Strategies for reducing COVID-19 transmission with social distancing measures

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Summary

- 80% contact tracing results in values of R_t<1 when other physical distancing measures are in place during phases 1, 2 and 3 and slighter greater than 1 during phase 4. The resulting build-up of immunity is not sufficient to prevent future outbreaks.
- 20% contact tracing results in values of R_t<1 when other physical distancing measures are in place during phase 1, and greater than 1 for phases 2, 3 and 4. Progression from phases 1 to 4 by 15 August 2020 does not create sufficient immunity to prevent future outbreaks.
- The level of contact tracing determines whether transmission is sustained.
- Phase 2 is epidemiologically indistinguishable from the current situation.
- Extending the duration of phase 3 with 20% contact tracing creates sufficient immunity to avoid a large-scale second peak.
- There is limited difference between tracing 30 or 15 contacts per index case.
- Phase 2 scenario 1 and scenario 2 result in similar reproduction numbers.

Methods

Data description

The Social Contact Survey surveyed 5,388 individuals in the UK in 2010 about their social contacts[1]. Participants were asked about the number of people they met, duration of the contact and the context.

Estimating the Reproduction Number

We use an individual-based approach for to calculate a reproduction number of each of the participants of the Social Contact Survey study[2]. The reproduction number for an individual is given by

$$R_{ind} = \tau \sum_{i=1}^{k} n_i d_i$$

Where k is the number of contact events reported by each participant, n_i is the number individuals in that contact (participants could report groups of similar contacts), d_i is the duration of the contact and τ is the probability of transmission.

The population-wide reproduction number, R_0, is calculated as the age-adjusted mean of the individual reproduction numbers, i.e.

$$R_0 = \frac{\sum_{j=1}^{N} a_j \left(R_{ind}^{j}\right)^2}{\sum_{j=1}^{N} a_j}$$

Where N is the number of participants in the Social Contact Survey and a_j is the age-specific weighting estimated to match the age distribution in the UK population, calculated as the ratio of the proportion of individuals aged a in the UK to the Social Contact Survey sample,

$$a_j = \frac{P_{UK}(a)}{P_{SCS}(a)}$$

We estimated the transmission probability τ by scaling the population-wide R_0 to match the measured reproduction number in the UK pre-control measures of 3.0. We assume that no age groups have pre-existing immunity against COVID-19 and therefore contribute equally to transmission.

The impact of physical distancing measures on the effective reproduction number R_t

We use participant age, contact context and contact duration to simulate the impact of interventions. We calibrated the reproduction number so that *R_t~0.8* for an 80% reduction in work and leisure contacts, and 2% of children attending school.

For each intervention, we sample the contacts to be restricted at random for a given level of adherence, remove those contacts and recalculate the reproduction number. We compared each of the following strategies as requested:

- PHASE 1: Starting on 11 May
  - an increase in workplace contacts representing a return of an additional 20% compared to now.
  - 11% of children attending school (representing key workers' children so assume mix of ages)
- PHASE 2: Starting on 1 June
  - An additional increase in workplace contacts of 10% on top of the phase 1
  - **Scenario 1**: 25% of children attending school (representing key workers' and vulnerable children plus transition years).
  - **Scenario 2**: 50% of children attending school (representing key workers' and vulnerable children and all primary schools)
  - 10% increase in leisure contacts from current levels
- PHASE 3: Starting on 1 July
  - An additional increase in workplace contacts of 10% on top of phase 1+2
  - 60% of children attending school (representing key workers children plus transition years plus primary school)
  - 30% increase in leisure contacts from current levels
- PHASE 4: Starting 15 August
  - An additional increase in workplace contacts of 10% on top of phase 1+2+3.
  - 100% of children attending school (bar those under household quarantine) from the start of the school year
  - 75% increase in leisure contacts from current levels

For each strategy, mean and confidence intervals for the reproduction number were calculated by sampling contacts 10 times then bootstrapping the data 1000 times.

Contact tracing

We modelled contact tracing from symptomatic index cases. We assumed that an age-specific proportion of index cases were symptomatic, where index cases under 18 years old had a 25% chance of being symptomatic, then assuming a linear increase with age in the chance of symptoms up to 75% for people over 80 years old.

For each contact, we drew a random number to determine if the index case was symptomatic, and therefore eligible for contact tracing. We assumed that 80% of contacts we traced, unless the *average* number of contacts traced per person was greater than 30, in which case we scaled down the percentage of contacts that were traced so that a maximum of 30 contacts were traced *on average*.

We repeated this analysis assuming a maximum of 15, 5 and 1 contacts traced per person, as well as with no contact tracing.

Modelling the application of social distancing strategies

To investigate the transmission dynamics associated with the different social distancing strategies, we developed a deterministic, age-structured, compartmental transmission model. The population was divided into 6 age groups. The fraction of people in each age group was determined by the age distribution of England. We assumed that COVID-19 could be captured by seven infection states: susceptible to infection (S), latently infected (E), Asymptomatic (A), symptomatic and infectious (I), hospitalised (H), critically ill (P) and recovered and immune (R).

$$\frac{dS_i}{dt} = -S_i \sum_{j=1}^{n} \beta_{ij} \, I_j / N_j$$

$$\frac{dE_i}{dt} = +S_i \sum_{j=1}^{n} \beta_{ij} \, I_j / N_j - \sigma_i E_i$$

$$\frac{dA_i}{dt} = f_i \sigma_i E_i - \gamma_a A_i$$

$$\frac{dI_i}{dt} = (1 - f_i) \sigma_i E_i - \gamma I_i$$

$$\frac{dH_i}{dt} = h_i \gamma I_i - \gamma_h H_i$$

$$\frac{dP_i}{dt} = \mu_i \gamma_h H_i - \gamma_p P_i$$

$$\frac{dR_i}{dt} = \gamma_a A_i + (1 - h_i) \gamma I_i + (1 - \mu_i) \gamma_h H_i$$

Model parameters

Parameter	**Meaning**	**Value**
β_{ij}	Transmission rate from group j to group i	Age-specific mixing matrix scaled to achieve desired R_t
$1/\sigma_i$	Incubation period	5.2 days
f_i	Age-specific fraction of cases that are asymptomatic	0.06
$1/\gamma_a$	Length of time asymptomatically infected	Same as the infectious period
$1/\gamma$	Infectious period	1.2 days
h_i	Age-specific fraction of cases that are hospitalised	{0.001, 0.0013, 0.0075, 0.0268, 0.1, 0.18}
$1/\gamma_h$	Time in hospital if cured	4 days
$1/\gamma_p$	Additional time in hospital if case dies	8 days
μ_i	Age-specific mortality rate	{0.04, 0.04, 0.04, 0.05, 0.18, 0.44}

The model was initialised with a single infectious case and run with a baseline reproduction number of $R_0 = 3.0$. When the number of deaths reached 200 deaths (equivalent to the number of deaths recorded on 30 March 2020 in England), we simulated “lockdown” by decreasing the reproduction number to $R_t = 0.8$ by scaling the transmission matrix by R_t/R_0.

We then moved through the phases listed above, each time scaling the transmission matrix by R_t, as estimated using the Social Contact Survey.

Results

R_t Estimates

We modelled transmission between 30 March and 11 May with R_t~0.8, which resulted from an 80% reduction in work and leisure contacts and a 98% reduction of children attending school.

For phase 1, we assumed that 60% of regular workplace contacts and 80% of regular leisure contacts did not occur, and that school attendance increased to 11% of children. With 80% of contacts traced, up to a maximum of 30 contacts per person on average, this resulted in $R_t = 0.49\ (0.47, 0.52)$. There was minimal difference for tracing a maximum of 15 contacts per person on average, $R_t = 0.49\ (0.46, 0.52)$, figure 1.

For phase 2, we assumed that 50% of regular workplace contacts and 70% of regular leisure contacts did not occur. In scenario 1, phase 1 children and transition years attended school, resulting in $R_t = 0.63\ (0.59, 0.67)$. Again, there was minimal difference between tracing a maximum of 30 or 15 contacts. In scenario 2, phase 1 children plus primary-school aged attended school, resulting in a slightly larger $R_t = 0.67\ (0.63, 0.71)$.

For phase 3, we assumed that 30% of regular workplace contacts and 40% of regular leisure contacts did not occur. Phase 1 children plus transition years and primary years attended school, $R_t = 0.88\ (0.83, 0.93)$.

For phase 4, we assumed that 40% of regular workplace contacts and 10% of regular leisure contacts did not occur, with all children attending school, $R_t = 1.19\ (1.08, 1.30)$.

Assuming that 20% of contacts are traced increases R_t for all phases, and R_t is greater than 1 for phases 2, 3 and 4. See figure 1.

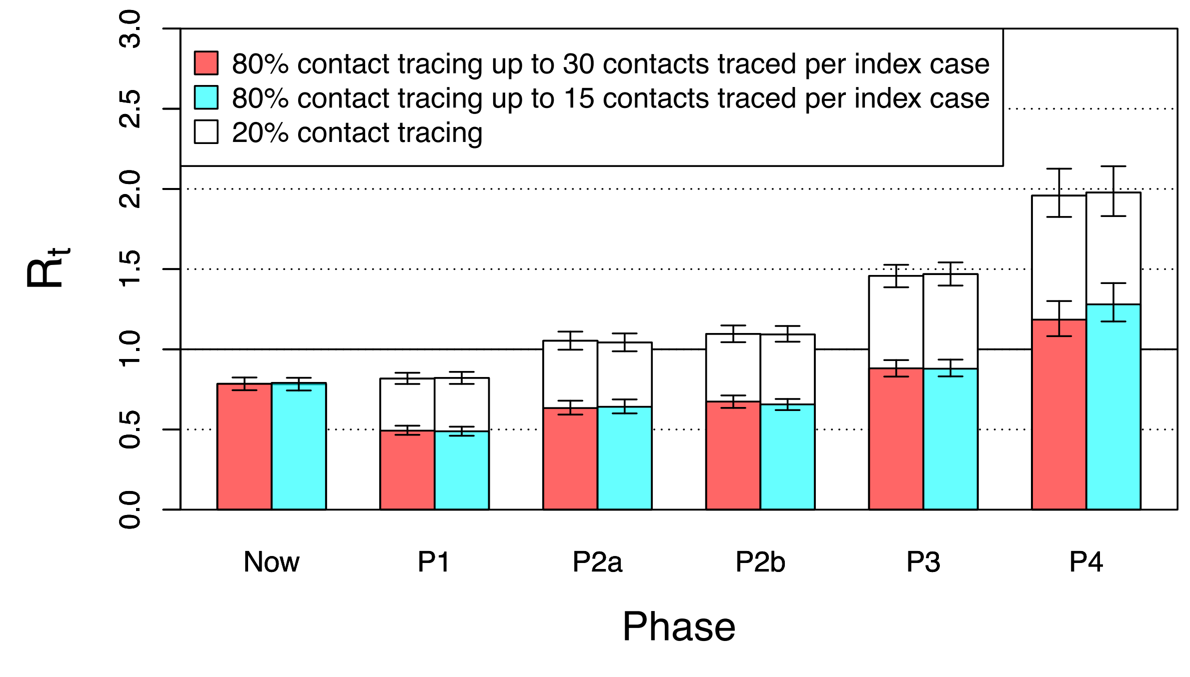

Figure 1: The estimated effective reproduction number R_t for each phase of physical distancing measures, with a maximum of 30, 15 contacts traced per individual. The filled bars are assuming that 80% of contacts are traced and the empty bars are assuming that 20% of contacts are traced. Baseline R_0 was set to 3.0. P2a is phase 2 in scenario 1 and P2b is phase 2 in scenario 2.

We explored the impact of contact tracing on R_t by limiting the average number of contacts traced per person. There is no difference between contact tracing at 80% compared to 20% when less than 5 contacts are traced per person. All phases were associated with epidemic growth in the absence of contact tracing, figure 2.

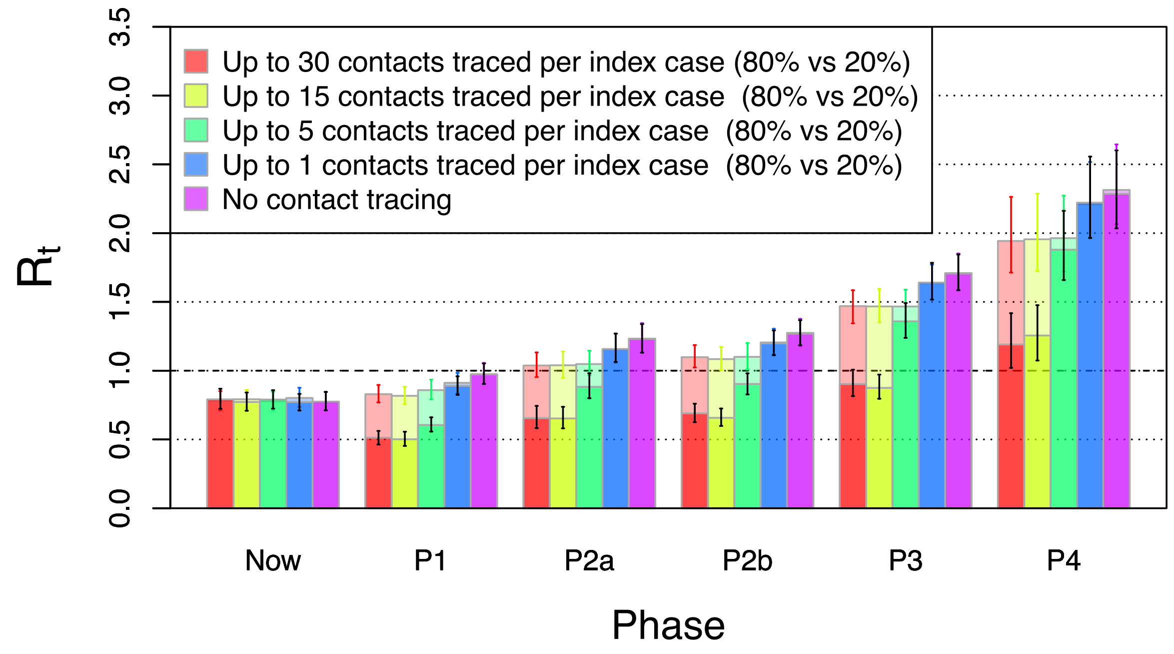

Figure 2: The estimated effective reproduction number R_t for each phase of physical distancing measures, with a maximum of 30, 15, 5, 1 and no contacts traced per individual. The darker filled bars are assuming that 80% of contacts are traced and the lighter bars are assuming that 20% of contacts are traced. Baseline R_0 was set to 3.0. P2a is phase 2 in scenario 1 and P2b is phase 2 in scenario 2.

Epidemic scenarios

With 80% of contacts traced no further epidemic peaks are observed, although this relies on contact tracing remaining at high levels indefinitely. The resulting build-up of immunity is not sufficient to prevent future outbreaks (figure 3). The effective reproduction number is below 1, or very slightly above 1 (figure 3a).

With 20% of contacts traced, immunity is developed in the population and without additional measures, a second epidemic peak occurs in Autumn/Winter 2020 (figure 4). The effective reproduction number is above 1 during phase 3 and phase 4 until sufficient immunity is created and R_{eff} falls below 1. Phase 2 is epidemiologically indistinguishable from the current situation.

As an alternative, we considered extending phase 3 into 2021 until sufficient levels of immunity exist in the population to prevent a large resurgence, figure 5. There are two further peaks, comparable in size to the April 2020 peak.

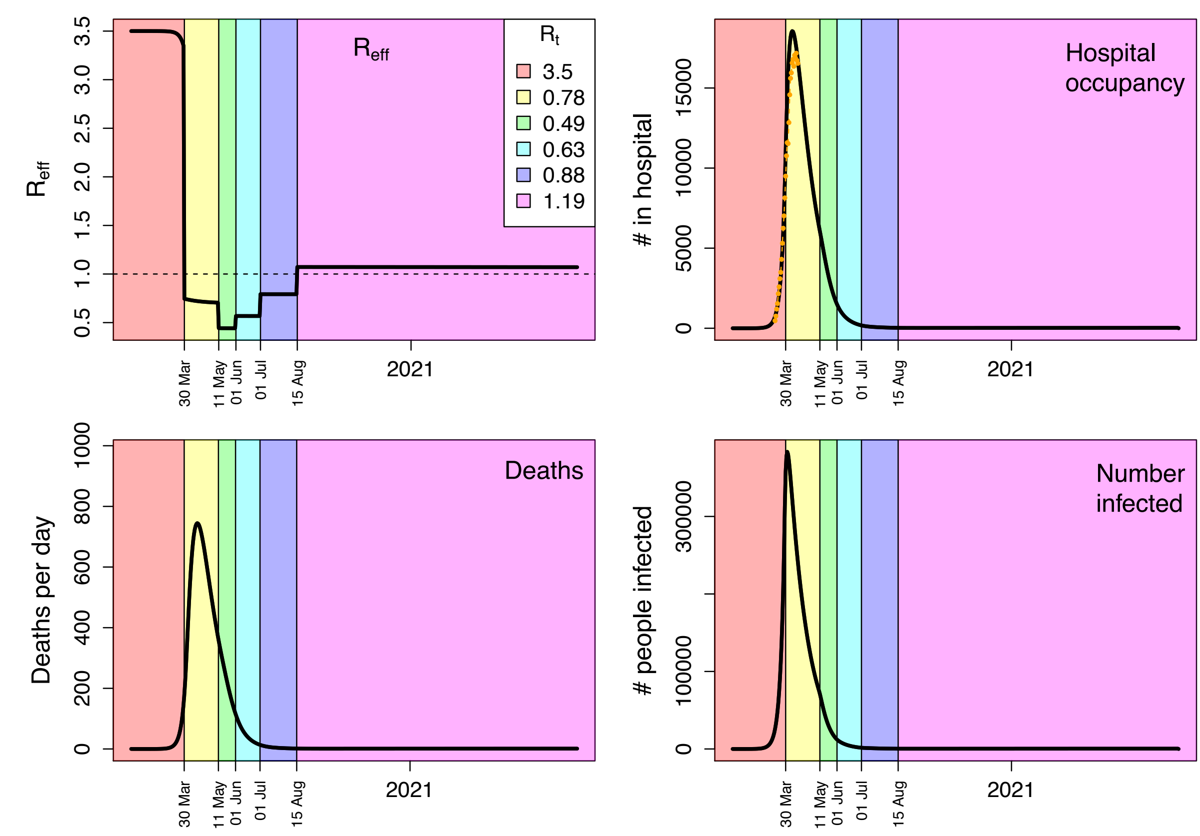

Figure 3: COVID-19 epidemic scenarios for England with 80% of contacts traced when physical distancing restrictions are gradually lifted over time, from phase 1 to phase 4.

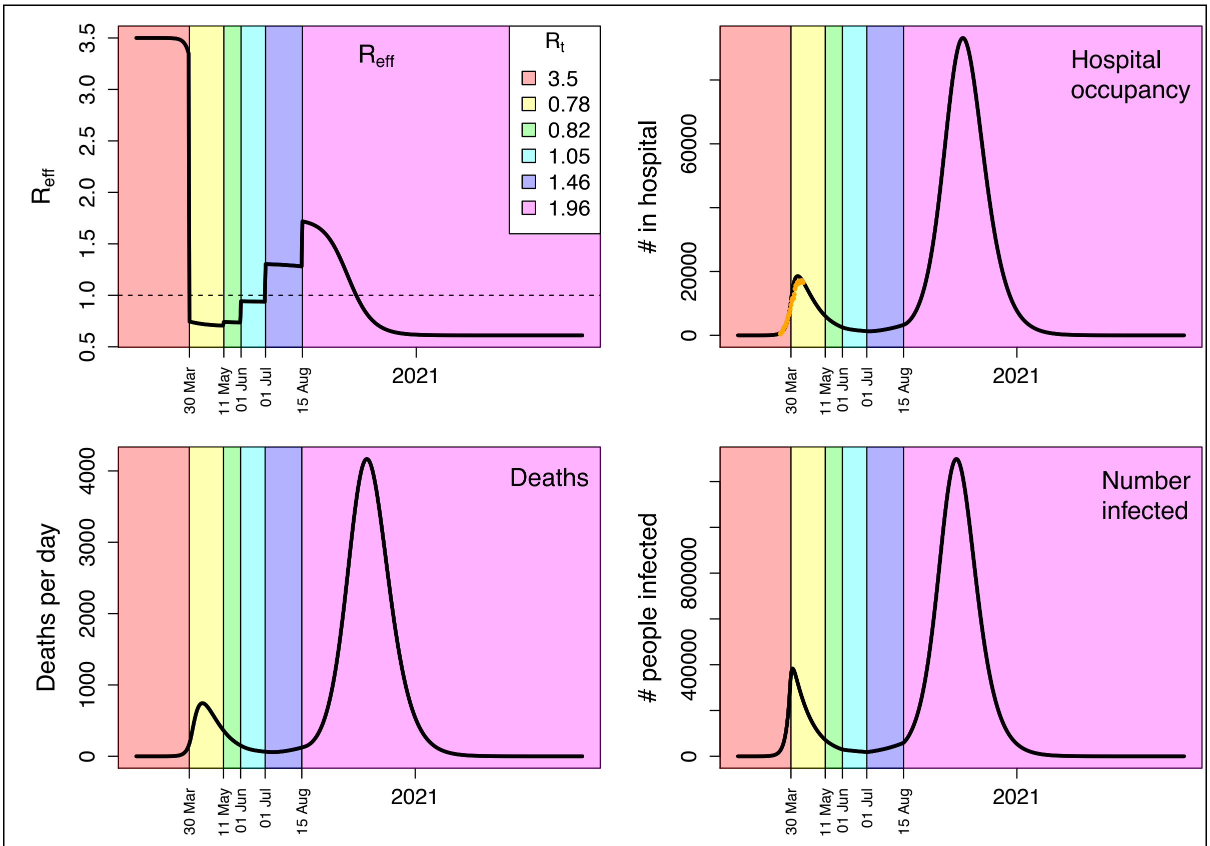

Figure 4: COVID-19 epidemic scenarios for England with 20% of contacts traced when physical distancing restrictions are gradually lifted over time, from phase 1 to phase 4.

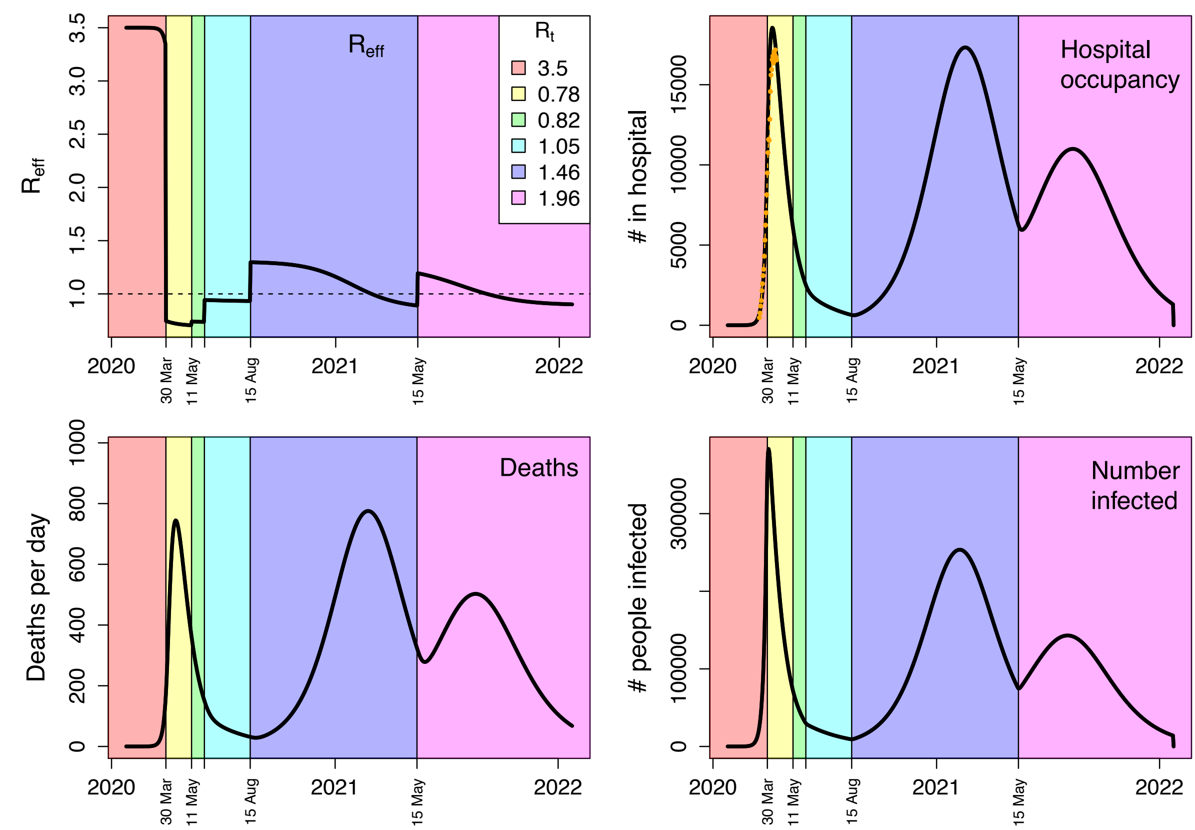

Figure 5: COVID-19 epidemic scenarios for England with 20% of contacts traced when physical distancing restrictions are gradually lifted over time, from phase 1 to phase 4, with an extended period in phase 3.

References

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