COVID-19 health care demand and mortality in Sweden in response to non-pharmaceutical (NPIs) mitigation and suppression scenarios

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Abstract

Background:

While the COVID-19 outbreak in China now appears contained, Europe has become the epicenter, with both Italy and Spain reporting more deaths than China. Here we analyse the potential consequences of different response strategies to COVID-19 within Sweden, the resulting demand for care, critical care, deaths and their associated direct health care related costs.

Methods:

We use an age stratified health-care demand extended SEIR compartmental model fitted to the municipality level for all municipalities in Sweden, and a radiation model describing inter-municipality mobility.

Results:

Our models fit well with the observed deaths in Sweden up to 25th of March. The critical care demand is estimated to peak just above 16,000 patients per day by early May in the unmitigated scenario, while isolation of elderly and intermediate social distancing can reduce it to around 5000-9000 per day peaking in June. These peaks exceed the normal critical care capacity in Sweden at 526 beds by an order of magnitude. We find, however, that by employing strong social distancing and isolation of families with confirmed cases, as guided by testing, the outbreak can be suppressed to levels below the normal critical care capacity. We estimate death rates in COVID-19 are closely related to the different response strategies.

Conclusion:

The impact of different combinations of non-pharmaceutical interventions, especially the extent of social distancing and isolation, reduce deaths and lower health care costs in Sweden. In most mitigation scenarios, demand on ICU beds would rapidly exceed total ICU capacity, thus calling for immediate expansion of ICU beds. These findings have relevance for Swedish policy and response to the COVID-19 pandemic.

Introduction

In response to the COVID-19 outbreak, China implemented extraordinary public health measures at great socio-economic cost, moving swiftly and decisively to ensure early identification of cases, prompt laboratory testing, facility-based isolation of all cases, contact tracing and quarantine.(1) In the community, social distancing was implemented at a grand scale, all mobility put to an halt, and the city of Wuhan was in lock-down for about 9 weeks. China's tremendous efforts showed success. Other Asian countries facing a major explosion such as South Korea also managed to curb the epidemic. South Korea employed very liberal testing, hospital-based isolation of all cases (even mild ones), combined with extensive contact tracing enhanced by mobile phone and digital technologies, but did not use a lock-down.(2, 3) Despite many importations early on in the outbreak, Singapore has seen a flat rate of daily new cases, by focusing on prompt and aggressive pro-active case detection and attempting to interrupt every chain of transmission and keeping clusters at bay.(4)

While the outbreak in China now appears contained, since mid March 2020, the epicentre of the COVID-19 pandemic is in Europe(5), with both Italy and Spain reporting more deaths than China. Various European countries have seen an exponential growth in daily new cases, and without strong reduction in transmission rates, the epidemic is expected to hit all of Europe by the end of March 2020. There is thus an urgent need to reduce transmission rates and tcontrol the growth of this epidemic, to reduce the height of the epidemic peak and the peak demand on healthcare services, as well as lowering the total number of eventually infected persons.

In the absence of vaccines, a wide range of control measures can be considered to contain or mitigate COVID-19. These include active case finding with prompt isolation of cases, contact tracing with quarantine of contacts, school closures and closures of public places, mobility restrictions, social distancing in the community, social distancing only of the elderly, and a lock-down (also known as cordonaire sanitaire).(1) There is currently no consensus about which measures should be considered, in which combination, and at which epidemiological threshold such measures should be implemented for maximum public health impact.(6)

Two strategies can be considered: (a) containment which aims to reverse epidemic growth, thereby reducing case numbers to low levels, and (b) mitigation, which focuses on slowing but not necessarily stopping epidemic spread – reducing peak healthcare demand while protecting those most at risk of severe disease from infection. Each policy has major challenges. Containment aims to reduce the reproduction number, R, to below 1, thus causing case numbers to decline. Mitigation aims to slow spread by reducing R, but not indefinitely below 1.

Therefore there is an urgent need to quantify the effects of these measures and specifically whether they can reduce the effective reproductive number below 1, because this will guide the response strategies.

Here we estimate the impact of COVID-19 on the Swedish population at the municipality level, considering demography and human mobility under scenarios of mitigation and suppression. We estimate the timelines of incidence, hospitalization rates, the intensive care (ICU) need, and the mortality in relation to the current Swedish ICU capacity as well as the costs of care.

Methods

We fitted a compartmental SEIR alike model including compartment for health and ICU care with age groups of 0-59, 60-79, and 80+ years at the level of municipality in Sweden. The model include age stratified compartments for susceptibles, exposed, and mild or asymptomatic infections, symptomatic infections, and for those in hospital care, those in ICU, those dead, and those recovered (see supplementary material). We linked municipalities to each other using a radiation model for human mobility. The radiation model was calibrated using a N1H1 Influenza A for the period 2015-2018. Demographic data was obtained at municipality level for the year 2018 from Statistics Sweden and all estimates and model parameters were derived by weighting by 10 year age groups at the level of municipality.

The case fatality ratio (CFR) varies across regions, partly depending on age structure of population, but also potential underreporting of mild and asymptomatic disease.

Hospitalization and ICU needs among symptomatic infections was taken from Ferguson et al.(7). Like Ferguson et al., we assumed the infection fatality ratio (IFR) was lower than the CFR adjusting for potential underreporting of the number of infectious cases which affect the development of immunity, i.e. the time to herd immunity in the population. Reports indicates a proportion of 30% of all infections may be asymptomatic (8). Preliminary reports from Iceland indicate 50% asymptomatic transmission. Additionally, we assumed that all subclinical cases (mild instances of the disease) are not reported, and that a total 1/3 of all infections yield symptoms potentially renderring hospital care.

We modelled the impact of COVID-19 on the Swedish population under selected counter measures associated with suppression strategies. The baseline scenarios include isolation of cases in health care and home isolation, which is restricting the infectious period of the average population. The infectious period in severely ill hospitalized patients is likely to vary by individual and range from days to weeks. In most cases, viral shedding for about 7-22days, even in the mildest of cases,(9) is likely a major driver of disease transmission. Isolating patients, or staying home if presenting with symptoms, will reduce transmission to contacts, and is the key strategy to contain COVID-19. It affects the period a person is actually infectious to others, which is important in models. However, transmission from infected but asymptomatic or pre-symptomatic persons can still occur with less constrains.(10) We thus assumed that the average effective infectious period in the general population was around 5 days, with a β of 0.6, which results in an R_0 of 3 for a 5 days infectious period, consistent with the reported basic reproduction rates for COVID-19(11). However, symptomatic patients needing hospital care were assumed isolated after 3 days. The model and the daily reproductive rate β was calibrated to age specific observations of deaths from COVID-19 within Sweden (www.worldometers.info). We assume ages 80+ years have overall 50% lower contact rates than everyone else, thus lower β. In the mitigation versus suppression scenarios we assumed that isolation based on symptoms was present from the first day of reported COVID-19 cases in Sweden, February 24th, 2020, while the mitigation and suppression strategies was activated first 20th of March, 2020, and 3rd of April respectively. The model and parameters are described in the supplementary material.

The model was initiated to predicting the municipality transmission dynamics and inter-municipality spread across Sweden starting from 24th of February and ending 6 months later, August 23, 2020. Due to the many travelers infected with SARS-CoV-2 arriving from Italy in the week of the 24th of February, the model was seeded with 1 cases per 50,000 population. If anyting, this number likely understimates the actual number of undetected infected persons returning to Sweden from Europe (Italy, Spain, France, etc.).

Our analyses aim to predict the demand on the Swedish health care system including ICU beds, We modelled scenarios of community-based distancing and shielding of elderly by varying the model contact rates proportionally from the original 100% as described by the parameter β. We further assessed the effect of timing on the introduction of behavior change (distancing and isolation), and the effect of shortening the time infective people are around in households by expanding testing and isolation among sick people.

We additionally investigate the effect rigorous testing, fever screening and isolation of family members to confirmed infected people. The assumption is that these efforts reduces the period a person is infectious among other people (from 5 to 3 days) by more effective isolation. Furthermore, we estimated the direct health care costs based on the health-care demand (see supplementary information).

ICU capacity: we compared the forecast ICU demand against the currently available of ICU beds in Sweden which is 526. Due to ongoing preparedness activites in increasing ICU capacities we estimated the deaths from ICU shortage assuming the normal capacity was doubled.

Results

The model showed a good fit against the reported COVID-19 related deaths in Sweden (Figure 1) up to 25 March, 2020 not considering impacts of mitigation and suppression interventions. We chose to validate against this date as the infections that resulted in fatal outcomes by 25th of March are likely due to infections that happened approximately 3 weeks before death, and thus before any mitigation measures were initiated in Sweden.

The baseline scenarios the model estimates a case fatality ratio of 1.59% for the average Swedish population (deaths over symptomatic cases that seek health care), which translates to an IFR of 0.53% assuming that two-thirds of the population experience mild or asymptomatic transmission and are not reported.

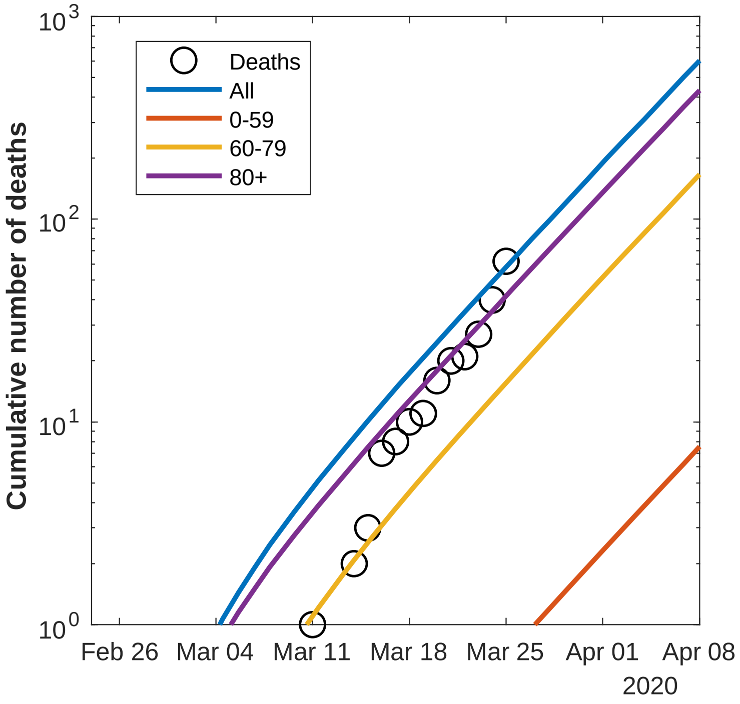

Figure 1. *Cumulative number of predicted total deaths in Sweden from COVID-19 in different age groups and for the whole population assuming no mitigation or suppression. Observed cumulative death counts are illustrated as circles (O) and amount to 62 by the 25th of March, 2020.*

In Figure 2 we present the scenarios of COVID-19 critical care demand over time aggregated over Sweden in the different age groups, and in total. With only home self-isolation when having symptoms and isolation of confirmed cases, the outbreak would peak in the beginning of May and reach critical care demands of nearly 16,000 patients (Figure 2a). The age group below 60 years of age alone would take up more than the baseline critical care resources of 526 beds at during a month around the peak. If the contacts would be reduced by 75% for the age group below 60 years and 50% for the age group from of 60 years and above, the critical care demand would decrease to around 9000 at the peak in June (Figure 2b). The demand would be flattened and continue for a longer period. The critical care demand for those below 60 years of age would take up the baseline critical care beds for around 1 month. If the contacts in the community would be reduced by 50% for the age group below 60 years and 25% for the age group of 60 years and above, the critical care demand would decrease to around 5000 at the peak in the middle of July (Figure 2c). The demand would be flattened and continue for a longer period. The critical care demand for those aged below 60 years would almost take up the baseline critical care beds for a period slightly less than 1 month. If the contacts on the community would be reduced by 50% for those aged below 60 years and 90% for those aged 60 years and above, the critical care demand would not increase beyond 400 and be quite stable for whole period (Figure 2d). However, in this scenario, it would likely resurge unless others means exist to control the transmission when the countermeasures are lifted. If the contacts would be reduced by 50% for those below 60 years of age and 90% for those aged 60 years and above and the period of transmissibility shortened, i.e. by testing persons and quarantining of contacts to infected persons, the critical care demand would be very small for the whole study period (Figure 2e). However, again likely to resurge unless others means are there to control the transmission when the countermeasures are lifted.

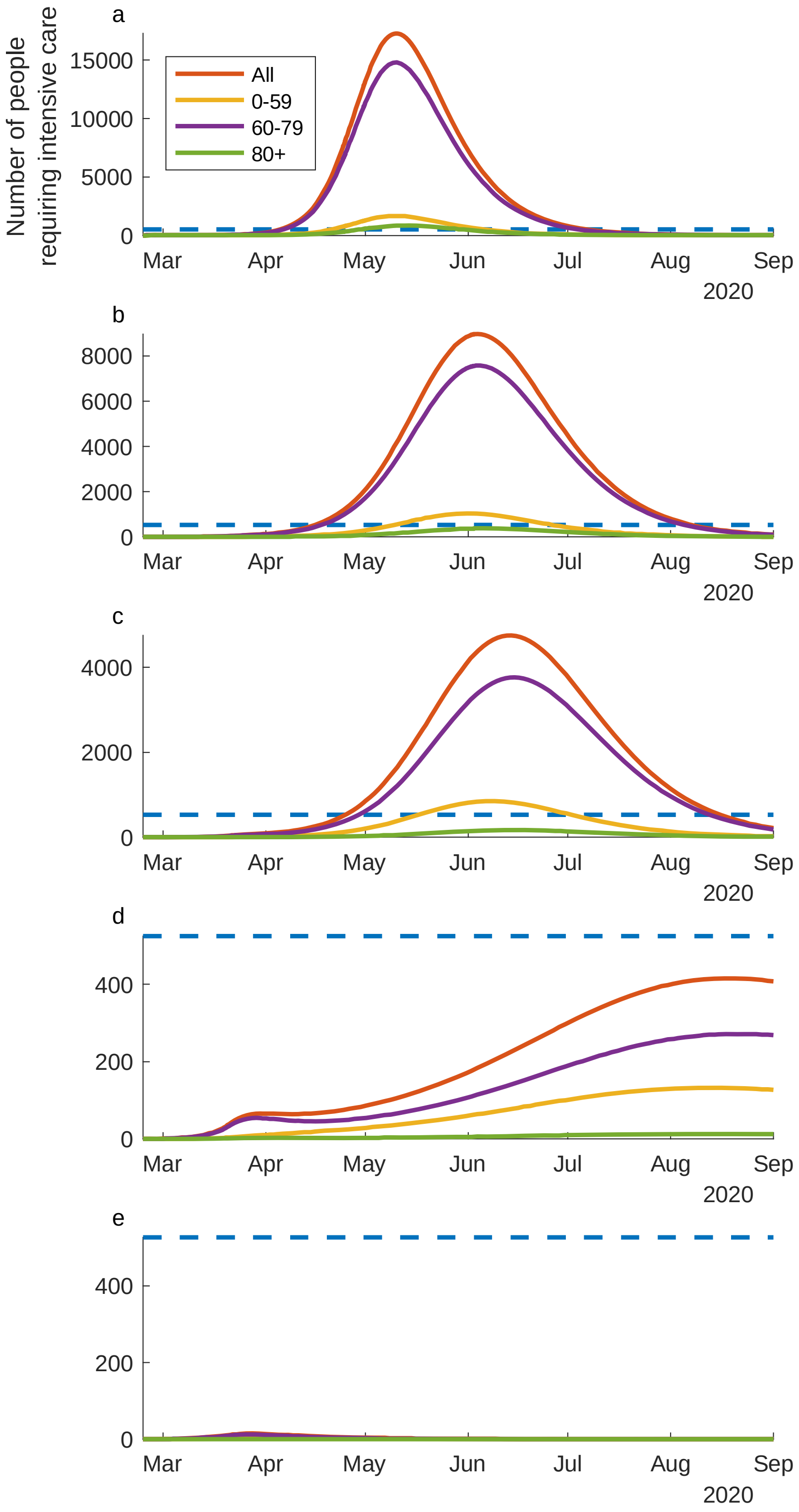
a
Number of people requiring intensive care
15000
10000
5000
0
All
0-59
60-79
80+
Mar
Apr
May
Jun
Jul
Aug
Sep
2020
b
8000
6000
4000
2000
0
c
4000
2000
0
d
400
200
0
e
400
200
0

Figure 2. *The predicted intensive care demand per day from 24th of February to the 23rd of August, 2020, overall in Sweden in relationship to mitigation and suppression actions. Panel a) no changes in policy and behavior; b) 25% reduction in contacts in ages 0-59 years and 50% reduction contact in ages 60+ years; c) 25% reduction in contacts in ages 0-59 years and 75% reduction in ages 60+ years; d) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years; e) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years and more efficient isolation of households members. Mitigation and suppression change giving rise to these predicted values had onset the 20th of March.*

In Figure 3 we show the same scenarios as in Figure 2 but here the mitigation and suppression measures have onset the 3rd of April instead of the 20th of March. The main visual difference in this scenario compared to Figure 1 is observed in panel d) and e) of Figure 3, where the mitigation and suppression is less effective, but still low. Numerical differences comparing Figure 2 and 3 are shown in Table 1.

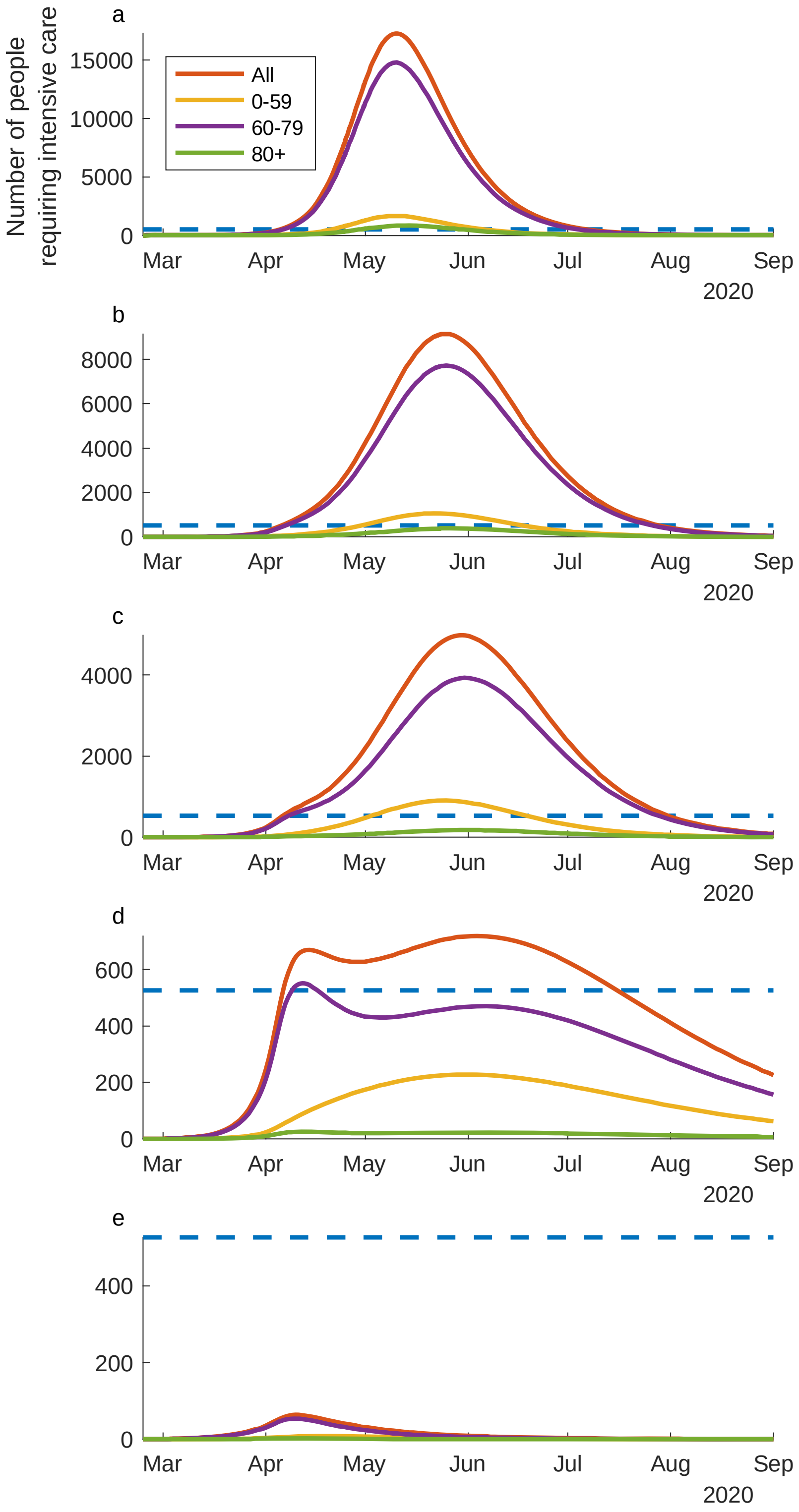
a
Number of people requiring intensive care
15000
10000
5000
0
All
0-59
60-79
80+
Mar
Apr
May
Jun
Jul
Aug
Sep
2020
b
8000
6000
4000
2000
0
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Figure 3. *The predicted intensive care demand per day from 24th of February to the 23rd of August, 2020, overall in Sweden in relationship to mitigation and suppression actions by late onset of mitigation and suppression actions the 3rd of April. Panel a) no changes in policy and behavior; b) 25% reduction in contacts in ages 0-59 years and 50% reduction in ages 60+ years; c) 25% reduction in contacts in ages 0-59 years and 75% reduction in ages 60+ years; d) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years; e) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years and more efficient isolation of household members.*

In the supplement we show how the timing of the increase in cases across the scenarios a-e of Figure 2 and 3 is somewhat sensitive to mobility between municipalities (Figure S1), with earlier increase in the critical care demand with higher inter-municipality mobility.

In Table 1 we describe the cumulative predictions of the number of people infected, the cumulative person days of care, the cumulative person days of critical care, the potential number of deaths assuming all critical care demands are satisfied, and the deaths from shortage of critical care demand assuming a limit of critical care beds at 100% above the current baseline level. Following on this, we estimate the direct costs of the care and critical care demands in Table 2.

The number of infected people in Sweden will be very high if not mitigated or suppressed, to the level of 96% attach rate (Table 1). In this situation, herd immunity will be reached around 60-70% infections and R_t will drop below 1, but still a substantial proportion will be infected beyond this threshold due to the built up momentum in the force of infection, reflecting the many infected people in the population. In the lowest suppression scenario only around 0.15% of the population will be infected. The demand on in-patient care varies from over 1,4 million person-days to just below 2000 person-days. The demand on critical care range from around 650,000 to around 600 person-days.

All of these estimates increase a bit if the mitigation and suppression is delayed 2 weeks with onset 3rd of April (Table 1). The death rates assuming no limits in the access to critical care varies from around 50,000 to 38 depending on the mitigation and suppression actions, and their timing. Assuming a cap of the critical care capacity of 100% above normal levels today, the estimated number of additional excess deaths from lack of critical care varies from 47,507 to 0 depending on the mitigation and suppression response.

Table 1*. Estimates of infections and health care demand aggregated over Sweden for the period 24th February to 23rd August, 2020.*

Mitigation and suppression actions	Cumulative number people infected	Cumulative person days in in-patient care	Cumulative person days critical care	Cumulative number of deaths assuming all critical care demands are satisfied	Cumulative number of deaths from critical care shortage
	Mitigation and suppression onset date 20th of March, 2020				
a) no changes in policy and behavior	9,633,962	1,431,681	656,043	50,695	47,507
b) 25% reduction in contacts for age groups 0-59 years and 50% reduction in ages 60+ years	8,223,160	1,147,566	499,539	35,204	31,793
c) 25% reduction in contacts in ages 0-59 years and 75% reduction in ages 60+ years	7,138,296	846,879	308,879	19,823	15,744
d) 50% reduction in contacts in ages 0-59	1,764,783	153,012	37,692	2,237	0

years and 90% reduction in ages 60+ years					
5 *e) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years and more efficient home isolation of household members.*	14,603	1,668	589	38	0
	Mitigation and suppression onset date 3rd of April, 2020				
a) no changes in policy and behavior	9,633,962	1,431,681	656,043	50,695	47,507
b) 25% reduction in contacts in ages 0-59 years and 50% reduction in ages 60+ years	8,243,602	1,152,467	502,524	35,435	32,174
c) 25% reduction in contacts in ages 0-59 years and 75% reduction in ages 60+ years	7,196,237	861,940	318,064	20,468	16,384
d) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years	3,118,228	308,292	86,754	5,117	0
5 *e) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years and*	63,569	7,326	2,592	166	0

more efficient isolation of household members.					

*assuming critical care capacity in Sweden increases by 100%, i.e. 1052 ICU beds in Sweden available for COVID-19 patients.

The total direct medical cost range between 42 billion to 44 million to SEK depending on the mitigation or suppression strategy (Table 2). The later onset of mitigation would not yield much difference in costs, but earlier onset of suppression compared later could save 151 million.

***Table 2**. Estimates direct costs of infections and health care demand aggregated over Sweden for the period 24th February to 23rd August, 2020.*

Mitigation and suppression actions	Costs of cumulative person days in in-patient care (SEK/2020)	Costs of cumulative person days in critical care (SEK/2020)	Total direct health care costs
	Mitigation and suppression onset date 20th of March, 2020		
a) no changes in policy and behavior	22,000,000,000	20,000,000,000	42,000,000,000
b) 25% reduction in contacts in ages 0-59 years; 50% reduction in contacts ages 60+ years	18,000,000,000	16,000,000,000	34,000,000,000
c) 25% reduction in contacts in ages 0-59 years; 75% reduction in contacts ages 60+ years	13,000,000,000	10,000,000,000	23,000,000,000
d) 50% reduction in contacts in ages 0-59 years and 90%	2,000,000,000	1,000,000,000	3,000,000,000

reduction in contacts ages 60+ years			
5 *e) 50% reduction in contacts in ages 0-59 years; 90% reduction in contacts ages 60+ years and more efficient isolation of household members.*	26,000,000	18,000,000	44,000,000
	Mitigation and suppression onset date 3rd of April, 2020		
a) no changes in policy and behavior	22,000,000,000	20,000,000,000	42,000,000,000
b) 25% reduction in contacts in ages 0-59 years; 50% reduction in contacts ages 60+ years	18,000,000,000	16,000,000,000	34,000,000,000
c) 25% reduction in contacts in ages 0-59 years; 75% reduction in contacts ages 60+ years	13,000,000,000	10,000,000,000	23,000,000,000
d) 50% reduction in contacts in ages 0-59 years and 90% reduction in contacts ages 60+ years	5 000,000,000	3,000,000,000	8,000,000,000
5 *e) 50% reduction in contacts in ages 0-59 years; 90% reduction in contacts ages 60+ years and more efficient isolation of household members.*	114,000,000	81,000,000	195,000,000

Discussion

Our nowcasting and forecasting estimates indicate the start of exponential growth of the number of deaths in Sweden towards the end of March and beginning of April. In the absence of prevention and control measures other than isolation of symptomatic cases, the probability of continued transmission with the projected trajectory remains high. Evidence from China indicates that in 80% of cases the disease is mild to moderate, 14% of cases have severe disease needing high-dependency wards, and 6% of cases are critical needing ventilation in intensive care units.(12) Data from Europe suggest that 30% of cases are hospitalized and 4% require critical care.(12) Under these circumstances, it seems that the health care capacity in Sweden will be strained if the epidemic continues on its projected course. The strong demand on health care resources will exceed the capacity, in particular ICU capacities, resulting in even higher case fatalities in relation. Our results also show that the demand on ICU beds can be reduced by implementing combinations of non-pharmaceutical interventions dependent upon the extent of mobility restrictions and the timing of instituting such measures. The current situation (25th of March, 2020) in Sweden is similar to Figure 2 b or c. Accordingly, we expect a peak demand of critical care between 5000-9000 per day in Sweden by May or June, respectively. The Swedish normal critical care capacity with 526 highly utilized ICU beds distributed across the regions. The capacity can likely be expanded by 50-100% in response to the emergency, or perhaps more. However, according to our analysis the normal ICU capacity risk being exceeded by more than 10 times at the peak even with strong mitigation. To prevent deaths the outbreak peak must likely be further flattened, or suppressed. Without these very stronger counter measures and substantially increased health-care capacity, Sweden experience health care demands that exceed the currently available capacity and availability, including ventilators, ICU beds, and personal protective equipment. Health care workers (HCW) are at risk of falling sick at a time when many more HCW are needed. In Italy, more than 2,000 HCW are infected, with 46 deaths in doctors by 28 March 2020. There could also be shortages of staff and space due to increased needs for triage and isolation.

Of note, due to the strong triage in our model with only 10% of those aged 80+ being allowed ICU care, the ICU demand of this group is overall already estimated to be very low.

These analyses deal with the predicted impacts from COVID-19 on the health care demand, deaths, and direct health care costs in Sweden in relation to responses. As such it is in line with the assessment of the European Center for Disease Prevention and Control regarding the COVID-19 pandemic. It does not consider other societal or economic impacts. We find that the direct health care related costs are substantial of around 20-30 billion SEK for the middle of the road mitigation scenarios. Stronger mitigation or suppression can yield large reduction in costs compard to less mitigation or suppression. These costs estimates are likely underestimating the true costs because they are only measuring the direct costs per patient per day during normal health care demand in 2018. Further on, the costs of the health sector would need to be balanced to the cost of the economy as a whole. The estimates here does not capture impacts within the health care from other acute health problems which treatment is down prioritized or postponed due to the acute situation of the epidemic. We do not value the deaths overall using the societal willingness to pay for reducing risks.

Our analyses builds on state-of-the-art knowledge on COVID-19 and makes informed estimates of the quantitites studied for a period of 6 months. However, there are many uncertainties and the analyses may need to be revisited as information and knowledge develops. For example, the role of seasonality in the transmission of the virus is not well understood, nor considered here. Some studies has suggested a potential for a very high proportion of asymptomatic transmission, but there is no concrete support for this claim in areas where frequent testing is conducted(7),(8). Preliminar findings from Iceland found no more than 50% asymptomatic carriers. High fatality rate per population affected is documented in various places, including villages in Italy, where the death rates due to COVID-19 in whole village populations has been observed to 0.8%. In this situation with the denominator as the whole village population, this estimate is the absolute lowest limit of the case fatality rate, equaling the IFR if all village population was infected. This strongly indicates that underreporting, or asymptomatic transmission, is not a strong driver of herd-immunity. However, this need to be further investigaged in serological studies.

Health care demand and mortalities could be substantial from COVID-19 in Sweden in the next months. A strong suppression strategy followed by containment, including social distancing, and testing, as recommended by the WHO, could reduce the impacts on the health care demand and the public health substantially (13). However, it would need to consider impacts on other sectors in the society which are not covered here, potential resurge as measures are relaxed.

Overall, given the potential health and economic impacts estimated in our study we find early action to suppress the outbreak before it has been established and by so containing transmission, a preferable option. This includes a range of containment activies which need to be triggered very early, and specifically testing, contact tracing and isolation of cases and families with suspected disease, an effective response measure, as has previously been reported (14).

Conflict of interest statement

None declared

References

1. Wilder-Smith A, Freedman DO. Isolation, quarantine, social distancing and community containment: pivotal role for old-style public health measures in the novel coronavirus (2019-nCoV) outbreak. J Travel Med. 2020.
2. Korean Society of Infectious D, Korean Society of Pediatric Infectious D, Korean Society of E, Korean Society for Antimicrobial T, Korean Society for Healthcare-associated Infection C, Prevention, et al. Report on the Epidemiological Features of Coronavirus Disease 2019 (COVID-19) Outbreak in the Republic of Korea from January 19 to March 2, 2020. J Korean Med Sci. 2020;35(10):e112.
3. Covid-19 National Emergency Response Center E, Case Management Team KCfDC, Prevention. Contact Transmission of COVID-19 in South Korea: Novel Investigation Techniques for Tracing Contacts. Osong Public Health Res Perspect. 2020;11(1):60-3.
4. Lee VJ, Chiew CJ, Khong WX. Interrupting transmission of COVID-19: lessons from containment efforts in Singapore. J Travel Med. 2020.
5. Livingston E, Bucher K. Coronavirus Disease 2019 (COVID-19) in Italy. JAMA. 2020.
6. Flahault A. COVID-19 cacophony: is there any orchestra conductor? Lancet. 2020;online.
7. Ferguson AD. Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand. 2020.
8. Nishiura H, Kobayashi T, Suzuki A, Jung SM, Hayashi K, Kinoshita R, et al. Estimation of the asymptomatic ratio of novel coronavirus infections (COVID-19). Int J Infect Dis. 2020.
9. Zou L, Ruan F, Huang M, Liang L, Huang H, Hong Z, et al. SARS-CoV-2 Viral Load in Upper Respiratory Specimens of Infected Patients. N Engl J Med. 2020.

10. Atlani-Duault L, Ward JK, Roy M, Morin C, Wilson A. Tracking online heroisation and blame in epidemics. Lancet Public Health. 2020.
11. Liu Y, Gayle AA, Wilder-Smith A, Rocklov J. The reproductive number of COVID-19 is higher compared to SARS coronavirus. J Travel Med. 2020.
12. Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19) [Available from: https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf.
13. Coronavirus: three things all governments and their science advisers must do now. Nature. 2020;579(doi: 10.1038/d41586-020-00772-4):319-20.
14. Koo ea. Inteventions to mitigate early spread of SARS-COV-2 in Singapore: a modelling study. Lancet Infectious Disease. 2020.

Supplementary Information

To account for time delays in the spatial spread of SARS-CoV-2 over the large geographical ranges in Sweden, we set up a spatial compartmental model. We distinguish between local (municipality) and global (Sweden) processes. The effects of local contact structures are assumed to be well described by the law of mass action; at local scales we assume a well-mixed contact-structure. The effects of global contact structures are assumed to be well described by a radiation model[1], which gives rise to time delays in the spatial progression of infections over Sweden.

We apply an age-structured SEIR-based compartmental model for each municipality. In each municipality i, we account for all individuals that are susceptible S_i; latent (exposed) E_i; infectious but not requiring health care I_i; infectious and requiring health care J_i; in health care H_i; in critical care C_i; recovering in health care after critical care $\widetilde{H}_i$; dead due to SARS-CoV-2 infection D_i; or, recovered R_i. Each respective variable is age-structured (i.e., vectors with age-specific component values). We account for three age-classes, $a = (0-59, 60-79, 80+)$ years. The compartmental model, with dot-notation for time derivatives, can then be written

$$
\begin{aligned}
\dot{S}_i &= -\beta\left(\frac{S_i\left(1-\sum_{j\neq i} t_{ji}\right)\left(\left(\sum_a (I_i+J_i)\right)+\sum_{i\neq j}\langle T_I\rangle_{ij}-\sum_{j\neq i}\langle T_I\rangle_{ji}\right)}{N_i}\right.\\
&\qquad\qquad \left. + S_i\sum_{j\neq i}\frac{t_{ji}\left(I_j+J_j\right)}{N_j}\right)\\
\dot{E}_i &= \beta\left(\frac{S_i\left(1-\sum_{j\neq i} t_{ji}\right)\left(\left(\sum_a (I_i+J_i)\right)+\sum_{i\neq j}\langle T_I\rangle_{ij}-\sum_{j\neq i}\langle T_I\rangle_{ji}\right)}{N_i}\right.\\
&\qquad\qquad \left. + S_i\sum_{j\neq i}\frac{t_{ji}\left(I_j+J_j\right)}{N_j}\right)-\frac{E_i}{p_E}\\
\dot{I}_i &= \frac{E(1-\epsilon_i)}{p_E}-\frac{I_i}{p_I}\\
\dot{J}_i &= \frac{E\epsilon_i}{p_E}-\frac{J_i}{p_J}\\
\dot{H}_i &= \frac{(1-\chi_i)J_i}{p_J}-\frac{H_i}{p_H}\\
\dot{C}_i &= \frac{(1-\tau)\chi_i J_i}{p_J}-\frac{C_i}{p_C}\\
\dot{\tilde{H}}_i &= \frac{(1-\mu)}{p_C}C_i-\frac{\tilde{H}_i}{p_{\tilde{H}}}\\
\dot{D}_i &= \frac{\mu}{p_C}C_i+\frac{\tau\chi_i J_i}{p_J}\\
\dot{R}_i &= \frac{I_i}{p_I}+\frac{H_i}{p_H}+\frac{\tilde{H}_i}{p_{\tilde{H}}}
\end{aligned}
\qquad \text{S.1}
$$

where $N = S_i + E_i + I_i + J_j + R_i$, and see table S1 for model parameterization. Infection are carried between municipalities, and $\langle T_I\rangle_{ij}$ denotes the number per day of infected individuals that are resident to the jth municipality and are visiting the ith municipality; $S_i\sum_{j\neq i} t_{ji}$ denotes the number per day of susceptible individuals that are resident to the ith municipality and are visiting other municipalities. This should be seen as daily averages. These mobility rates are given by a radiation model[1], where we used the time dependent rate scaling $\alpha(t)$, with 0.01 as the baseline, i.e., the counter-scenario of inter-municipality travel-reductions. The radiation model for the average number (denoted by angle-brackets) of travellers per day of X_i, from municipality i to municipality j, can be written $\langle T_X \rangle_{ji} = X_i t_{ji}$, with the per person travel-probability

$$t_{ji} = \alpha(t) \frac{n_i n_j}{(n_i + s_{ji})(n_i + n_j + s_{ji})},$$

where n_i is the number of citizens in municipality i; where s_{ji} is the total population size within a circle with a radius equal to the distance between two municipalities i and j. Note that t without subscript denotes time. See table S1 for $\alpha(t)$.

Population data was collected from the Swedish Statistics and the demographical geographical statistical units' database. The database provides population data in 5-year age categories for almost 6,000 different regions in Sweden and was compiled by the end of 2018. Data was then aggregated to the municipal level in 10-year age-groups.

The municipality level age-classes distribution was derived by first aggregating the population data of 5-year age categories into 10-year age categories and was then grouped into thress age classes, that is, 0-59, 60-79 and 80 above, respectively to extract the model parameters according to the Ferguson et al.[2] for UK study of SARS-CoV-2. The geographical coordinates at municipality levels were obtained using the R software libraries (sp, rgdal, rgeos, foreign) by converting the shape files data from statistical units' database into the latitude-longitudes of all 290 Swedish municipalities. The coordinates data was then used to calclulate the distance matrix for the municipalities in order to obtain inter-municipality travel rates of the radiation model.

Table S1. Parameters in equation system S.1 and their respective values.

Parameter	Notation and value	Notes	Unit
Age-classes	$a = (0-59, 60-79, 80+)$		Years
Time-dependent transmission rate	$\beta = 0.6\, c(t)$		Days^{-1}
Latent period	$p_E = 4$		Days
Infectious period	$p_I = 5$		Days
Pre-hospitalization infectious period	$p_J = 3$		Days
Hospitalization period	$p_H = 7$		Days
Critical-care period	$p_C = 12$		Days
Post critical-care period	$p_{\tilde{H}} = 7$		Days
The proportion of infected cases requiring hospitalization	ϵ_i	See table 2 for age structured values	
The proportion of hospitalized cases requiring critical care	χ_i	See table 2 for age structured values	
The proportion in critical care that dies	$\mu = (0.2, 0.49, 0.49)$		
Triage proportion	$\tau = (0, 0, 0.9)$		
Time-dependent contact rate	$c(t) = c_0\left(\frac{1-\hat{c}}{1+\exp\left(5(t-\hat{t})\right)} + \hat{c}\right)$	Contact rate reduced to $\hat{c}$ around time $\hat{t}$ with $c_0 = (1, 1, 0.5)$ for ages (0-59, 60-79, 80+).	Days^{-1}
Time-dependent inter-municipality travel-rate scaling	$\alpha(t) = \alpha_0\left(\frac{1-\hat{\alpha}}{1+\exp\left(5(t-\hat{t})\right)} + \hat{\alpha}\right)$	Travel rate reduced to $\alpha_0\hat{\alpha}$ around time $\hat{t}$; with $\alpha_0 = 0.01$ (or $\alpha_0 = 0.02$ for the sensitivity	Days^{-1}

		analysis).	
Contact rate scaling (reduction)	$\hat{c}$	This parameter was used to test for changes in the degree of age-dependent social distancing.	Days^{-1}
Travel rate scaling (reduction)	$\hat{\alpha}$	This parameter was used to test for changes in the degree of inter-municipality travel.	Days^{-1}

Drawing on age-structured data[2] (TableS2), we derived the corresponding *proportion of infected cases requiring hospitalization* for age-classes $a = (0-59, 60-79, 80+)$ by assuming only 1/3 of infections would yield symptomatic disease rendering risk of hospital care. We took a weighted average for each age-class in a. We also derived the *proportion of hospitalized cases requiring critical care* by the weighted averaging. Note that we further assumed a 90% critical-care triage for the ages 80+ years.

Table S1. Conditional risks for in-patient care and critical care

Age-class (years)	Percent of reported cases requiring in-patient care	Percent of in-patient cases requiring critical care
0-9	0.1	5.0
10-19	0.3	5.0
20-29	1.2	5.0
30-39	3.2	5.0
40-49	4.9	6.3
50-59	10.2	12.2
60-69	16.6	27.4
70-79	24.3	43.2
80+	27.3	70.9

The influence of between municipality mobility

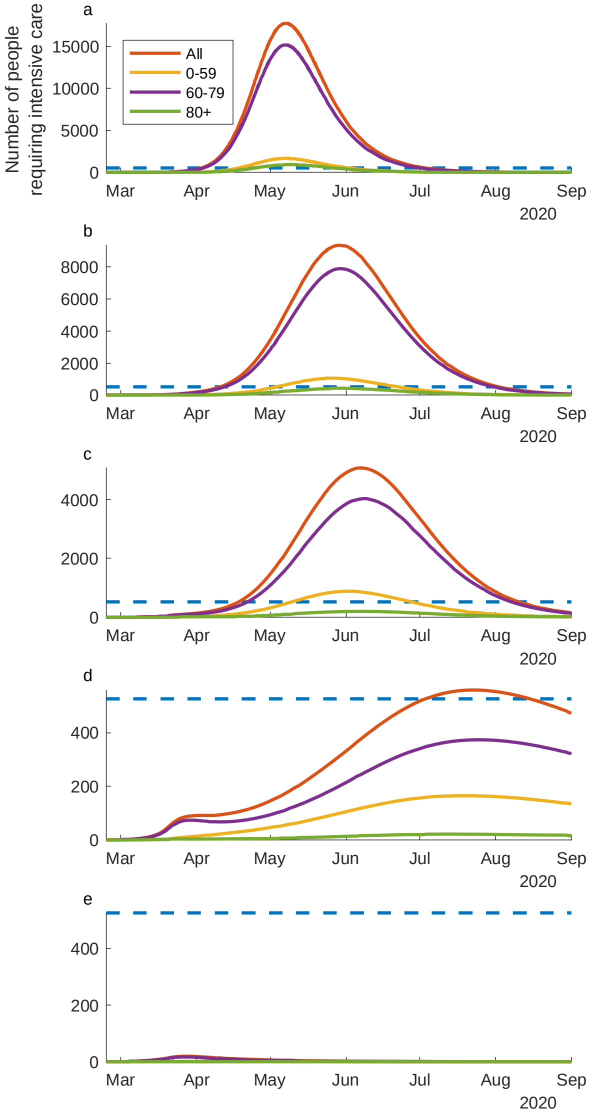

Figure S1. *The model assumes the mobility between municipalities is doubling and shows the predicted intensive care demand per day from 24th of February to the 23rd of August, 2020, overall in Sweden in relationship to mitigation and suppression actions by late onset of mitigation and suppression actions the 3rd of April. Panel a) no changes in policy and behavior; b) 25% reduction in contacts in ages 0-59 years and 50% reduction in ages 60+ years; c) 25% reduction in contacts in ages 0-59 years and 75% reduction in ages 60+ years;*

d) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years; e) 50% reduction in contacts in ages 0-59 years and 90% reduction in ages 60+ years and more efficient isolation of familes.

Cost estimates

The cost estimates were retrieved using Cost per Patient (CPP) database that reports costs for every individual care event. The database use Diagnose Related Group (DRG) to group the care events to be able to report costs that describe well the average costs at a group level. The database provides average time in care and the average costs per care event. More information on the database: https://statva.skl.se/SKL_KPP_information.html

Average treatment costs calculation for inpatient care

To account the costs per day in care, we used costs reported under following diagnose codes S.40 Virus infection; Main diagnoses: B.349 Virus infection, unspecified; J.108 Influenza due to other identified influenza virus with other manifestation. Average cost per day was calculated dividing the total cost with average number of days spent in care.

Average treatment costs calculation for ICU care

To calculate the ICU care all costs reported under respiratory diseases (D.20) receiving invasive ventilation treatment were extracted from database and divided by average number of days for treatment to calculate the average cost per day.

For both inpatient and ICU care cost estimates the total average cost for all age groups reported in 2018 was used to calculate the costs. All cost estimates are adjusted for consumer price index and reported in 2020 SEK value. Cumulative patient days were multiplied with the average cost estimates for inpatient care and ICU care.

The Sweden Intensive Care Register Yearly Rapport 2018 estimates that an average cost per day in intensive care lies between 50 000 – 80 000 SEK, which is a higher estimate than the one we are using. This suggests that we may underestimate some treatment costs e.g., because some patients with COVID-19 will receive extracorporeal membrane oxygenation-treatment, which is more resource heavy as comaped with ventilation treatment.

References

1. Simini, F., González, M.C., Maritan, A. & Barabási, A.-L. (2012). A universal model for mobility and migration patterns. *Nature*, 484, 96–100.

2. N Ferguson, et al. Impact of non-pharmaceutical interventions (npis) to reduce covid-19 mortality and healthcare demand. DOI: https://doiorg/1025561/77482 2020.