MRC Centre for Global Infectious Disease Analysis, Imperial College London **05/03/2020**

Timing and local triggering of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demands

Policies examined

MG - stopping mass gatherings. Includes shutting, in order of significance, bars/pubs, restaurants, cinemas, night clubs, sporting fixtures, places of worship and theatre. These represent about 12m contact hours of activity per day, or 5.3% of all hours outside home, school or work. Assuming a 3-fold higher risk of transmission than other activities, preventing them might reduce transmission outside household, school or work contacts by 16%.

PC - closure of schools and universities. 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.

CI - case isolation in the home. 70% of symptomatic cases withdraw to the home for 7 days, reducing non household contacts by 75%. Household contacts unchanged.

HQ - voluntary home quarantine. Following the identification of a symptomatic case in the household, all other 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.

SDO – Social distancing of those over 65 years of age. 75% compliance with policy. Those who do comply reduce contacts in schools or workplaces by 50%, increase household contact rates by 25%, but reduce all other contacts by 75%. This policy implies cessation of all activities outside the household (including social contact between different households) bar the essentials. Policy would need to include rigorous infection control in care/nursing homes. This policy is assumed to continue for 4 weeks longer than all other policies.

SD - social distancing of entire population. 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.

Triggers: detection of cases in ICUs: (a) absolute numbers of cases diagnosed per week per county; (b) cases per capita diagnosed per week per county.

Duration: the majority of results shown assume a policy duration of 2 months (3 for social distancing of those over 65), but a sensitivity analysis showing the effects of 3 (4 for SDO) month duration is shown.

Transmissibility of COVID-19 in the absence of interventions: R_0 values of 2.2 and 2.4 examined.

Severity scenarios: Two scenarios explored for rates of ICU demand: reasonable worst-case scenario and an alternative “milder” scenario, where RWC rates are reduced four-fold.

Infection seeding in the UK and spatial connectivity: results are shown for a ‘best estimate’ scenario (Figure 2), but conclusions are relatively insensitive to both infection seeding levels and locations, and to the precise human mobility model assumed. More focal seeding and lower spatial connectivity enhance the benefits of local triggering over national triggers.

Model used

This work uses a spatially explicit individual based simulation of respiratory virus transmission in the entire GB population. The model was first previously developed for pandemic influenza planning [Ferguson et al., Nature, Nature, 2005. 437(7056): p. 209-14], including non-pharmaceutical interventions (NPIs) [Halloran et al, PNAS, 2008. 105:4639-4644]. The model has been parameterised to reproduce current knowledge of COVID-19 epidemiology, including age-dependence in severity and healthcare utilisation. Healthcare demand assumptions match the RWC and NHSE models.

General conclusions

1. Within the range of scenarios examined, overall policy effectiveness is relatively insensitive to the precise choice of trigger (absolute case counts or per-capita incidence), R_0, and overall severity (within the 0.25%-1% IFR range) – see Tables 1-4.
2. Policy effectiveness is generally higher for lower triggers, and lower triggers make policies more robust to lower severity, given the reliance on ICU based surveillance. RCGP ILI surveillance does not have sufficient coverage to be used to trigger local interventions.
3. It should be noted that ICU admissions are expected to peak 1-2 weeks later than case incidence detected via GP surveillance.
4. While the overall effectiveness of triggers based on absolute case numbers and per-capita incidence is similar, per-capita triggers give a more equitable effect between counties of different population sizes. However, the effects are complex and depend on county area and population density. It is possible that triggering in smaller units (e.g. boroughs) in London and other large population units might improve policy targeting.
5. Policy combinations with higher effectiveness tend to layer multiple interventions, most notably case isolation, social distancing of those over 65, and to a slightly lesser extent, voluntary household quarantine and closure of schools and universities.
6. A minimum initial policy would be case isolation in the home and social distancing of those over 65. Adding household quarantine to that initial policy mix would likely increase policy effectiveness. Closure of schools and universities might be able to be added later, though additional work would be needed to examine such staggered interventions.
7. General social distancing of the entire population might have the largest impact of any single policy, but in combination with other policies risks supressing transmission sufficiently to lead to a second wave of transmission when the policy is lifted (see Figure 1).
8. Stopping mass gatherings has a minimal effect, particularly on its own (not included in the following Tables 1-5, but see prior report).
9. Extending policy duration beyond the default 2 months shown here only increases effectiveness marginally, for most scenarios (Table 5). However, in reality the key stopping criteria for all policies would be a sustained drop in case incidence. Social distancing of those over 65 needs to be continued for longer than other policies for maximum reduction of mortality (until community transmission is at low levels).

Table 1. Relative impact of NPI combinations on total deaths and peak hospital bed demand for different choices of triggers. Table shows percentage reduction in peak bed demand and total deaths for a variety of NPI combinations and for triggers based on the absolute number of ICU cases diagnosed in a county per week. Results shown are for the agreed RWC severity scenario (1% IFR). Tables are colour-coded (green= higher effectiveness, red=lower)

	Trigger (ICU cases per county per week)	PC	CI	SDO	CI_HQ	PC_CI	PC_SD	PC_CI_HQ_SD	PC_CI_SD	PC_SDO	SD	PC_CI_HQ	CI_SDO	CI_HQ_SDO	PC_CI_HQ_SDO	PC_CI_SDO	MG_PC_CI_HQ_SDO
R0=2.4 Peak beds	1	12%	31%	26%	49%	43%	23%	15%	17%	39%	45%	54%	55%	66%	62%	61%	58%
	5	9%	30%	25%	51%	43%	49%	39%	39%	37%	66%	64%	56%	70%	74%	61%	78%
	10	7%	29%	25%	47%	38%	66%	51%	54%	35%	72%	56%	54%	66%	68%	57%	73%
	20	5%	24%	24%	40%	32%	67%	67%	70%	32%	64%	47%	49%	56%	59%	50%	62%
R0=2.2 Peak beds	1	20%	32%	25%	48%	47%	13%	9%	10%	46%	38%	37%	56%	65%	43%	58%	37%
	5	19%	34%	25%	55%	55%	38%	28%	31%	45%	62%	64%	58%	71%	67%	70%	62%
	10	17%	32%	25%	53%	51%	54%	46%	45%	43%	68%	67%	57%	71%	76%	66%	74%
	20	15%	30%	24%	48%	44%	67%	63%	61%	40%	70%	58%	54%	65%	67%	60%	70%
R0=2.4 Total deaths	1	1%	13%	30%	18%	9%	4%	2%	3%	9%	18%	29%	41%	37%	24%	29%	21%
	5	2%	15%	29%	23%	13%	11%	7%	8%	15%	29%	30%	43%	44%	30%	34%	28%
	10	2%	15%	28%	25%	15%	16%	10%	11%	19%	36%	30%	43%	46%	33%	36%	31%
	20	1%	15%	27%	25%	16%	21%	15%	17%	21%	39%	29%	42%	46%	36%	37%	35%
R0=2.2 Total deaths	1	1%	12%	30%	15%	7%	3%	2%	2%	6%	15%	28%	38%	32%	17%	24%	15%
	5	2%	16%	29%	22%	12%	8%	5%	6%	12%	27%	30%	43%	40%	24%	30%	22%
	10	2%	17%	29%	25%	14%	12%	9%	9%	16%	33%	31%	44%	44%	28%	33%	26%
	20	3%	17%	28%	27%	17%	18%	13%	14%	20%	39%	30%	43%	46%	33%	36%	30%

Table 2. As Table 1 but for triggers based on the number of ICU cases diagnosed in a county per week per 200,000 population (the median size of county populations). Results shown are for the agreed RWC severity scenario (1% IFR).

	Trigger (ICU cases per 200k per week)	PC	CI	SDO	CI_HQ	PC_CI	PC_SD	PC_CI_HQ_SD	PC_CI_SD	PC_SDO	SD	PC_CI_HQ	CI_SDO	CI_HQ_SDO	PC_CI_HQ_SDO	PC_CI_SDO	MG_PC_CI_HQ_SDO
R0=2.4 Peak beds	1	11%	32%	26%	53%	45%	29%	11%	16%	38%	66%	67%	57%	71%	71%	63%	63%
	5	6%	29%	26%	45%	35%	64%	41%	48%	34%	70%	52%	54%	63%	64%	55%	69%
	10	4%	24%	25%	37%	27%	60%	64%	64%	31%	59%	40%	47%	53%	52%	46%	55%
	20	3%	18%	22%	25%	19%	44%	47%	46%	26%	44%	27%	35%	38%	38%	34%	39%
R0=2.2 Peak beds	1	20%	35%	25%	57%	57%	19%	6%	9%	45%	54%	52%	59%	74%	52%	72%	45%
	5	17%	33%	25%	53%	47%	50%	42%	41%	42%	73%	63%	58%	70%	72%	64%	73%
	10	15%	31%	25%	48%	42%	68%	63%	64%	40%	67%	53%	55%	63%	62%	58%	64%
	20	12%	26%	24%	36%	32%	53%	55%	54%	36%	53%	39%	47%	49%	48%	46%	50%
R0=2.4 Total deaths	1	1%	15%	29%	24%	13%	8%	4%	5%	13%	28%	31%	44%	44%	28%	34%	25%
	5	1%	16%	28%	27%	17%	19%	12%	14%	22%	41%	30%	44%	48%	36%	39%	33%
	10	2%	15%	27%	26%	17%	26%	18%	21%	25%	45%	29%	42%	48%	39%	39%	37%
	20	1%	14%	24%	24%	16%	31%	24%	26%	25%	44%	26%	38%	44%	39%	36%	39%
R0=2.2 Total deaths	1	2%	16%	30%	22%	10%	6%	4%	4%	10%	23%	31%	43%	38%	22%	29%	19%
	5	3%	18%	29%	28%	17%	16%	10%	12%	19%	39%	31%	45%	47%	31%	36%	28%
	10	3%	17%	28%	29%	19%	21%	14%	16%	23%	45%	31%	44%	49%	34%	37%	31%
	20	3%	16%	25%	28%	20%	26%	20%	22%	25%	46%	29%	41%	47%	36%	38%	34%

Table 3. As Table 1 (absolute case number triggers) but for an alternative "milder" severity scenario with hospitalisation and mortality rates four-fold lower than the RWC.

	Trigger (ICU cases per county per week)	PC	CI	SDO	CI_HQ	PC_CI	PC_SD	PC_CI_HQ_SD	PC_CI_SD	PC_SDO	SD	PC_CI_HQ	CI_SDO	CI_HQ_SDO	PC_CI_HQ_SDO	PC_CI_SDO	MG_PC_CI_HQ_SDO
R0=2.4 Peak beds	1	10%	31%	26%	51%	43%	46%	33%	37%	38%	69%	63%	57%	70%	73%	61%	76%
	5	6%	25%	24%	39%	32%	67%	68%	70%	32%	62%	46%	49%	57%	58%	50%	61%
	10	4%	19%	21%	30%	24%	54%	58%	57%	27%	51%	35%	40%	45%	46%	40%	49%
	20	3%	14%	17%	21%	16%	41%	45%	44%	21%	38%	24%	30%	34%	34%	30%	37%
R0=2.2 Peak beds	1	17%	33%	24%	54%	54%	38%	24%	27%	44%	64%	64%	58%	71%	68%	69%	62%
	5	15%	30%	24%	47%	43%	69%	59%	61%	39%	69%	57%	54%	65%	66%	59%	69%
	10	11%	25%	22%	39%	35%	64%	68%	67%	35%	61%	47%	48%	55%	56%	50%	59%
	20	7%	19%	19%	28%	25%	50%	55%	54%	27%	47%	34%	37%	43%	43%	39%	45%
R0=2.4 Total deaths	1	1%	16%	29%	24%	14%	11%	7%	8%	16%	31%	31%	44%	45%	30%	35%	28%
	5	2%	15%	27%	25%	16%	22%	17%	18%	22%	40%	29%	41%	47%	37%	37%	36%
	10	2%	14%	25%	24%	16%	27%	22%	23%	23%	40%	27%	38%	44%	37%	36%	37%
	20	1%	12%	22%	21%	14%	29%	25%	27%	21%	37%	23%	34%	39%	35%	32%	36%
R0=2.2 Total deaths	1	2%	16%	29%	23%	13%	9%	6%	6%	12%	28%	30%	43%	42%	25%	31%	22%
	5	3%	17%	28%	26%	17%	19%	13%	14%	20%	39%	30%	43%	46%	33%	36%	30%
	10	3%	16%	25%	26%	18%	23%	17%	19%	22%	41%	28%	41%	45%	35%	36%	34%
	20	2%	15%	22%	23%	16%	27%	24%	25%	22%	39%	26%	36%	41%	34%	34%	34%

Table 4. As Table 2 (cases per 200k triggers) but for an alternative "milder" severity scenario with hospitalisation and mortality rates four-fold lower than the RWC.

	Trigger (ICU cases per 200k per week)	PC	CI	SDO	CI_HQ	PC_CI	PC_SD	PC_CI_HQ_SD	PC_CI_SD	PC_SDO	SD	PC_CI_HQ	CI_SDO	CI_HQ_SDO	PC_CI_HQ_SDO	PC_CI_SDO	MG_PC_CI_HQ_SDO
R0=2.4 Peak beds	1	8%	29%	26%	46%	36%	63%	43%	49%	35%	68%	53%	54%	63%	65%	55%	69%
	5	3%	16%	22%	24%	19%	44%	45%	46%	25%	42%	25%	35%	37%	36%	34%	39%
	10	1%	10%	14%	13%	10%	27%	28%	27%	15%	27%	14%	21%	22%	22%	20%	23%
	20	0%	4%	7%	5%	3%	12%	13%	12%	7%	12%	5%	9%	10%	9%	9%	10%
R0=2.2 Peak beds	1	16%	32%	24%	53%	47%	51%	40%	38%	42%	72%	64%	57%	70%	72%	64%	72%
	5	11%	24%	24%	36%	31%	53%	56%	55%	34%	53%	39%	46%	49%	48%	46%	49%
	10	6%	17%	21%	23%	19%	39%	41%	40%	25%	38%	24%	33%	35%	34%	31%	35%
	20	0%	7%	11%	9%	6%	18%	19%	19%	11%	18%	8%	15%	16%	15%	14%	16%
R0=2.4 Total deaths	1	2%	16%	28%	27%	17%	18%	13%	14%	21%	41%	30%	44%	48%	36%	38%	34%
	5	2%	14%	24%	24%	16%	32%	25%	27%	25%	43%	26%	37%	43%	40%	37%	39%
	10	2%	12%	21%	20%	14%	35%	31%	32%	22%	38%	22%	32%	36%	35%	31%	37%
	20	1%	9%	16%	15%	10%	30%	35%	34%	16%	29%	17%	24%	28%	27%	23%	28%
R0=2.2 Total deaths	1	2%	17%	29%	28%	17%	15%	10%	11%	18%	38%	32%	45%	46%	31%	35%	28%
	5	3%	17%	25%	27%	19%	26%	21%	22%	25%	46%	28%	40%	46%	36%	38%	35%
	10	3%	14%	22%	24%	18%	33%	29%	30%	26%	42%	26%	35%	41%	39%	36%	38%
	20	1%	11%	17%	17%	12%	34%	38%	37%	19%	32%	19%	27%	30%	29%	26%	31%

Table 5. As Table 1 but for a policy duration of 3 months (4 for social distancing of those over 65) rather than 2 months.

	Trigger (ICU cases per county per week)	PC	CI	SDO	CI_HQ	PC_CI	PC_SD	PC_CI_HQ_SD	PC_CI_SD	PC_SDO	SD	PC_CI_HQ	CI_SDO	CI_HQ_SDO	PC_CI_HQ_SDO	PC_CI_SDO	MG_PC_CI_HQ_SDO
R0=2.4 Peak beds	1	12%	31%	26%	52%	48%	32%	29%	23%	40%	73%	70%	56%	70%	79%	66%	73%
	5	9%	30%	25%	51%	43%	63%	56%	55%	37%	74%	64%	56%	70%	75%	61%	79%
	10	7%	29%	25%	47%	38%	78%	67%	71%	35%	72%	57%	54%	66%	68%	58%	72%
	20	5%	24%	24%	40%	32%	67%	73%	71%	31%	64%	46%	49%	56%	58%	50%	62%
R0=2.2 Peak beds	1	20%	34%	25%	56%	59%	24%	30%	30%	47%	73%	61%	59%	73%	60%	74%	54%
	5	19%	34%	25%	55%	55%	59%	48%	54%	45%	73%	74%	58%	73%	82%	70%	79%
	10	17%	32%	25%	53%	51%	74%	57%	61%	43%	73%	67%	57%	71%	76%	66%	78%
	20	15%	30%	24%	48%	44%	75%	67%	71%	40%	70%	58%	54%	65%	67%	60%	70%
R0=2.4 Total deaths	1	2%	17%	30%	29%	17%	6%	2%	3%	17%	39%	32%	47%	50%	30%	38%	27%
	5	2%	16%	29%	29%	19%	13%	7%	8%	22%	47%	32%	46%	53%	34%	41%	30%
	10	2%	16%	28%	29%	19%	18%	10%	12%	24%	50%	31%	45%	52%	36%	41%	33%
	20	2%	15%	27%	27%	19%	23%	15%	17%	25%	50%	30%	43%	50%	38%	41%	35%
R0=2.2 Total deaths	1	3%	20%	30%	29%	16%	5%	2%	2%	12%	35%	34%	48%	46%	24%	33%	19%
	5	4%	19%	30%	32%	20%	10%	5%	6%	18%	44%	34%	48%	51%	28%	37%	24%
	10	4%	19%	29%	32%	21%	14%	9%	9%	21%	48%	34%	47%	52%	30%	38%	26%
	20	4%	18%	28%	31%	22%	18%	12%	14%	23%	50%	33%	45%	52%	33%	39%	29%

Figure 1: Illustration of typical effects of interventions on an epidemic with R0=2.4 and RWC severity. General ward bed demand (top) and deaths (bottom) shown for a range of NPI policy packages, triggered at county level by exceeding 1 ICU case per week. Policies have a duration of 2 months after initiation (3 months for social distancing of adults). Policy notation detailed on page 1. Policies involving substantial social distancing of the whole population (dashed curves) risk a second wave of transmission when lifted. Black curve shows intervention policy, red curve the optimal policy.

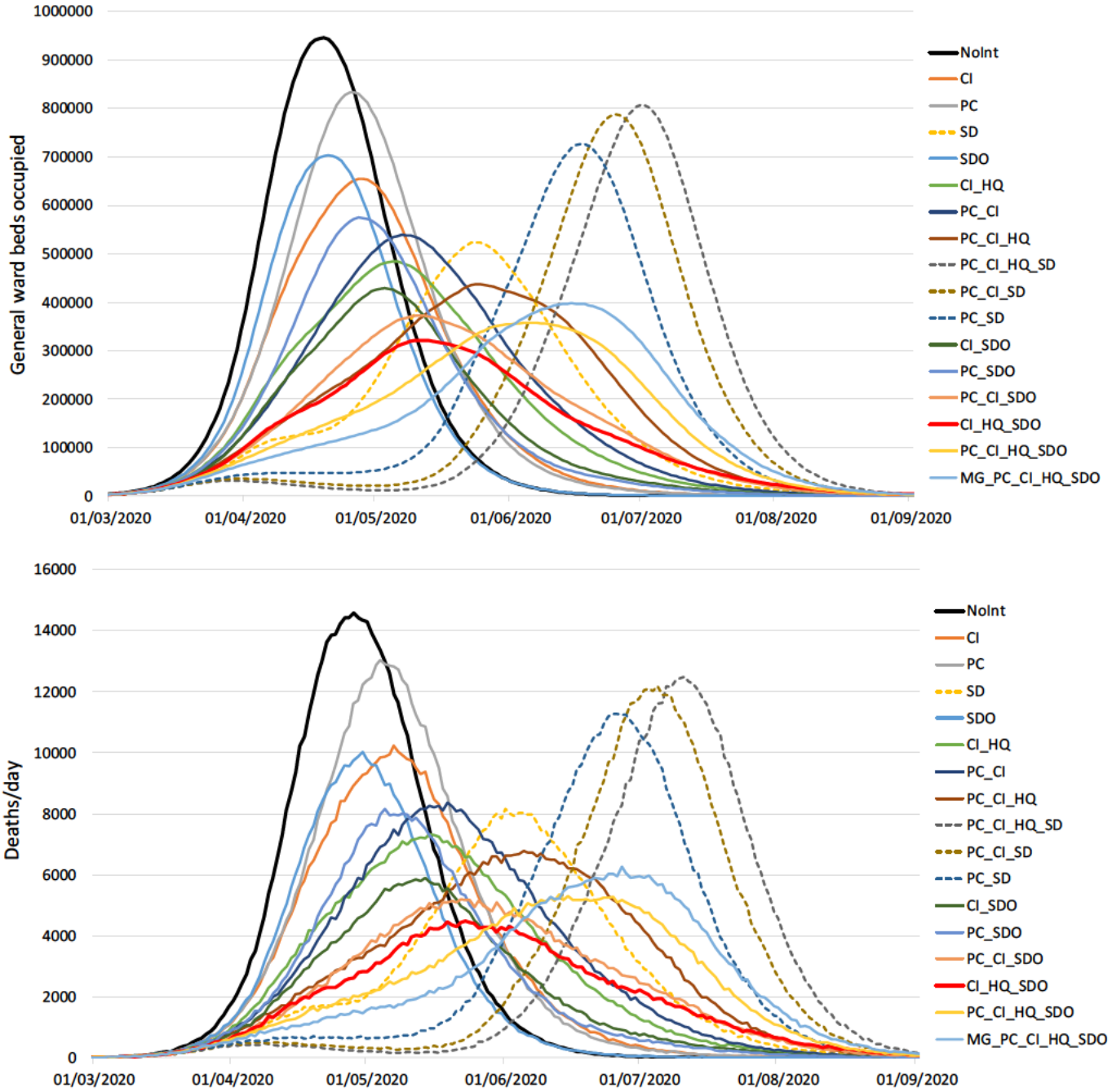

Figure 2. Illustration of likely desynchrony in epidemics across GB counties (R_0=2.4, no interventions). London epidemic shown in bold red, plotted on right axis. desynchrony could be greater, depending on the level of seeding of COVID-19 infection into the country.