COVID-19 Simulation Studies

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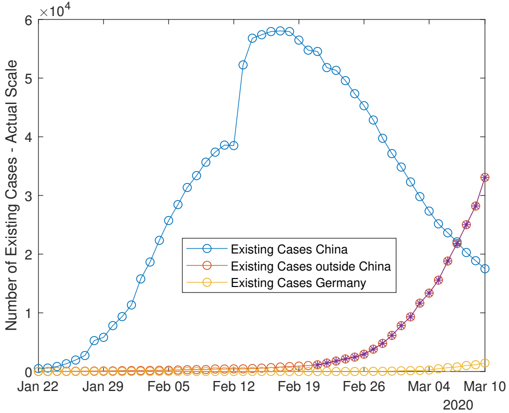
Outline

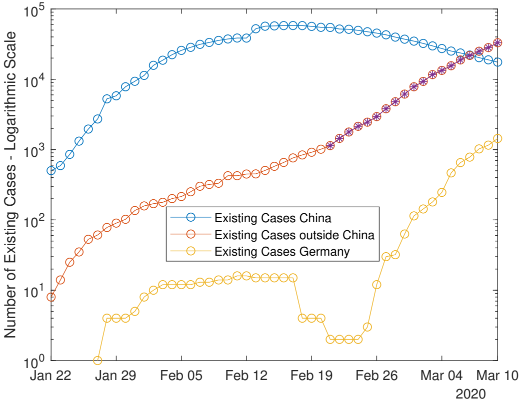
- The purpose of this exercise is to analyze a simple SIR infection model adapted to the recent outbreak of the novel Coronavirus disease 2019 (COVID-19).
- The standard SIR infection model is a classical deterministic model in epidemiology originally suggested in the 1920s.
- The SIR model consists of two coupled ODEs and can easily be implemented by undergraduate or interested high school students.
- We fit the baseline model using the exponential initial period of the infection and analyze several comparative case studies.
- The corresponding MATLAB code is available on our website `www.insurance.uni-hannover.de`.

Outline

- All projections in this study involve a **high level of uncertainty**:
    - The SIR model is a simple aggregate model with constant parameters that ignores many features of any real-world epidemic.
    - The amount of currently available data is limited; available data are also not fully reliable.
    - The epidemic dynamic is influenced by many unknown factors, including the future actions of the population, governments and the media, etc. These are ignored in a simple SIR model.

Outbreak Data





- Absolute number of existing (=confirmed-deaths-recovered) COVID-19 infections in China and in other locations worldwide (data provided by Johns Hopkins CSSE (2020)).
- The SIR model will be fitted to the data points marked with purple asterisks.

SIR Model

- The standard **SIR** (**S**usceptible-**I**nfected-**R**emoved) model is based on the ODEs

$$\frac{\partial}{\partial t} S(t) = -\alpha S(t) I(t), \qquad \frac{\partial}{\partial t} I(t) = \alpha S(t) I(t) - \beta \cdot I(t)$$

  with infection/transmission rate α and recovery rate $\beta = 1/T_I$ (where T_I denotes the average time an infected individual remains infectious before recovery or removal).

  $S(t)$ and $I(t)$ denote the proportions of individuals in the population that are susceptible or infected.

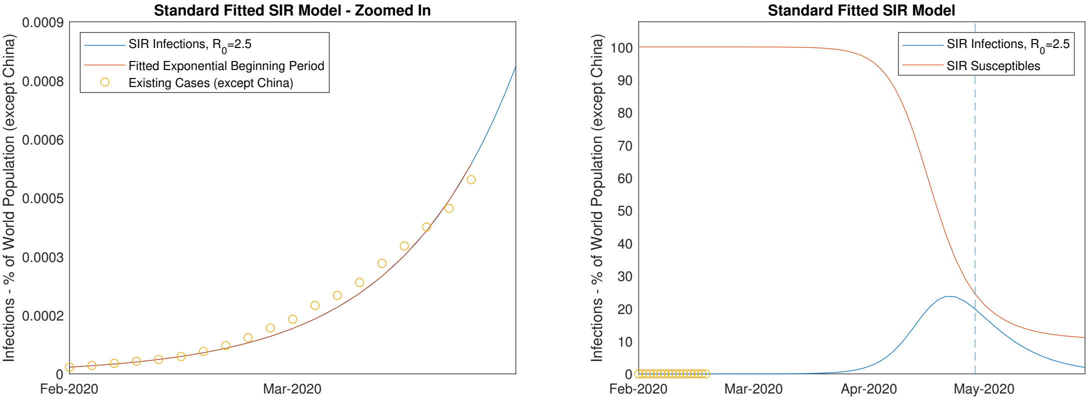
- The SIR model behavior is characterized by its basic reproduction number $R_0 = \frac{\alpha}{\beta}$.
  → An epidemic occurs if and only if $R_0 > 1$.

- We set
  - $N = 6.5 \cdot 10^9$ (estimate of world population size outside China),
  - $I(0) = 1139/N$ ($1139 =$ number of existing cases outside China on Feb. 21), $S(0) = 1 - I(0)$,
  - $\beta = 1/8$ (mean infection duration: 8 days (cf. Maier & Brockmann, Robert Koch Institute (2020))),

  and approximate α by fitting the initial exponential growth parameter $\varepsilon = \alpha - \beta$.

  [For $t \approx 0$, the infection dynamics are approximately described by $\frac{\partial}{\partial t} I(t) = (\alpha - \beta) I(t)$.]

Fitted SIR Model Results



Standard Fitted SIR Model - Zoomed In

Standard Fitted SIR Model

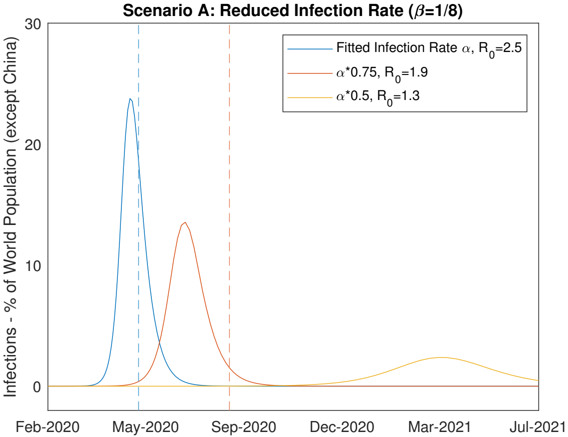
Evolution of proportions of infected and susceptible individuals in the SIR model. The vertical blue line in the right figure indicates when the cumulative proportion of infected individuals reaches 75% of the population.

Fitted SIR Model Results (2)

- The left figure shows the initial exponential evolution in the SIR model that is fitted to the selected data points (outside China).
- The right figure displays the evolution of the proportions of infected (blue) and susceptible (red) individuals in the SIR model over time.

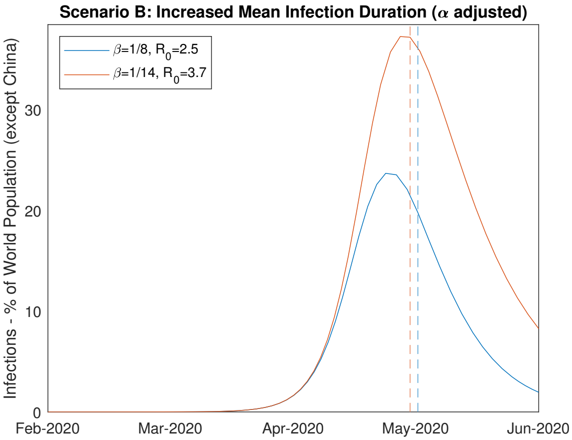
- Next, we vary the parameters of the SIR benchmark in three additional case studies:
  - **A** The recovery rate is set to $\beta = 1/8$ as in the previous case study. Denoting the fitted infection rate by α, we compare the evolution for infection rates α, $0.75 \cdot \alpha$ and $0.5 \cdot \alpha$.
  - **B** We vary the recovery rate and consider $\beta = 1/8$ and $\beta = 1/14$.
  - **C** We vary the initial exponential growth parameter to which we fit the model.

Case Study A: Reduced Infection Rate α



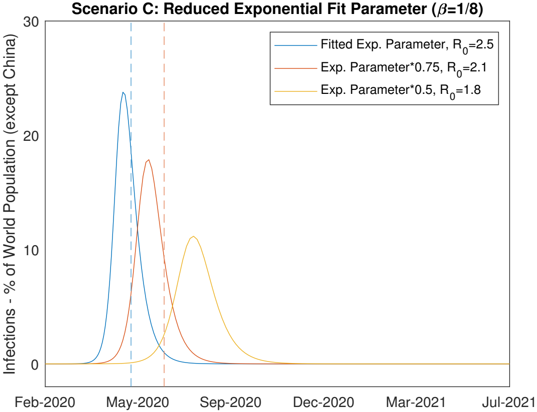
Case studies for varying infection rate and constant recovery rate $\beta = 1/8$. Vertical lines indicate when the cumulative proportion of infected individuals reaches 75% of the population for infection rates α and $0.75 \cdot \alpha$, respectively. For an infection rate $0.5 \cdot \alpha$, the infection affects approximately 39% of the population in total before it disappears.

Case Study B: Increased Mean Duration



SIR dynamics for varying mean duration $1/\beta$; the rate α is adjusted on the basis of the selected data. Vertical lines represent the points in time, when the infection has hit 75% of the population.

Case Study C: Reduced Exponential Fit Parameter

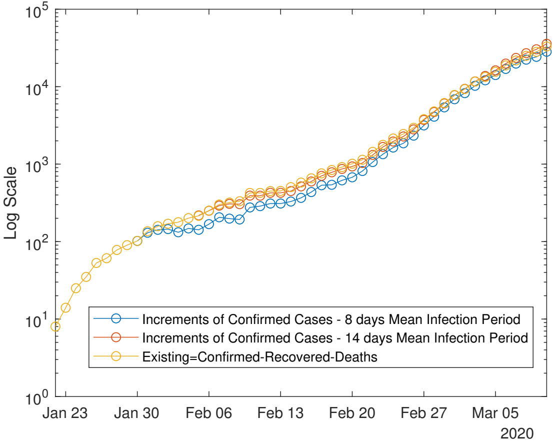


SIR dynamics for reduced initial exponential growth parameter $\varepsilon = \alpha - \beta$ and constant $\beta = 1/8$. Vertical lines indicate when the cumulative proportion of infected individuals reaches 75% of the population. In the scenario *0.5, the cumulative proportion of infected individuals equals approximately 72% before it disappears.

Case Study Results

- Decreased infection rates reduce the maximal number of simultaneous infections and prolong the duration of the epidemic.
- For the same initial exponential growth parameter, an increased mean duration is associated with larger numbers of simultaneously infected individuals.
- The selected data points were used for fitting the initial exponential growth parameter ε. If ε was smaller, this would reduce the maximal number of simultaneous infections and prolong the duration of the epidemic.

Alternative Way to Count Existing Cases

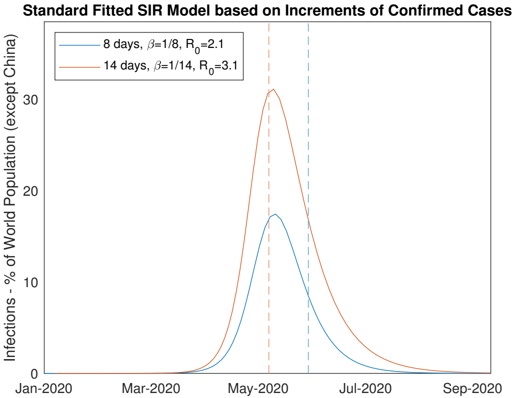


Increments of the number of confirmed cases for mean infection duration of 8 and 14 days vs. calculated existing cases (outside China).

Alternative Way to Count Existing Cases (2)

- Due to potential inaccuracies in the time series of the number of recovered individuals, we study an alternative methodology to count the existing cases:
    - On the basis of the time series of confirmed cases, we compute increments for mean infection durations of 8 and 14 days, respectively. These increments are used as an estimate of existing cases.
    - The SIR model is then fitted to the new time series of existing cases.

Fitted SIR Model - Alternative Way to Count Existing Cases



SIR dynamics for varying mean duration $1/\beta$; the rate α is computed on the basis of the adjusted selected data. Vertical lines indicate when the cumulative proportion of infected individuals reaches 75% of the population.

References

- Johns Hopkins University CSSE, 2020, CSSEGISandData/COVID-19, https://github.com/CSSEGISandData/COVID-19, accessed: March 11, 2020
- B. Maier & D. Brockmann, 2020, Robert Koch Institute, Effective containment explains sub-exponential growth in confirmed cases of recent COVID-19 outbreak in Mainland China, https://arxiv.org/abs/2002.07572v1, accessed: March 9, 2020