Analysis of the Spread of COVID-19 and Effectiveness of Containment Strategies

Case study of Germany

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The following slides presents an analysis of the spread of COVID-19 in Germany, and the effects of different containment strategies.

Details of the mathematical model and how the parameters of the model are estimated from the available data on the spread of COVID-19 is explained in:
`https://people.tuebingen.mpg.de/vbokharaie/Estimating_Covid19_contact_rates.pdf`

The following few slide provides enough information to make the presented figures understandable.

- The model deals with a population divided into age groups. Age groups are set to be $[0, 10), [10, 20), \cdots, [70, 80)$ and $80+$.
- **Contact rate** is a parameter in the model that captures the average share of individuals in one age group in transferring the disease to individuals in another age group. Hence in a model with 9 age groups, we need 81 of such values. How to estimate these values such that it matches the real-world data on the spread of COVID-19 is what is explained in the manuscript mentioned in the previous slide.
- It should be noted that the presented method can be used to estimate contact rates in every population whose age distribution in the age groups are known (which includes every country). Germany is used as a case study in the following slides.

SIS and SIR models

Since it is still not fully known if COVID-19 infers immunity in a population, I have presented all the results under two different assumptions: When humans are immune to COVID-19 once they catch the disease and recover from it (SIR Model) and when they are not immune to it (SIS Model).

The next slide shows the uncontained spread of COVID-19 in each age group when individuals do not have immunity to the virus after recovery, i.e. SIS case. It is assumed that initially, 0.1% of each age group is infected with the virus. It is assumed that the average time that each infected individual can transfer the virus to others is 20 days. Also, basic reproduction number, defined as below, is $R_0 = 2.28$.

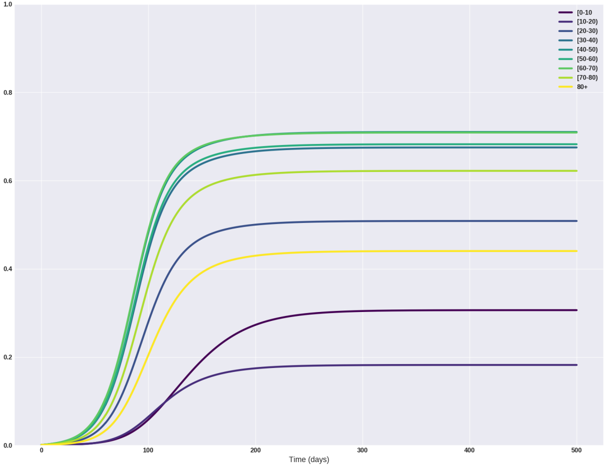
Definition 2.1 (Basic reproduction number).

The basic reproduction number is the expected number of secondary cases produced, in a completely susceptible population, by a typical infective individual during its entire period of infectiousness.

Please note that in all the plots, x-axis is time in days and all x-axes limits are $[0, 500]$ *days, even when plots converge to a steady state value much sooner than that. And in all the figures, y-axis is the ratio of the infectives in age groups or in the whole population, and all y-axes limits are set to* $[0, 1]$*.*

SIS Model — No Immunity after recovery

Ratio of infectives in each age group



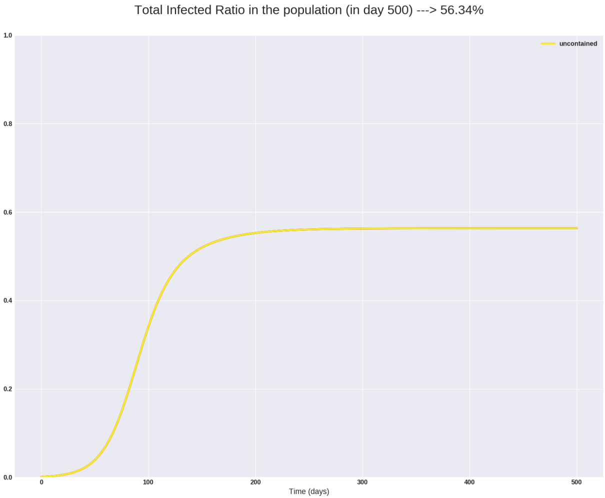
The following slide shows the ratio of infective individuals in the total population.

Remark 2.1.

When there is no immunity to the virus and $R_0 > 1$*, the trajectory tends to the so-called endemic equilibrium, and a ratio of the population would always be infected with the virus. If* $R_0 < 1$*, the trajectory would tend towards the disease-free equilibrium and the disease dies out.*

SIS Model — No Immunity after recovery

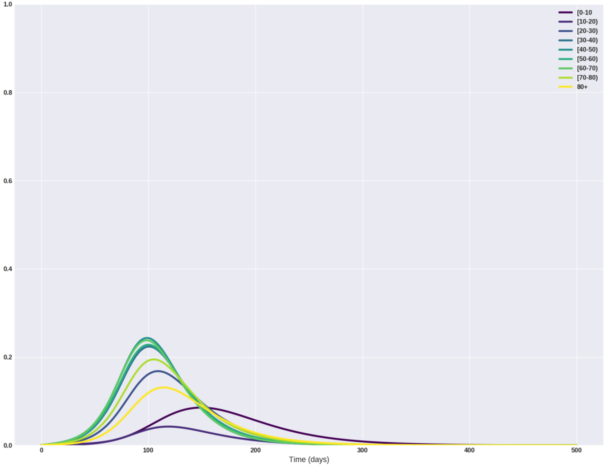
Ratio of infectives in the whole population.



When individuals naturally gain immunity to the virus, or (hopefully) with the help of a vaccine, then the ratio of infectives in each age group reaches a peak and starts to decrease, as shown in the next two slides.

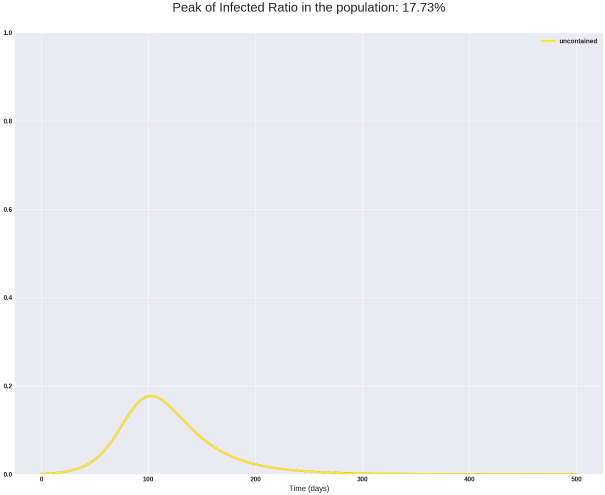
SIR Model — with Immunity after recovery

Ratio of infectives in each age group



SIR Model — with Immunity after recovery

Ratio of infectives in the whole population.

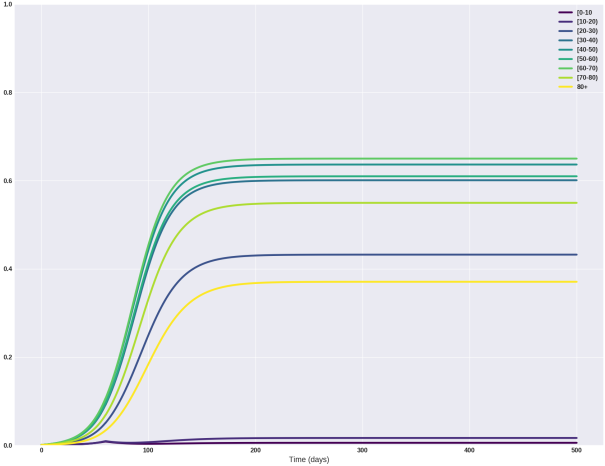


Closing down the schools

Now let's assume that to contain the spread of the virus, we close all the schools. I have considered it as a 10-fold decrease in the interactions of age groups $[0, 10)$ and $[10, 20)$ with other age groups. Applying that change to the contact rates would alter the value of R_0 from 2.28 to 2.18. The following slides shows the effects of such a change. The uncontained aggregate curves are also included as a point of reference.
In all the scenarios discussed in this section, I have assumed that initially, 0.1% of each age group is infected with COVID-19. The virus spreads in the population uncontained for 60 days, and then the containment strategy is enforced. These initial conditions are good enough to highlight the qualitative differences of different strategies.

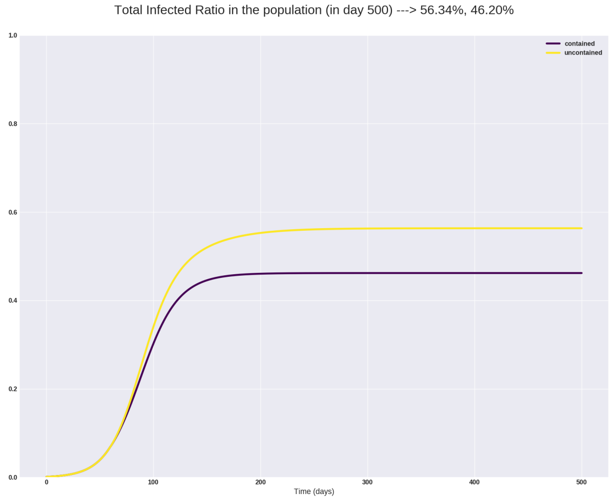
SIS Model — No Immunity after recovery

Ratio of infectives in each age group



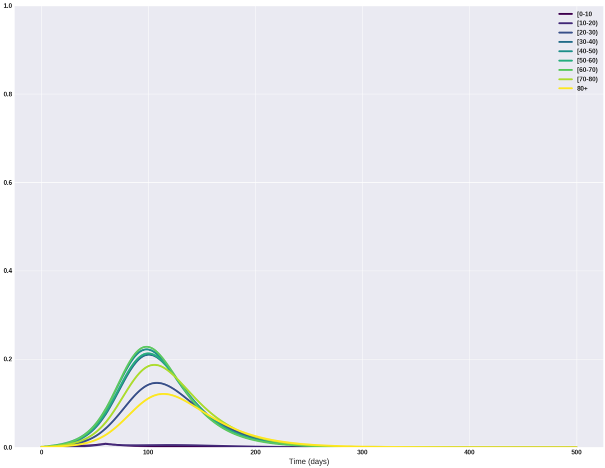
SIS Model — No Immunity after recovery

Ratio of infectives in the whole population.



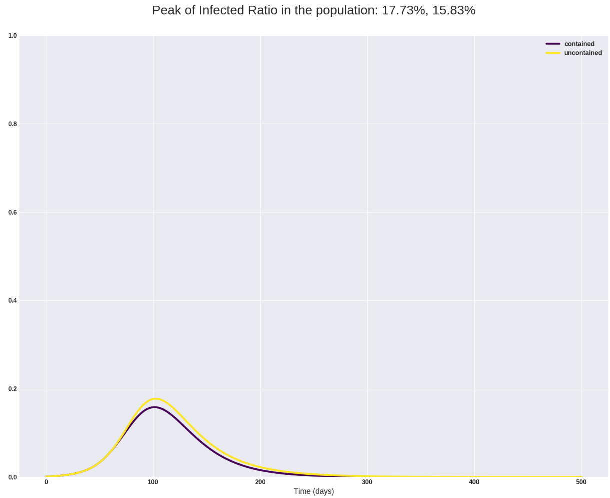
SIR Model — with Immunity after recovery

Ratio of infectives in each age group



SIR Model — with Immunity after recovery

Ratio of infectives in the whole population.

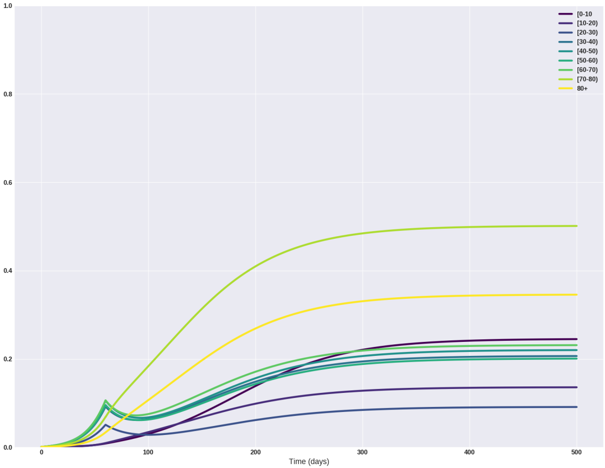


Adults self-isolating

If only adults in $[20-70)$ age-range are forced to self-isolate, equivalent to 5-fold decrease in their interactions with other age groups and without any isolation policy for people younger than 20 or older than 70, the spread of the virus changes more significantly, compared to the previous case. This would reduce the $R0$ to 1.47.

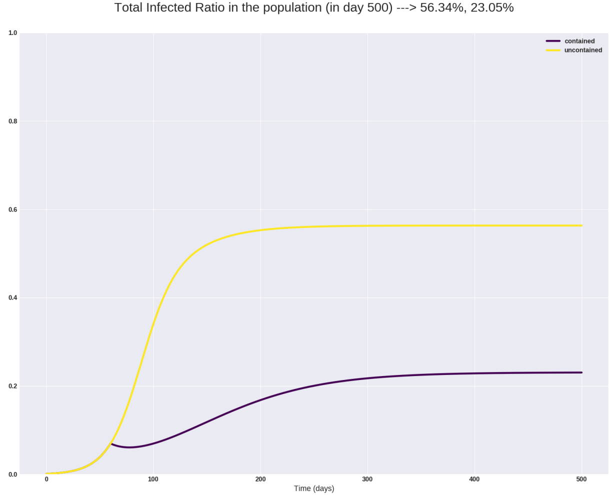
SIS Model — No Immunity after recovery

Ratio of infectives in each age group



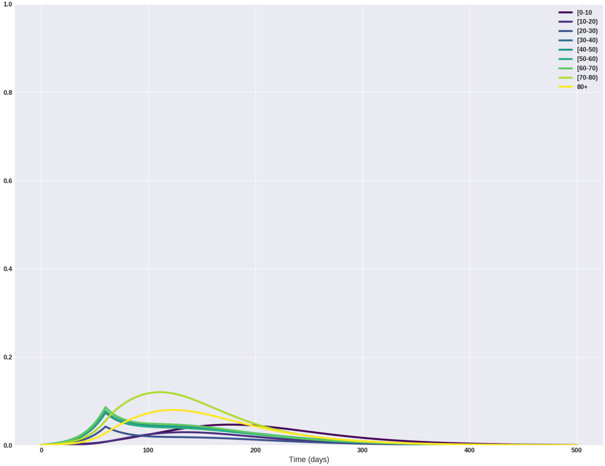
SIS Model — No Immunity after recovery

Ratio of infectives in the whole population.



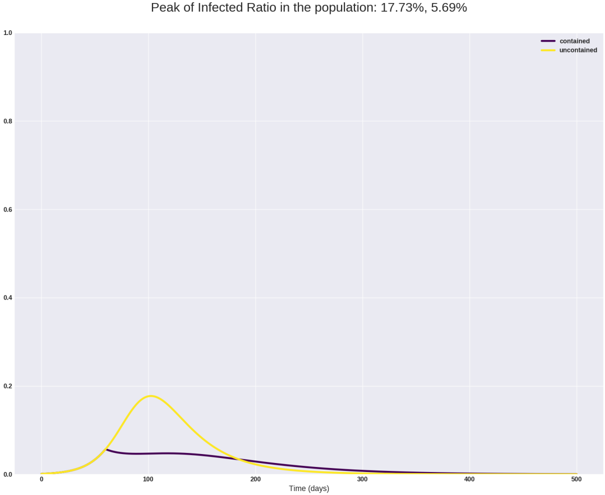
SIR Model — with Immunity after recovery

Ratio of infectives in each age group



SIR Model — with Immunity after recovery

Ratio of infectives in the whole population.

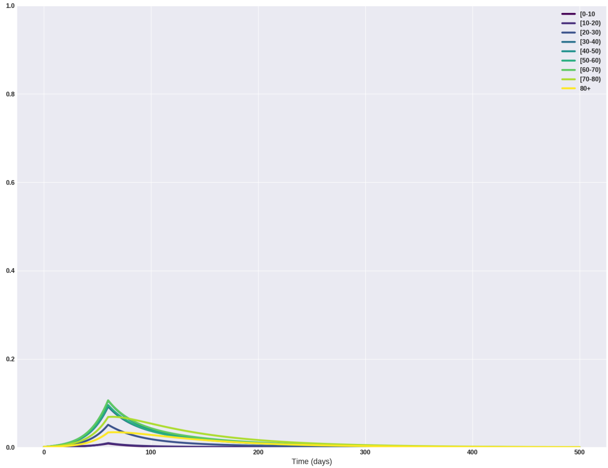


Whole Country in Lock-down

In this scenario, the contact rates for individuals younger than 20 is divided by 10, for adults in 20-70 age range by 5, and for people older than 70 by 2. This will bring the R_0 down to 0.77, which means the disease would die out even in SIS case.

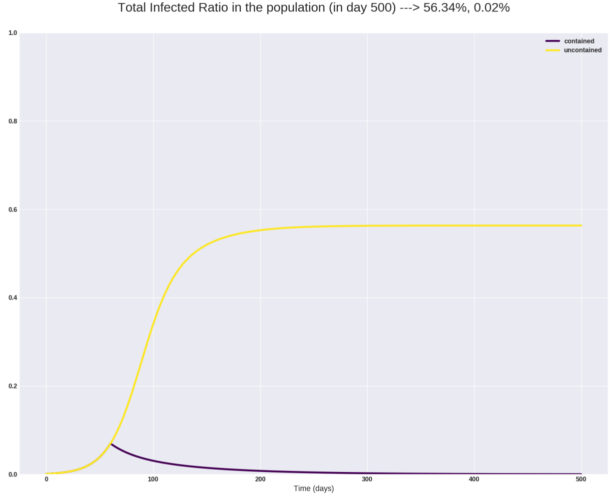
SIS Model — No Immunity after recovery

Ratio of infectives in each age group



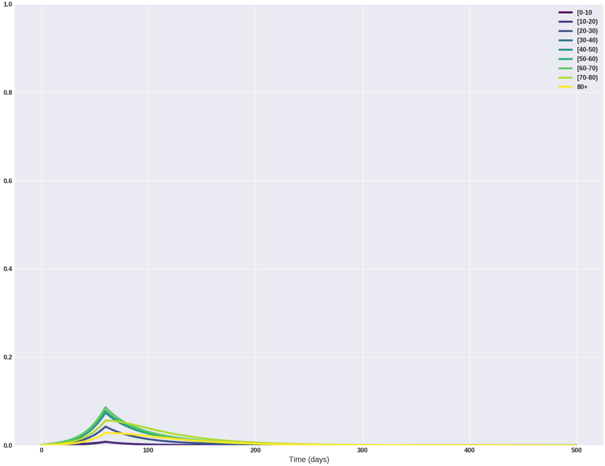
SIS Model — No Immunity after recovery

Ratio of infectives in the whole population.



SIR Model — with Immunity after recovery

Ratio of infectives in each age group



SIR Model — with Immunity after recovery

Ratio of infectives in the whole population.