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COVID-19: ABOUT WEAKENING SOCIAL DISTANCING MEASURES AND SCHOOL OPENINGS A CASE STUDY FOR THE CITY OF BERLIN

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ABSTRACT. Semi-realistic microsimulations for Berlin, on the basis of our model, give strong indications that the opening of schools together with the reduction of social distancing can only be realized safely under a highly immunized population. The opening of schools and the reduction of social distancing measures is in our opinion too early.

DISCLAIMER

This study uses results and computer programs from the MOCOS International research group www.mocos.pl, which was founded in Wrocław in February 2020. The computer programs and algorithms were mainly developed by M. Bodych and T. Ożański.

1. INTRODUCTION

1.1. **Model description.** We use an individual based SIR model to describe the spread of COVID-19. The model is a non-Markov stochastic process in continuous time based on the infection probability of susceptibles in contact with infected individuals. The contact structure outside of households is represented as an inhomogeneous directed random graph where each node corresponds to an infected individual and the degree of that node corresponds to the number of secondary infections created by that individual. The degree itself depends on how long the individual stays infectious (infectivity time).

Population structure: Our sample population is based on a synthetic reproduction of the microcensus in Germany (2014)[9]and involves age and household composition. In addition a sample population was used to represent the city of Berlin. Since we focus on a conceptual question, more detailed structures like spatial assignment, gender, profession or comorbidity relevant health status are omitted.

Disease progression within patients: The Covid-19 progression within patients is modelled according to the present medical knowledge. The incubation time is assumed to follow a lognormal distribution with median 3.92 and variance 5.516 [lognormal parameters: shape=0.497, loc=0.0, scale=3.923]. The age dependence of the probability to be hospitalised or to have severe progression or to have critical progression with requirement for ICU treatment is given in Table 1.

The time till hospitalisation from the onset of symptoms is assumed to be Gamma distributed with median 1.67 and variance 7.424 [gamma parameters: shape=0.874,

Symptoms	**Age groups**			
	0-40	**40-50**	**50-60**	**60-70**
Asymptomatic	0.006	0.006	0.006	0.006
Mild	0.845	0.842	0.826	0.787
Severe	0.144	0.144	0.141	0.134
Critical	0.004	0.008	0.027	0.073

TABLE 1. Age dependence of the probability to develop a certain level of symptoms. The probability for death was assumed to be 49% within the critical patients.

loc=0.0, scale=2.915][10] Patients with non severe progression eventually stay at home and the time from onset of symptoms till staying at home is also assumed to be Gamma distributed with median 2.31. and variance 8.365 [gamma parameters: shape=0.497, loc=0.0, scale=3.923].[11] The maximal duration of the infectious period is assumed to be 14 days.[12]

Contact structure and infection transport: Within the households we assume a clique contact structure. Empirical studies have shown that a large fraction of secondary infections are taking place within households.[13] We hence assumed that the probability of a household member to become infected by an already infected household member, who is infectious within a time interval of length T, scales as $1 - \exp(-T/L)$, where $L + 1$ is the household size. Here, the time T is measured in days. Outside of the households we assume that infected individuals create on average $c \cdot T$ secondary infections, given that all contacts of these individuals are susceptible, where c is an intrinsic parameter. Note the time T being infectious is different for contacts inside and outside the household. The out-reproduction number R^* is defined as the expectation of $c \cdot T$, which is equal to $2.34c$ under our assumptions of disease progression within patients. The actual number of secondary infections of an individual outside the household is assumed to be Poisson distributed with mean $(c{\cdot}T)$. The total reproduction number R_0 is given by the sum of R^* and the number of secondary infections generated inside the household. The duration of the infectivity time T implicitly depends on age. This is due to the fact that infectivity time is reduced for individuals with severe disease progression, as those patients become hospitalized. Severe progression is in turn more probable for older infected individuals. The outside household contact structure was intentionally chosen to be simple in order to have only one relevant and easily interpretable parameter in the model. We do not consider super-spreading events that could enhance the progression of the epidemic. Such events might have a strong impact at the beginning of an epidemic outbreak but, as the number of cases increases, the mean number of secondary infections R will dominate the evolution.

Testing and quarantine: We included additional model features to study the effect of testing followed by household quarantine in case the testing was positive. We assume that individuals with severe symptoms will always be detected and individuals with mild symptoms will be detected with probability q two days after the onset of symptoms. A detection is followed up by quarantine of the corresponding household with the effect that all out-household contacts by members of those households are stopped. The parameter q can be interpreted as the likelihood that a person with characteristic mild symptoms will be tested for COVID-19.

2. Outside Household Contacts before Social Distancing and Mitigation

	Observed data	**Intervals of $\mathbf{R}^*$**		**Intervals of $\mathbf{R}^*$ obtained for the quarantine scenario (detecting 50% of mild cases and 100% of severe/critical)**	
Entity	**Predicted $\mathbf{R}^*$**	$\mathbf{R_{min}}$	$\mathbf{R_{max}}$	$\mathbf{R_{min}}$	$\mathbf{R_{max}}$
Germany	3.04	0.37	0.42	—	—
Berlin	3.88	0.44	0.46	0.94	>1.4

Table 2. Intervals of $R_{min} \leq R^* \leq R_{max}$ for a possible successful overcritical mitigation.

Table 2 shows the intervals of $R_{min} \leq R^* \leq R_{max}$ which contain the inteval in which a successful overcritical mitigation is possible for both countries and towns. In other words R_{max} and R_{min} are upper and lower bounds for a successful mitigation, see.[17]

Here, successful means that even at the peak of the outbreak the epidemic stays below the capacity threshold of intensive care units. Our capacity thresholds for Germany and Poland are based on public statistical sources[14, 15] and on the very moderate assumption that only 80% of the existing ICU places are occupied.[16]

The upper bound for R^* of those intervals is denoted by R_{max}. This value is transferred into an average per day growth rate of prevalence, as it is reported by most health offices in their daily situation reports. An average per day growth rate was calculated from the first 50 days of the epidemic. We defined R_{max} as the smallest R^* value for which 10 sample paths surpassed the ICU threshold within D days. For cities D was chosen to be 200 days and for countries 700 days. The critical value R_{min} was defined as the largest $R^* < R_{max}$ for which the daily incidence at day 200 was below 50% of the initial number N_o of infected, see.[?]

3. Scenarios for Weakening Measures

3.1. **Immunization.** The degree of immunization, i.e. the part of the population already recovered from the disease plays a role in the spread of the epidemic. Of course this value can not be evaluated explicitely, since only data for tested cases is at hand. Up to now Berlin had 5677 recorded cases of COVID-19 of which 127 died and 4652 recovered (`https://www.rki.de`).
An immunization of 5% of the citizens in Berlin would correspond to 170000 people. This would correspond to a detection rate of 3,3% of the COVID-19-cases.
It is hence to expect that the immunization is less than this value.

3.2. **Opening Schools.** In this scenario we mimick the opening of schools for different age classes. We focus here on the pupils of the ages 15-18, 16-18 and 17-18. A study for primary schools and kindergarten will appear in a forthcoming tech report. We assume that this happens at a time point at which Berlin is almost virus-free. The initial number of active COVID-19 cases not detected inside the population at the initial date is assumed to be 1000. Those cases are randomly distributed among the 3.4 mln citizens of Berlin.
The outer house contact rate of the teenagers sent to school is assumed to be higher than the outer house contact of the rest of the population. Here different in-age-group contact rates are considered. For the other part of the population we simulate a the scenario of strict social distancing ($\sim 9\%$ of outer-household contacts compared to the time before March 15, 2020) and milder social distancing ($\sim 18\%$ of outer-household contacts compared to the time before March 15, 2020). Inside the household the contact rate is set as above, scaled in such a way that the attack rate is around 65%.
The results are presented for different stages of immunization. Note that every 1% of immunization would correspond to around 34000 cases. At this moment (April,28,2020) Berlin has 5500 registered cases of COVID-19. Assuming a 2% immunization inside the population hence means on the other side that just around 8% of all cases had been detected so far.
For the scenario we assumed a detection rate of $q = 0.1$, i.e. mild cases are detected after two days with probability 0.1 and all hospitalized COVID-19 cases are detected and followed by a quarantine for the whole household.
Results and discussion:
Note: In our simulations the fact that the ICU threshold is exceeded does not affect the number of deceased patients. This assumption very likely is too optimistic.

Table 3 shows prevalences and deaths for different scenarios of school openings. As to expect higher rates of inner-school and outer-school contacts lead to higher prevalences. The age itself seem to play a minor role. This can be explained by the family structures. It is to expect, that the age difference between siblings is traditionally 1-3 years. This is exactly the age difference we used in our scenarios. In the cases in which just one sibling is send to school the other sibling is likely to be infected inside the household. The table also shows that the school opening has a remarkable effect on the prevalence. In the scenario with milder contact reduction the reduction of the prevalence by closing schools is however not so big as under strict contact reduction.

Prevalence & death under strict contact reduction (9 % of the outer household contacts before March 15, 2020) and detection rate q=0.1

	Immunization	0,5 %		1 %		2 %		4 %		8 %	
		Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)	Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)	Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)	Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)	Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)
	contacts in school compared to before social distancing										
without school opening		5507	128	5709	125	5381	124	5268	117	4676	107
with opening for 17-18 y.o.	**18 %**	9414	178	7633	150	7191	158	6580	132	5312	124
	30 %	110232	1707	108876	1624	101359	1502	90273	1343	71898	1019
	48 %	175051	2627	171338	2546	165754	2436	153020	2195	131717	1803
	80 %	203884	3033	199931	2976	193577	2866	181525	2616	159624	2211
with opening for 16-18 y.o.	**18 %**	7346	151	7563	150	7027	147	6541	139	5427	121
	30 %	112858	1700	108817	1603	101994	1531	91673	1362	69788	1012
	48 %	180100	2687	177777	2636	170871	2542	157043	2252	135935	1897
	80 %	212176	3128	208471	3091	203533	2992	189122	2709	165946	2239
with opening for 15-18 y.o.	**18 %**	7765	156	7362	155	6864	144	6610	145	5254	124
	30 %	112416	1690	107706	1654	101648	1523	89783	1312	68886	992
	48 %	184865	2696	180162	2742	175036	2522	161413	2335	138332	1892
	80 %	217355	3207	214538	3143	206917	3027	194205	2770	170655	2319

Prevalence & death under strict contact reduction (18 % of the outer household contacts before March 15, 2020) and detection rate q=0.1

	Immunization	0,5 %		1 %		2 %		4 %		8 %	
		Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)	Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)	Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)	Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)	Prevalence after 300 days (Median)	Accumulated deaths after 300 days (Median)
	contacts in school compared to before social distancing										
without school opening		879342	19523	832603	18503	770441	16964	616556	13273	337398	6976
with opening for 17-18 y.o.	**30 %**	969804	21691	948324	21323	891088	19855	781341	17361	569584	12408
	48 %	1035020	23016	1002545	22254	958108	21202	859704	18935	668930	14592
	80 %	1062280	23577	1038602	23073	985280	21759	890509	19565	712504	15432
with opening for 16-18 y.o.	**30 %**	977973	21891	949464	21294	896491	20000	777615	17232	570449	12334
	48 %	1037899	22988	1012937	22478	960717	21217	865745	19078	672527	14708
	80 %	1072225	23657	1044435	23004	996448	22031	898825	19751	720667	15416
with opening for 15-18 y.o.	**30 %**	981902	21890	947852	21201	896327	20019	788704	17468	567768	12290
	48 %	1037726	23090	1009305	22465	966282	21423	865935	19119	678453	14693
	80 %	1074125	23645	1052148	23115	997850	21946	907327	19922	724424	15566

TABLE 3. Prevalences and Deaths for different school opening scenarios with different outer household contacts

3.3. **Testing and household quarantine vs social disctancing.** In recent discussions massive testing with household quarantine is suggested as the key ingredient for the fight against COVID-19 in the absence of vaccination. In this subsection we studied the effect of social distancing measures in combination with testing and household quarantine. The effect of backtracking will appear in a forthcoming techreport.

Prevalence in Berlin after 300 days - Detection rate q vs contact reductions compared to the contacts before March 15, 2020

	6 %	12 %	18 %	24 %	30 %	36 %	42 %	48 %	54 %	60 %
q=0	43	60	690846	2087612	2482338	2715665	2866098	2968554	3040095	3092955
0.1	43	57	48543	1828998	2309512	2591281	2771452	2893839	2980862	3045099
0.2	43	56	1880	1430148	2100458	2438415	2656276	2804680	2909323	2986273
0.3	31	52	178	521268	1840798	2253079	2516468	2695702	2821374	2914677
0.4	26	44	104	17957	1500827	2025551	2344345	2561644	2714886	2827721
0.5	25	42	85	386	612989	1743193	2131618	2398088	2582953	2720054
0.6	25	32	59	138	16061	1338029	1868323	2190759	2419105	2586507
0.7	24	31	59	138	239	384804	1521225	1928223	2209903	2415781
0.8	22	31	50	98	139	2918	874792	1591068	1941268	2200614
0.9	22	31	50	67	76	178	330	1110096	1590869	1918573
1	21	29	42	52	47	100	128	60692	1117517	1542432

Table 4. Prevalences for different detection rates and outer household contact rates. At the beginning Berlin was assumed virus-free with 10 imported cases.

Table 4 shows the prevalences after 300 days for different detection rates and social distancing measures. The number of initially infected was 10 while we assumed no immunization. The green fields correspond to prevalences less than 1000, while the yellow fields represent combinations with prevalences between 1000 and 1000000. In the red fields the prevalences are more than 1000000. The table shows a very steep phase transition between a subcritical (green) and overcritical (red) epidemic. As described before and in[17] The margin of allowable contacts between these two phases is very small. As Table 4 shows, also a massive testing does not change this fact. On the other hand the higher the detection rate the more contacts can be allowed be still in the subcritical regime. With a contact reduction of 54% even a detection rate of 100% of all mild cases after 2 days does not prevent an epidemic, where the intensive care threshold is exeeded and the the health system will break down. We hence conclude that massive testing has to be combined with social distancing measures.

4. Summary and Conclusion

Semi-realistic microsimulations for Berlin, on the basis of our model, give strong indications that the opening of schools together with the reduction of social distancing can only be realized safely under a highly immunized population. If strict social distancing measures are imposed by state authorities the opening of schools is possible under severe hygienic and social distancing rules. The interplay of massive testing, household quarantine and social distancing does not prevent from steep phase transition and hence a narrow mitigation interval as already pointed out in.[17]

The main reason for this is the household structure. Infections within the households for patients with mild progression can hardly be avoided and therefore a small number of infection links between the households can already make the epidemic overcritical. We conclude that instead of a household quarantine, an extinction strategy implemented by quick, effective and drastic countermeasures similar to those put in action in China is ultimately required to reduce social contacts outside households. If contact reduction is not kept in force until disease extinction a second epidemic outbreak may result.[8] Therefore, in order to control the epidemics it is nessesary to wait until it gets extinct. The application of an epidemic management plan based on a flawed strategy of herd immunity may easily lead to an uncontrollable epidemic. We also strongly advise combining social distancing and contact related countermeasures with an extensive testing strategy including individuals with characteristic symptoms but unknown contact history. The opening of schools and the reduction of social distancing measures is in our opinion too early.

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