Estimating R for intermittent interventions (V3)

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Summary

This introduces and applies a method to address the intermittent school partial opening scenario to give an effective R. These results should be seen in context of the assumptions given by the studies using the BBC and POLYMOD datasets for the other scenarios.

MGT = 6d		S1	S7-	S7+	1W-	1W+	S9
BBC	inf = 1	1.	1.043	1.092	1.041	1.085	1.257
BBC	inf = 0.75	1.	1.035	1.073	1.034	1.07	1.179
BBC	inf = 0.5	1.	1.029	1.06	1.029	1.058	1.132
BBC	inf = 0.25	1.	1.025	1.051	1.025	1.05	1.106
POLYMOD	inf = 1	1.	1.096	1.214	1.089	1.192	1.669
POLYMOD	inf = 0.75	1.	1.065	1.147	1.06	1.131	1.46
POLYMOD	inf = 0.5	1.	1.036	1.082	1.033	1.073	1.242
POLYMOD	inf = 0.25	1.	1.013	1.03	1.012	1.027	1.075

S1: scenario 1 (current baseline)
S7-: scenario 7 (two weeks alternating) with half mixing rates
S7+ scenario 7 (two weeks alternating) with full mixing rates
1W-: (one week alternating) with half mixing rates
1W+ (one week alternating) with full mixing rates
S9: scenario 9 (schools fully open)

The half and full mixing rates are optimistic and pessimistic assumptions about how mixing would change with half size classes and R is normalised to scenario 1 each time. This abstracted results table is for a mean generation time of 6 days. Results for 5 days generation time included below – these are quite similar.

In brief summary: one week alternating is perhaps slightly better than two weeks alternating, but the sensitivity to this under different generation time distributions should be investigated further.

Introduction

For partial school closure interventions that are about which set of children go to school, we have the elegant method to modify contact matrices to see how the spectral radius changes. This is equivalent to the next generation matrix, same which will have the same set of eigenvalues.

This does not usually account for intermittent effects, like schools on for a week, off for a week (with two staggered groups), say. At first it looks like it might be necessary to go to full dynamic models, which then entails detailed assumptions an also a decision about where in the epidemic we are (or at least a baseline incidence). This method offered here is to permit continued use of spectral analysis by linking different matrices for intermittent controls by using a discrete generation time distribution.

Methods

Age-component: suppose an age-mixing matrix which can be separated into non-school and school components, m_{ij} and $\hat{m}_{ij}$, so for fully open schools on weekdays the average contact matrix per weekday is $m_{ij} + \hat{m}_{ij}$ and just m_{ij} at weekends (hence factor 7/5 may be involved in estimating $\hat{m}$ time averaged contact data). Then if we suppose that contact rate within school is a proportion θ of fully open, we can set the age-mixing as $m_{ij} + \theta\hat{m}_{ij}$.

Time-component of transmission: let β_τ be the generation time distribution: the mean infectiousness per day of someone infected τ days ago. To gain this from a continuous time distribution, here I have used:

$$\beta_\tau = \begin{cases} \int_0^{0.5} \beta(t)dt & \text{for } \tau = 0 \\ \int_{\tau-0.5}^{\tau+0.5} \beta(t)dt & \text{for } \tau \geq 1 \end{cases}$$

Here I use a Weibull distribution with shape parameter 2.826 (following Ferretti *et. al.*), and chosen the scale parameters to give mean generation times 5 days or 6 days (Steven Riley pers. comm.).

Intervention cycle: Suppose that we focus on a cyclical pattern of length T days (say 28). Let θ_t be an indicator function for schools being in session on day t (mod T) or not (and can use non-binary, e.g. 0.5 works for a given person having half their usual number of school contacts that day). (Either require assumption that the period T is longer than any generation time so $\beta_\tau = 0$ for $\tau \geq T$, or need to either wrap it around or just repeat cycles to increase T appropriately.)

Combining: make 4-D array A as follows

$$A_{i,j,s,t}(\beta, \theta) = (m_{ij} + \theta_i \hat{m}_{ij})\beta_{s-t \bmod T}$$

and this represents the transmission from someone of age class j who was infected on day t infecting someone who is age class i and the transmission happens on day s (and all times are modulo the cycle of four weeks or whatever).

This 4D object can be viewed as 2D matrix by unpacking the pairs $\{i, s\}$ and $\{j, t\}$ to be single dimensions. This effectively gives a next generation matrix where the population classes are now those who are age class i AND infected on day s modulo T. Then we can make use of standard spectral analysis, just of a larger matrix (but no problem in practice, carried out in Mathematica below).

Results

The matrices for scenario 1, scenario 9 and the split to find m and $\hat{m}$ were supplied by Petra Klepac for BBC and Edwin van Leeuwen for POLYMOD, and their studies should be seen for details of approaches taken and assumptions made.

With schools halved, one simple assumption is that contacts halve. Another much more conservative assumption is that total contacts per person are unchanged as children make new contacts to replace the ones missing from their staggered half cohort. Reality is surely somewhere in between, and will depend on how the half classes are implemented in practice, and may vary by age group. The extreme assumptions are shown below ('-' for epidemiologically optimistic half contacts, and '+' for pessimistic).

Results are presented for a mean generation time 5 days and 6 days. For a mean generation of time of 5 days, the resulting R ratios are very similar: within 0.0025, and will only vary for the intermittent strategies.

MGT = 6d		S1	S7-	S7+	1W-	1W+	S9
BBC	inf = 1	1.	1.043	1.092	1.041	1.085	1.257
BBC	inf = 0.75	1.	1.035	1.073	1.034	1.07	1.179
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POLYMOD	inf = 0.25	1.	1.013	1.03	1.012	1.027	1.075

MGT = 5d		S1	S7-	S7+	1W-	1W+	S9
BBC	inf = 1	1.	1.043	1.093	1.041	1.085	1.257
BBC	inf = 0.75	1.	1.035	1.074	1.034	1.069	1.179
BBC	inf = 0.5	1.	1.029	1.06	1.029	1.058	1.132
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The numbers given in the tables above are the ratio of R for the scenario as compared with scenario 1 for that row.

Scenario 9 should be comparable to values given in the main studies for these approaches, but given here as a cross-check and as a comparison for the effective R from intermittent controls.

Some caveats

- This approach I believe brings in the temporal effects correct to leading order, but I'm not aware that it has been used before, so has not been scrutinised by other modellers in the wider field.
- The results do not appear to be sensitive to changing mean generation time from 5 to 6 days, but may depend on the precise distribution used. However, these will be small effects compared to general simplifying assumptions
- The extremes of half and full contact numbers for half-sized classes are used to give a sense of the range here. It is unclear what would happen in reality, and will surely depend on how the half-classes are chosen. It is also possible that the scaling of contacts in reduced class sizes will vary with age.
- For all the staggered group assumptions, we are assuming that there is no transmission between the groups in the context of school, i.e. no overlap of the groups and no transmission via fomites.