# Supplementary material for Estimating the impact of reopening schools on the reproduction number of SARS-CoV-2 in England, using weekly contact survey data

## Methods detail

CoMix is a behavioural survey, launched on 24th of March 2020. The sample is broadly representative of the UK adult population with data collected from approximately 2000 individuals per week. Participants are invited to respond to the survey once every two weeks. We collect weekly data by running two alternating panels. Parents complete the survey on behalf of children (17 years old or younger). Participants record direct, face-to-face contacts made on the previous day, specifying certain characteristics for each contact including the age and sex of the contact, whether contact was physical (skin-to-skin contact), and where the contact occurred (e.g. at home, work, while undertaking leisure activities, etc). Further details have been published elsewhere [1]. The contact survey is based on the POLYMOD contact survey [2].

*Constructing contact matrices*

We constructed age-stratified contact matrices for nine age-groups (0-4, 5-11, 12-17, 18-29, 30-39, 40-49, 50-59, 60-69, and 70+). Participants did not report exact ages of contacts, we therefore sampled from the reported age-group with a weighting consistent with contacts reported in the POLYMOD survey. We fitted a truncated negative binomial model to calculate the mean contacts between each participant and contact age-groups. To ensure reciprocity in contacts, we multiplied the matrix by population size vector for England before taking the cross-diagonal mean and then dividing by the population vector again.

*Establishing age dependent transmission risk*

We calculated a reproduction number resulting from two-weekly rolling contact matrices $\mathbf{C}_t$ and assumed relative susceptibility and infectiousness vectors **s** and **i** to be:

$$R = r\ Eig\left(\mathbf{C}_t \circ (\mathbf{i} \otimes \mathbf{s})\right)$$

We simplified **s** and **i** such that adult age-groups (18+) were 1.0 and child age groups were equal, *s* and *i* . We inferred *s* and *r,* keeping i at 1.0*,* by fitting our estimates using maximum likelihood estimation to those calculated using the EpiNow2 package [3]. We assumed the gamma distributed uncertainty in the time-varying estimates which we parameterised using the mean $\mu_{rt}$ and standard deviation $\sigma_{rt}$ of these estimates over each survey period used to calculate CoMix derived eigenvalues.

$$R \sim\ Gamma(\mu_{R_t},\ \sigma_{R_t})$$

To show the likelihood surface of relative susceptibility and infectiousness, we calculated the likelihood of a range of combinations of *i* and *s* while fitting *r*.

We chose to fit over 2 periods of time. Firstly between 27th July and 10th October to most clearly capture the impact of schools returning in the summer. Unfortunately, due to the large proportion of positive tests during this time reflecting transmission outside of the UK, we identified that the $R_t$ estimates at the end of August were unreliable. We omitted data in the final days of August, where the estimate peaked. We also fit a longer period of time incorporating data from 10th June.

We fitted over the period between 27th July and 10th October, 2020 (Period 1), in order to capture the change in contact and reproduction number as schools returned in September 2020 whilst minimising issues related to gradual acquisition of natural immunity. We also provide estimates using an extended period (10th June to 10th October 2020, Period 2). We omitted data at the end of August in both due to a short spike in reproduction number estimates, which we believe resulted from large numbers of imported cases from recreational travel and omitted two weeks in July when contacts were not recorded for children. We assessed sensitivity to the fitted period, by using a range of fitting options (Figure S6)

*Evaluating the impact of reopening schools*

We created the matrix for the second lockdown using data from the period of 5th November to 2nd December 2020. We created the matrix for the third lockdown using data from the period of 5th to the 31st of January 2021. Individual element absolute differences of the matrices were calculated as well as the ratio of the dominant eigenvalues comparing the third and the second lockdown (Figure S1).

We constructed a contact matrix representing primary schools being open by replacing the contacts of 5-10 year-olds in the 'schools open' contact matrix (second lockdown), with those from the 'schools closed' contact matrix (third lockdown) (Figure S2). This was repeated for 11-17 year-olds to create a matrix for opening secondary schools.

Since the basic reproduction number scales linearly with the dominant eigenvalue of a matrix of effective contact [4], the ratio of the eigenvalues of two effective contact matrices provides a relative change in reproduction number between the three scenarios considered.

In the case where infectiousness and susceptibility are equal in all age groups, the effective contact matrix is proportional to the contact matrix itself. Under the scenarios where we assumed infectiousness and susceptibility vary with age, we converted measured contact matrices to effective contact matrices by taking the outer product of a the estimated age stratified infectiousness profile and susceptibility profile vectors and calculating the eigenvalues of the Hadamard product of the resulting matrix and the contact matrices.

For the profiles taken from Davies et al [5], we took the mean estimates of susceptibility. This work does not report age structured infectiousness directly but rather suggests 50% infectiousness of sub-clinical cases and reports clinical fraction by age. We used this to calculate infectiousness per age group in (Table S1).

For the profiles taken from Viner et al [6], we performed a meta-analysis using a random effects model based on the data from Figure 4 of their paper.

We calculated the proportion of children attending school on the day that contacts were measured for each survey week. Weekend observations and those when the schools were closed for holidays were removed, we present that proportion from September onwards in Figure S3.

## Supplementary tables and figures

**Table S1** Susceptibility and infectiousness profiles taken from Davies et.al.[5], ONS reports and Viner et al [6]

| Study | Age groups | Susceptibility | Infectiousness | Clinical Fraction |
|---|---|---|---|---|
| Davies et al[1] | 0-4 | 0.4 (0.25, 0.57) | 0.61 | 0.29 (0.18, 0.44) |
| | 5-10 | 0.4 (0.25, 0.57) | 0.61 | 0.29 (0.18, 0.44) |
| | 11-17 | 0.4 (0.27, 0.53) | 0.61 | 0.21 (0.12, 0.31) |
| | 18-29 | 0.79 (0.59, 0.96) | 0.64 | 0.27 (0.18, 0.38) |
| | 30-39 | 0.86 (0.69, 0.98) | 0.67 | 0.33 (0.24, 0.43) |
| | 40-49 | 0.80 (0.61, 0.96) | 0.70 | 0.40 (0.28, 0.52) |
| | 50-59 | 0.82 (0.63, 0.97) | 0.75 | 0.49 (0.37, 0.60) |
| | 60-69 | 0.88 (0.70, 0.99) | 0.82 | 0.63 (0.49, 0.76) |
| | 70+ | 0.74 (0.56, 0.90) | 0.85 | 0.69 (0.57, 0.82) |
| | | Susceptibility | Infectiousness | |
| ONS[2] | 0-4 | 0.5 (0.35, 0.75) | 1.0 (0.7, 1.5) | |
| | 5-10 | 0.5 (0.35, 0.75) | 1.0 (0.7, 1.5) | |
| | 11-17 | 0.5 (0.35, 0.75) | 1.0 (0.7, 1.5) | |
| | 18-29 | 1.0 | 1.0 | |
| | 30-39 | 1.0 | 1.0 | |
| | 40-49 | 1.0 | 1.0 | |
| | 50-59 | 1.0 | 1.0 | |
| | 60-69 | 1.0 | 1.0 | |
| | 70+ | 1.0 | 1.0 | |
| | | Susceptibility | Infectiousness | |
| Viner et al[3] | 0-4 | 0.64 (0.51, 0.81) | 1.0 (assumed) | |
| | 5-10 | 0.64 (0.51, 0.81) | 1.0 (assumed) | |
| | 11-17 | 0.64 (0.51, 0.81) | 1.0 (assumed) | |
| | 18-29 | 1.0 | 1.0 | |
| | 30-39 | 1.0 | 1.0 | |
| | 40-49 | 1.0 | 1.0 | |
| | 50-59 | 1.0 | 1.0 | |
| | 60-69 | 1.0 | 1.0 | |
| | 70+ | 1.0 | 1.0 | |
| | | Susceptibility | Infectiousness | |
| CoMix fit | 0-4 | 0.31 | 1.0 | |
| | 5-10 | 0.31 | 1.0 | |
| | 11-17 | 0.31 | 1.0 | |
| | 18-29 | 1.0 | 1.0 | |
| | 30-39 | 1.0 | 1.0 | |
| | 40-49 | 1.0 | 1.0 | |
| | 50-59 | 1.0 | 1.0 | |
| | 60-69 | 1.0 | 1.0 | |
| | 70+ | 1.0 | 1.0 | |

[1] 95% Credible Intervals
[2] Approximate results inferred from plot in [7] unknown quantification of uncertainty
[3] 95% Confidence Interval

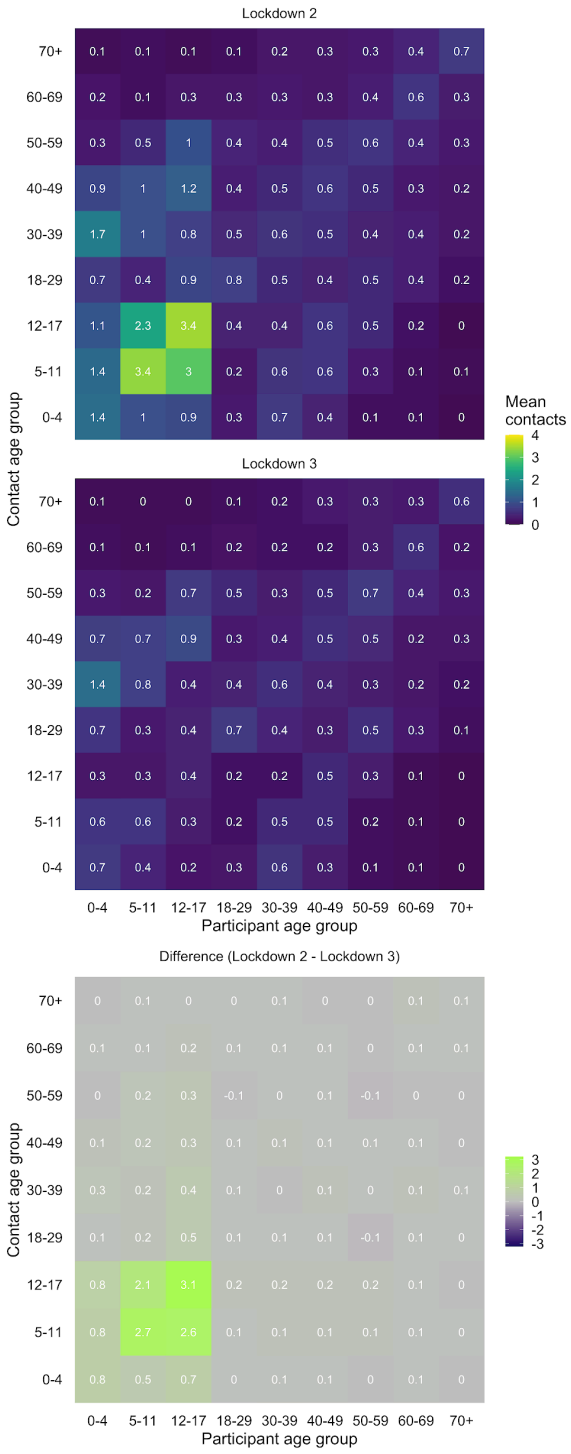


***Figure S1: Contact matrix for all contacts in England by age comparing Lockdown 2 and Lockdown 3 and the absolute difference of the cells of the matrices.*** Contacts truncated to 50 contacts per participant. Lockdown 2 data from *5th November to 2nd December 2020 and Lockdown 3 data from 5th to 18th of January 2021*

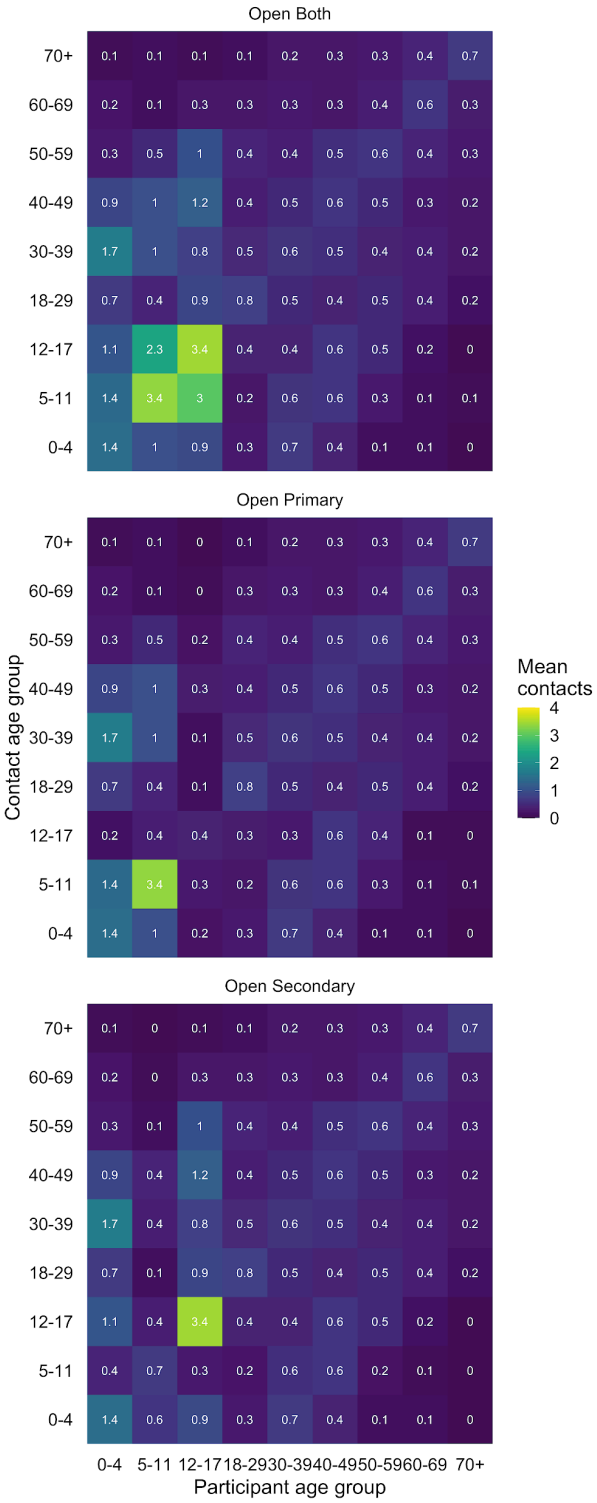


***Figure S2: Contact matrix for Scenarios included in analysis of school reopening. For all schools open the matrix calculated for Lockdown 2 was used.*** *Scenarios with Primary or Secondary schools closed replaced the 5-11 or 12-17 (respectively) column and row replaced with those calculated for Lockdown 3.* Contacts truncated to 50 contacts per participant. Lockdown 2 data from *5th November to 2nd December 2020 and Lockdown 3 data from 5th to 18th of January 2021*

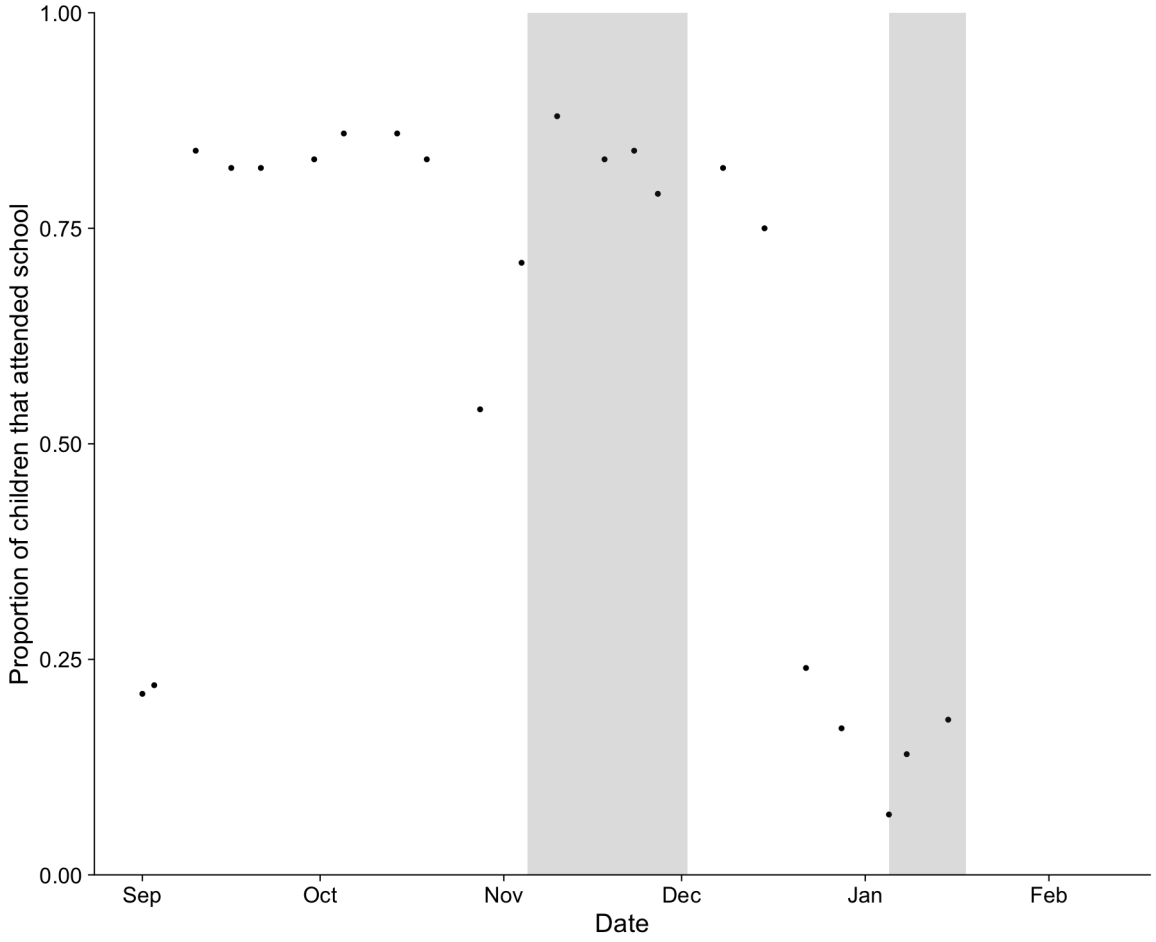


***Figure S3: The proportion of child participants who attended school on the day when contacts are recorded (with weekends removed).*** Grey bands represent the periods over which data used for this analysis was recorded (second and third lockdown).

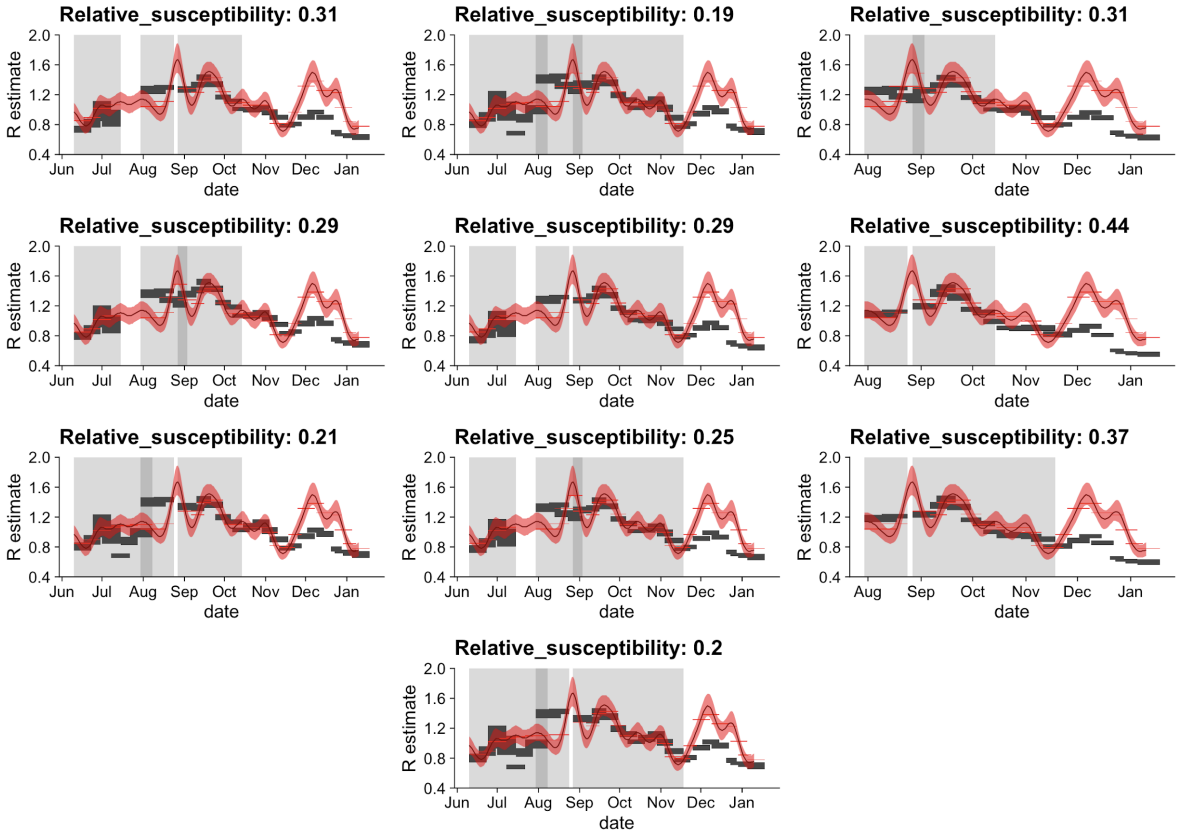


***Figure S4: Relative susceptibility found by fitting to various parts of the time-varying reproduction number estimate time series.*** *90% Confidence intervals of the estimates are shown by Grey rectangles for CoMix and the red ribbon for the time-varying reproduction number estimates from case data, red bars show their mean for the CoMix survey periods. Grey shaded areas indicate fitted periods*

**References**


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2. *Mossong J, Hens N, Jit M, Beutels P, Auranen K, Mikolajczyk R, et al. Social contacts and mixing patterns relevant to the spread of infectious diseases. PLoS Med. 2008;5: e74.*

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6. *Viner RM, Mytton OT, Bonell C, Melendez-Torres GJ, Ward J, Hudson L, et al. Susceptibility to SARS-CoV-2 Infection Among Children and Adolescents Compared With Adults: A Systematic Review and Meta-analysis. JAMA Pediatr. 2020. doi:10.1001/jamapediatrics.2020.4573*

7. *Scientific Advisory Group for Emergencies. TFC: Children and transmission, 4 November 2020. GOV.UK; 13 Nov 2020 [cited 22 Jan 2021]. Available: https://www.gov.uk/government/publications/tfc-children-and-transmission-4-november-2020*