Comparison of COVID19 policies using a SIR-model

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Background

• COVID19 can be analyzed using a SIR-model
  – In the SIR-models the population is compartmentalized into susceptible-, infected- and recovered compartments
• Different strategies have been used to contain the spread of COVID19
  – Policy = Any non-pharmaceutical intervention (NPI) against COVID19
  – Example policies
    • Lockdowns
    • Distancing
    • Online teaching
Objective

- Use a SIR-model to compare COVID19 policies in countries
- Fit SIR-model to (weekly) data of Finland, France, Italy and Sweden (ECDC data)
- Government response data set
  - Contains a list of tracking policy changes in the countries
- Compare the COVID19 situation in the countries
Limitations

• Testing rates are not taken into account
• Government response data set is simple
  – Policies are also implemented at the same time
  – Only general insights of the policies are gained
• Economic outcomes excluded from the analysis
• Vaccination also excluded
SIR-model

\[
\begin{align*}
\Delta s(t + 1) &= -\beta s(t)i(t), \\
\Delta i(t + 1) &= \beta s(t)i(t) - \gamma i(t), \\
\Delta r(t + 1) &= \gamma i(t),
\end{align*}
\]

(4) (5) (6)

where \( s \), \( i \) and \( r \) are susceptible, infected and recovered proportions of the population, \( \beta \) is the rate of transmission and \( \gamma \) is the rate of recovery

- If \( D \) is the infectious period = time until recovery, then \( \gamma = 1/D \)
- Expected new infections resulting from one infected := Basic reproduction number \( R. \)
- \( R = \beta / \gamma \)
Fitting the SIR-model

- The rate of transmission is estimated for consecutive time intervals
  - Time intervals chosen visually and based on policy changes (during the times)
- Rate of recovery constant (1/2 weeks, since $D=2$ weeks)
- Fit using sum of least squares estimation
- Time period: 52 weeks of 2020 (before vaccination)
Estimation

• Minimize the loss function

\[ l(\hat{\beta}) = \sum_t (i(t) - \hat{i}(t))^2. \]

where \( \hat{i} \) is the fitted infected proportion of the population

• Optimal solution obtained by the following procedure:

\[
\hat{\beta}^+ = \hat{\beta}_n + d, \\
\hat{\beta}^- = \hat{\beta}_n - d, \\
\hat{\beta}_{n+1} = \text{argmin}_{\hat{\beta}}(\{l(\hat{\beta}^+), l(\hat{\beta}^-)\}),
\]

where \( \beta_n \) is the \( n \)th estimate, \( d \) is the stepsize

• Iterate for a long time or until improvements are tiny
## Results: Estimated coefficients

Table 1: Estimated rate of transmission $\hat{\beta}$ of different countries at varying time intervals

<table>
<thead>
<tr>
<th></th>
<th>Finland</th>
<th></th>
<th>France</th>
<th></th>
<th>Italy</th>
<th></th>
<th>Sweden</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Interval</td>
<td>$\hat{\beta}$</td>
<td>Interval</td>
<td>$\hat{\beta}$</td>
<td>Interval</td>
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<td>Interval</td>
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<tr>
<td>5-12</td>
<td>1.900</td>
<td>9-13</td>
<td>3.679</td>
<td>5-12</td>
<td>3.553</td>
<td>10-16</td>
<td>1.353</td>
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<tr>
<td>13-15</td>
<td>0.900</td>
<td>14-25</td>
<td>0.300</td>
<td>13-17</td>
<td>0.380</td>
<td>17-22</td>
<td>0.500</td>
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<tr>
<td>16-19</td>
<td>0.400</td>
<td>26-38</td>
<td>0.800</td>
<td>18-20</td>
<td>0.200</td>
<td>23-25</td>
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<td>20-30</td>
<td>0.200</td>
<td>39-41</td>
<td>0.611</td>
<td>21-27</td>
<td>0.200</td>
<td>26-32</td>
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<td>31-41</td>
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<td>0.852</td>
<td>28-33</td>
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<td>33-35</td>
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<td>46-49</td>
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<td>47-52</td>
<td>0.341</td>
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<td></td>
</tr>
</tbody>
</table>

- Note that time intervals differ between countries
Estimated SIR-model (Finland)
Estimated SIR-model (France)
Estimated SIR-model (Italy)
Estimated SIR-model (Sweden)
Summary

• The SIR-model can be fit to COVID19 data
  – Using methods such as sum of least squares estimation
• NPI policy reduces the rate of transmission
  – The rate of transmission increases when the policies are removed or replaced with more mild policies
Improvement suggestions

• Include vaccination
  – For example, a certain proportion of susceptible individuals become recovered
• COVID19 forecasting using the model
• Hybrid models
  – SEIRD-ARIMA [4]
  – Branching process+SIR [2]
• Economic reactions to policies such as in [5]
References


