Potential effect of non-pharmaceutical interventions on a COVID-19 epidemic

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Policies examined

We use a model previously developed for pandemic influenza planning [1-2], including non-pharmaceutical interventions (NPIs) [3] to assess the potential effectiveness of NPIs for COVID-19. Four types of non-pharmaceutical intervention (NPI) are modelled, with all their combinations:

1. **Closure of schools and universities (PC)**: schools assumed to completely close, 25% of universities remain open. Household contact rates for student families increased by 50% during closure. Contacts outside the household increase by 25% during closure.
2. **Home isolation of symptomatic cases (CI)**: 65% of symptomatic cases withdraw to the home for 7 days, reducing non household contacts by 75%. Household contacts unchanged.
3. **Voluntary household quarantine (HQ)**: on occurrence of a symptomatic case in a household, all household members withdraw to the home for 14 days. Household contacts double during quarantine, all contact outside the household are reduced by 75%. 50% of households are assumed to comply with the policy.
4. **Social distancing (SD)**: All households reduce contacts outside the household or school/workplace by 75%. School contact rates are assumed to be unchanged. Workplace contact rates are reduced by 25%. Household contact rates are assumed to increase by 25%. *This policy implies cessation of all activities outside the household (including social contact between different households) bar the essentials and attending school and work*.

With the exception of school closure, we do not have reliable estimates of the impact of these policies, even for influenza. Plausible values have been selected. Other values can be explored.

We consider national policies triggered by national weekly symptomatic disease incidence triggers. We assume 90% of symptomatic disease can be detected (e.g. via a community-based surveillance system such as FluSurvey). We assume an incidence trigger of 100 or 300 cases per 100,000 of population per week, and either 13 or 26 weeks of policy enforcement. We vary R_0 between 2.0 and 2.4. We evaluate impacts via three summary statistics: (a) reduction in cumulative final symptomatic attack rate; (b) reduction in peak symptomatic incidence; (c) Delay in mid-point of epidemic.

Results

Figure 1 illustrates the impact of the NPIs examined for a policy duration of 26 weeks for R_0=2.2. Combination policies are predicted to be sufficiently effective at reducing transmission to give rise to double-peaked epidemics (second peak in late 2020) when the interventions are lifted. Interventions have greater impact (and are thus more likely to give double-peaked epidemics) for lower R_0 values and have somewhat less impact for higher values. A shorter policy duration reduces impact, with second peaks in transmission after policy cessation occurring earlier (September 2020).

Table 1 summarises impact for 13 weeks of closure, and Table 2 (Appendix) for 26 weeks.

Table 1: Impact of 13 weeks of NPIs on overall attack rate, peak incidence, and epidemic timing.

	% reduction in overall attack rate			% reduction in peak incidence			% delay in midpoint of epidemic (days)		
	R_0=2	R_0=2.2	R_0=2.4	R_0=2	R_0=2.2	R_0=2.4	R_0=2	R_0=2.2	R_0=2.4
PC	11%	8%	6%	40%	29%	21%	11	9	7
CI	4%	4%	6%	23%	20%	18%	19	16	13
HQ	6%	6%	7%	29%	24%	17%	16	13	10
SD	22%	23%	24%	66%	64%	62%	35	29	25
PC_CI	11%	10%	10%	53%	44%	42%	39	30	25
PC_HQ	12%	10%	10%	56%	47%	44%	36	27	22
PC_SD	4%	6%	5%	39%	21%	6%	113	96	90
CI_HQ	3%	4%	6%	21%	17%	27%	34	28	25
CI_SD	14%	15%	16%	55%	63%	67%	70	63	54
HQ_SD	15%	15%	17%	57%	65%	68%	67	60	51
PC_CI_HQ	11%	11%	11%	62%	61%	53%	80	58	49
PC_CI_SD	2%	4%	4%	16%	24%	6%	131	114	103
PC_HQ_SD	2%	4%	4%	19%	23%	5%	129	110	100
CI_HQ_SD	13%	12%	13%	54%	51%	57%	79	74	70
PC_CI_HQ_SD	1%	2%	4%	7%	23%	9%	143	124	113

Conclusions

Aggressive NPIs may have a substantial impact on COVID-19 transmission, potentially dramatically slowing epidemic growth or reducing R to below 1 while in operation. Recent reported case incidence data from China support this conclusion.

However, the primary impact of such measures is to delay transmission and reduce peak incidence; when they ae lifted, transmission can be expected to resume given the measures only protect the population while in operation (unlike vaccination). The overall impact on overall attack rate is therefore limited – though if measures are fine-tuned to allow sufficient transmission to allow population immunity (acquired through infection) to reach the herd-immunity threshold, significant reductions in overall attack are also possible. In this context, measures which are too effective merely push all transmission to the period after they are lifted, giving a delay but no substantial reduction in either peak incidence or overall attack rate.

We have insufficient data to parameterise the simulation model used here accurately enough to give a high level of confidence in model predictions of individual policies. In particular, the conclusion that social distancing alone would be optimal (in the reduction in overall attack rate achieved, at least) is dependent on the assumed impact of that policy on contact rates outside households, schools and workplaces.

However, it is likely that a policy package combining two or more of the interventions explored here could have a major impact on COVID-19 transmission while in force.

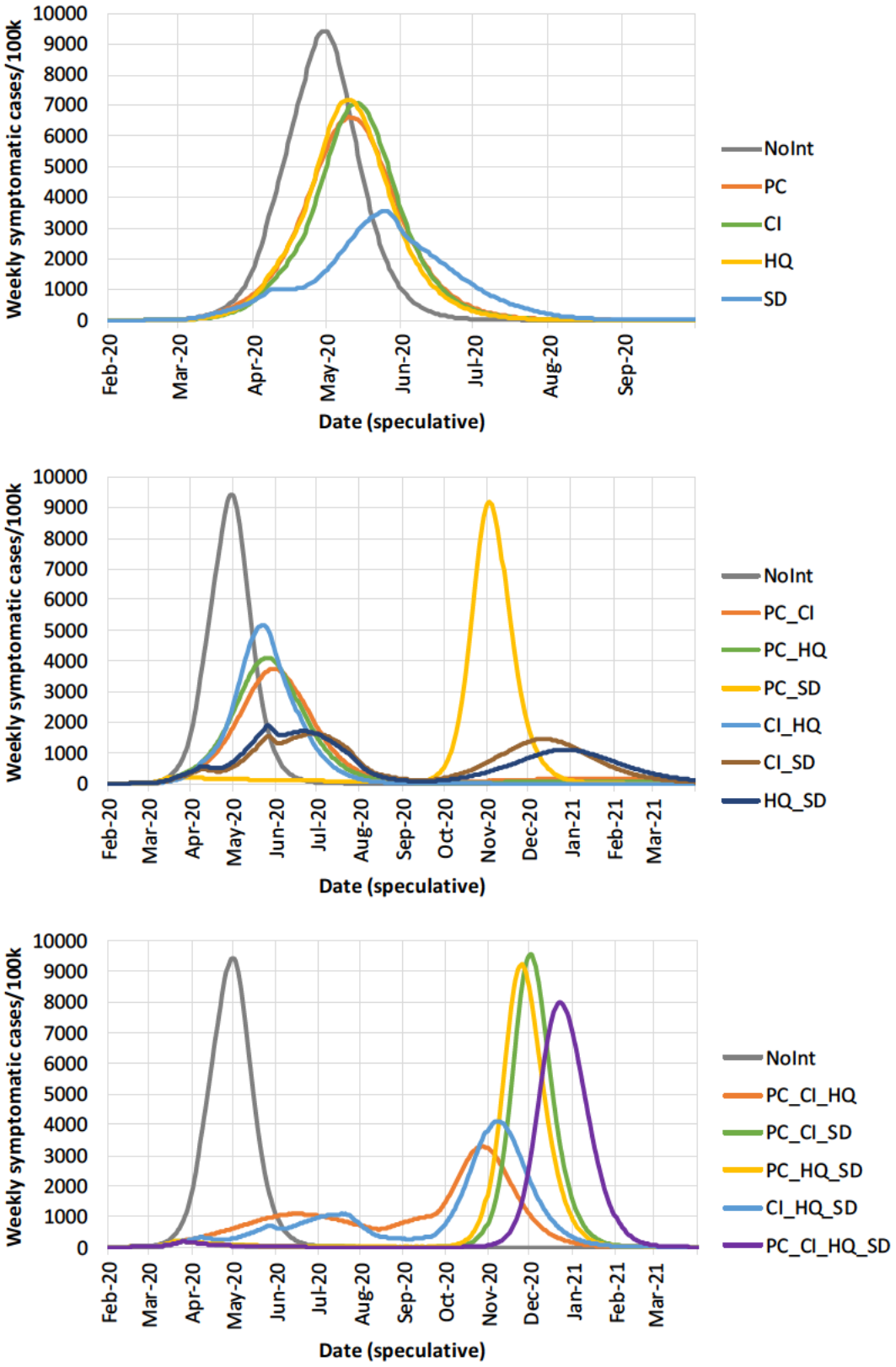

Figure 1: Impact of 26 weeks of NPIs triggered at 100 cases/100k, for R_0=2.2. Single interventions shown in top panel, pairs in middle panel, and combinations of 3 or 4 interventions in the bottom panel. Model has been only crudely calibrated to expected importations, so peak timing is approximate, and may occur later. NoInt=no interventions. PC=Place closure, CI=case isolation, HQ=household quarantine, SD=social distancing. School holidays are modelled.

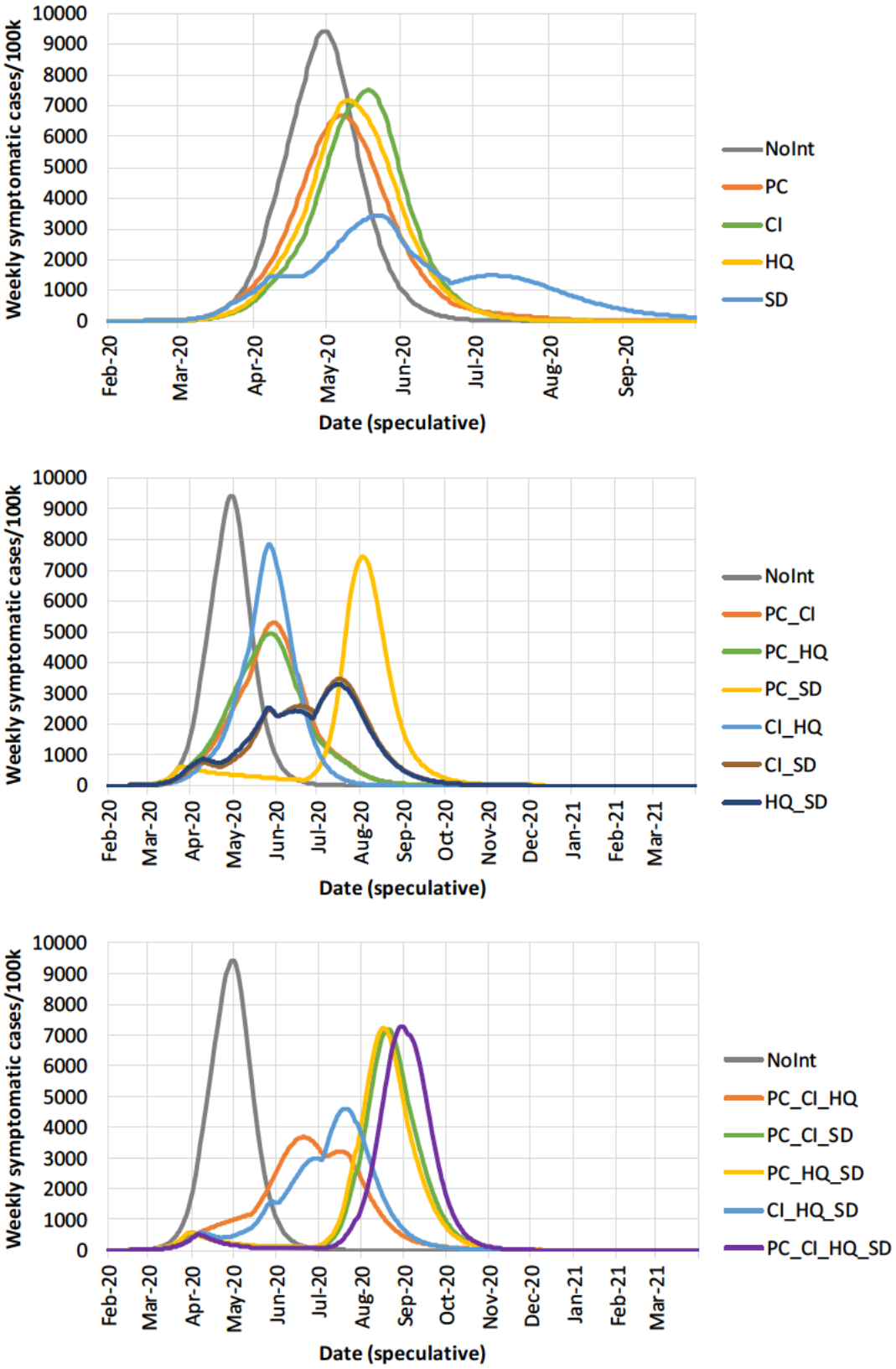

Figure 2: As Figure 1, but for 13 weeks of policy duration, triggering the policy at a cumulative symptomatic case incidence of 300/100k.

Methods

We use an adapted version of the individual-based simulation previously used to inform UK influenza pandemic planning (1-3). To briefly summarise, this model has the following features:

- Spatially explicit and individually based: models the entire population of England, Scotland and Wales (64.4 million).
- Transmission in households, school/work locations, and other spatially local included.
- Distribution of schools and workplaces and distances travelled to each matched against national data.
- Household size and age distributions are matched to UK census data.
- Spatially localised transmission modelled using a gravity model to represent probability of contact, parameterised against GB mobility data, accounting for age variation.
- Proportion of transmission occurring in households and schools matched to influenza data. Transmission in workplaces assumed to occur at half the efficiency of schools. All other transmission assumed to be spatially local and mass action.
- In the absence of immunity, approximately 1/3 of transmission occurs in each of (a) households, (b) schools and workplaces, and (c) other spatially local contacts.
- The simulation includes an explicit representation of absenteeism- both due to sickness, and due to caring for sick (or well, in the case of school closure) children in the household.
- School holidays are included.
- The model broadly reproduces the age-dependent mixing rates seen in POLYMOD and similar data.

COVID-19 specific parameterisation was as follows:

- For COVID-19, assume gamma distributed latent period with mean 4.59 days, SD 3.94 days
- A fixed 0.5 day delay from the end of latency to symptom onset (giving a 5.09 day mean IPD).
- Time varying infectiousness which is proportional to the density function of a gamma distribution with mean 2.2 days and SD 1.64 days. This gives a generation time distribution with mean 6.48 days, SD 3.83 days, of gamma form, matching current estimates from contact tracing studies.
- Assume individuals vary in infectiousness according to a gamma distribution with mean 1, SD 1/sqrt(k) where k=0.25. This gives a negative binomial offspring distribution with k=0.25.
- Exponentially growing seeding of infection into the UK, with a 5-day doubling time. This study is not intended to examine the impact of case isolation, and results regarding school closure are not sensitive to seeding assumptions.
- 2/3 of all infections assumed to be symptomatic (at least mildly). 25% of symptomatic children assumed to attend school, 50% of symptomatic adults to attend work.
- Symptomatic infections 1.5-fold more infectious than asymptomatic, but 50% less likely to make spatially local contacts outside the school or household.
- R_0 =2.2 gives a 5-day epidemic doubling time.

References

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2. Ferguson, N.M., D.A. Cummings, C. Fraser, J.C. Cajka, P.C. Cooley and D.S. Burke, *Strategies for mitigating an influenza pandemic*. Nature 2006;**442**(7101):448-52.
3. Halloran, M.E., N.M. Ferguson, S. Eubank, I.M. Longini, D.A.T. Cummings, B. Lewis, S.F. Xu, C. Fraser, A. Vullikanti, T.C. Germann et al. Modeling targeted layered containment of an influenza pandemic in the United States. P NATL ACAD SCI USA, 2008. 105:4639-4644.

Appendix

Table 2: Impact of 26 weeks of NPIs triggered at 100 cases/100k on overall attack rate, peak incidence, and epidemic timing.

	% reduction in overall attack rate			% reduction in peak incidence			% delay in midpoint of epidemic (days)		
	R_0=2	R_0=2.2	R_0=2.4	R_0=2	R_0=2.2	R_0=2.4	R_0=2	R_0=2.2	R_0=2.4
PC	14%	10%	7%	41%	30%	20%	15	12	10
CI	17%	13%	11%	32%	25%	18%	16	14	12
HQ	14%	12%	10%	30%	24%	17%	13	11	10
SD	38%	38%	37%	68%	62%	60%	30	27	24
PC_CI	18%	21%	20%	73%	60%	48%	58	37	26
PC_HQ	19%	20%	19%	69%	56%	45%	47	30	23
PC_SD	1%	2%	3%	7%	3%	7%	207	188	180
CI_HQ	29%	24%	21%	59%	45%	35%	31	25	21
CI_SD	17%	21%	23%	72%	83%	76%	182	98	71
HQ_SD	20%	23%	24%	80%	80%	73%	170	78	60
PC_CI_HQ	6%	11%	14%	39%	65%	79%	176	158	88
PC_CI_SD	0%	0%	1%	11%	0%	0%	240	217	200
PC_HQ_SD	0%	1%	1%	11%	2%	0%	231	211	196
CI_HQ_SD	7%	11%	14%	37%	56%	67%	183	182	182
PC_CI_HQ_SD	0%	0%	0%	28%	15%	0%	278	240	215