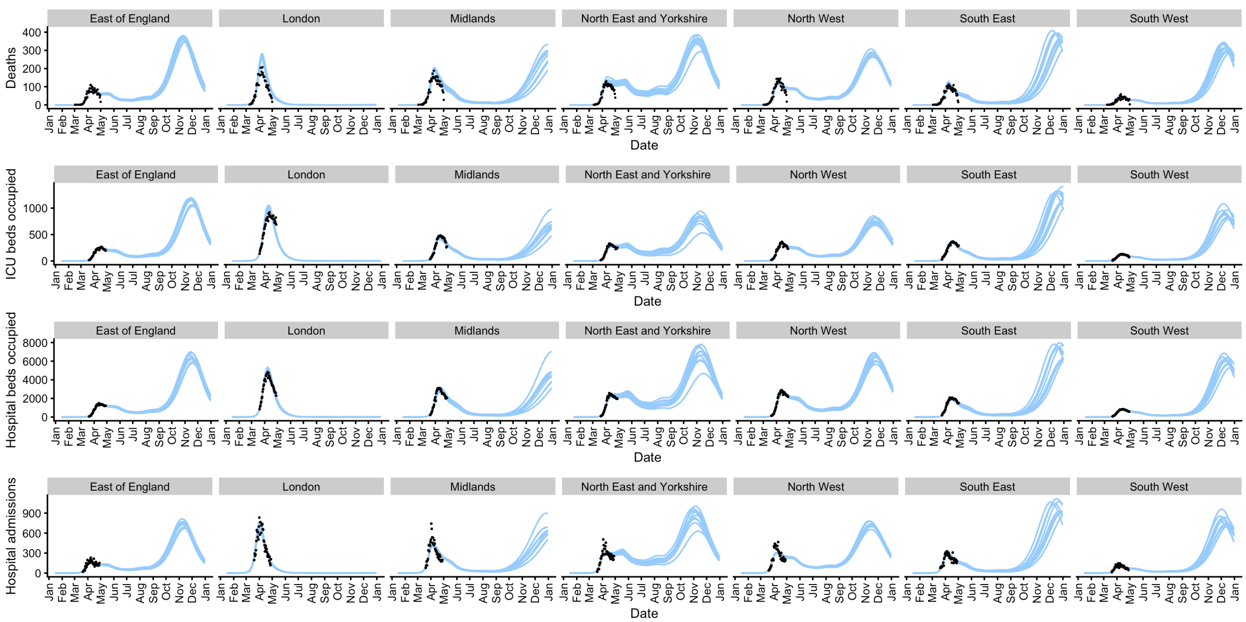


Fig. 4, continued. Potential for resurgence as measured by deaths in hospital, ICU and total hospital beds occupied, and hospital admissions under **(a)** scenario 1, **(b)** scenario 2, **(c)** scenario 3, **(d)** scenario 4. Note, this assumes that restrictions will be lifted as specified with no additional restrictions enacted.

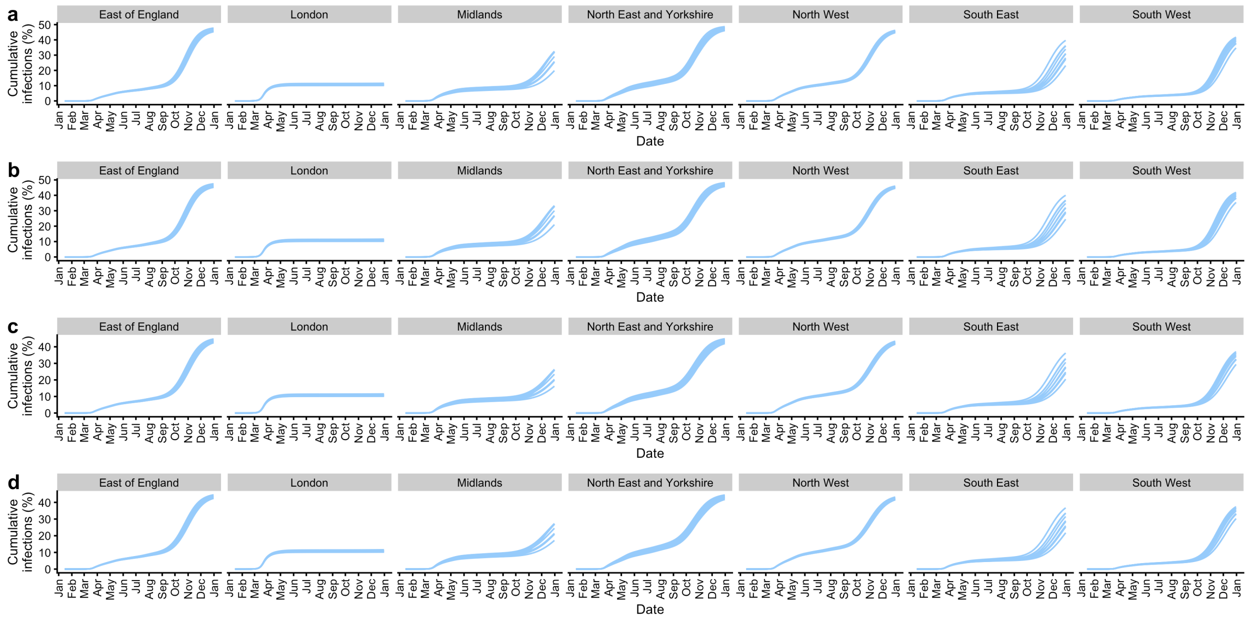


Fig. 5. Cumulative infections by region for **(a)** scenario 1, **(b)** scenario 2, **(c)** scenario 3, **(d)** scenario 4.

Methods

Data and transmission model

We use a previously published age-stratified model of SARS-CoV-2 transmission (1) fitted to temporal data on hospital admissions, ICU and non-ICU bed occupancy, and hospital deaths in each region of England (**Fig. 1**).

Isolation and contact tracing

The model assumes that symptomatic individuals are already self-isolating at a fairly high rate. Surveys have suggested that the introduction of contact tracing and rapid testing is likely to increase adherence to self-isolation, so we assume that from May 11th the rate of self-isolation upon symptom onset goes from 60% (the model's current estimate based on overall transmission alone, which is subject to substantial uncertainty) to 90%.

To simulate the impact of contact tracing, we assume that, from the point at which contact tracing starts, each symptomatic individual has a 90% chance of notifying, which occurs an average of 6 hours after symptom onset. We assume that without social distancing individuals in the UK make 10.9 contacts per day on average (POLYMOD), of which 79% are known to the index case (BBC Pandemic) and hence could be tracked; up to 15 contacts per index case can be tracked (Specification; we also test the impact of 30 contacts per index case being tracked); and that of these contacts, 80% can be notified within 48 hours (Specification).

We simulate the notification process as follows. Each newly-infected individual (i.e., an individual entering the "exposed" class) has either been infected by an asymptomatic/subclinical individual who will not notify, or by a symptomatic individual who has a 90% probability of notifying. We therefore calculate the probability that the individual's infector has notified. We calculate that 58% of secondary cases will be successfully quarantined before they become infectious (this is P(latent period < time to quarantine), where the time to quarantine is the time from infectiousness onset to notification for the index case plus the time from notification to quarantine of the secondary case). For the other 42% of secondary cases, quarantine will occur after they have entered the infectious period; we calculate the average length of time such individuals will spend in the infectious period before being quarantined as E(time to quarantine - latent period) among the 42% of secondary cases for whom this quantity is greater than 0. This calculation suggests that individuals who enter the infectious period but then become quarantined are infectious for 2.0 days prior to quarantine. On this basis, we multiply the infectiousness of all notified individuals by 0.42 * 2.0 / 5.0, where 5 days is the total duration of the infectious period.

Relaxing of control measures

To simulate the impact of a gradual easing of restrictions, we increase school contacts to 11% on May 11th, to 25% on June 1st (scenario 2/4: 50%, Specification), to 60% on July 1st, to 0% between July 22nd and 1st September, and to 100% from 1st September onwards. For work contacts, these are increased by 20% on 11th May, by a further 10% on 1st June, and by a further 6% on 1st July, at which work contacts reach 70% and further increases cease

(Specification). Finally, for leisure contacts, we increase all "other" contacts by 10% on 1st June, by a further 20% on 1st July, and by a further 45% on 15th August (an increase of 75% in total). We apply these to all "other" contacts rather than solely to leisure contacts (as in the Specification), because the gradual reopening of businesses over this period implies an increase in shopping and transport as well as of leisure activities.

Table 2: Scenarios considered

Scenario	**Contact tracing**	**School attendance in June**
Scenario 1	Up to 15 contacts traced	25%
Scenario 2	Up to 15 contacts traced	50%
Scenario 3	Up to 30 contacts traced	25%
Scenario 4	Up to 30 contacts traced	50%

References

1. Davies NG, Kucharski AJ, Eggo RM, Gimma A, CMMID COVID-19 Working Group, Edmunds WJ. The effect of non-pharmaceutical interventions on COVID-19 cases, deaths and demand for hospital services in the UK: a modelling study [Internet]. MedRxiv; 2020 Apr [cited 2020 Apr 16]. Available from: http://medrxiv.org/lookup/doi/10.1101/2020.04.01.20049908