Estimating and Simulating a SIRD Model of COVID-19 for Many Countries, States, and Cities

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Extended results for Austria
Based on data through August 24, 2020
Outline of Slides

• Basic data from Johns Hopkins CSSE (raw and smoothed)
• Brief summary of the model
• Baseline results \((\delta = 1.0\%, \gamma = 0.2, \theta = 0.1)\)
• Simulation of re-opening – possibilities for raising \(R_0\)
• Results with alternative parameter values:
  o Lower mortality rate, \(\delta = 0.8\%\)
  o Higher mortality rate, \(\delta = 1.2\%\)
  o Infections last longer, \(\gamma = 0.15\)
  o Cases resolve more quickly, \(\theta = 0.2\)
  o Cases resolve more slowly, \(\theta = 0.07\)
• Data underlying estimates of \(R_0(t)\)
Underlying data from Johns Hopkins CSSE

- Raw data
- Smoothed = 7 day centered moving average
- No “excess deaths” correction (change as of Aug 6 run)
Austria: Daily Deaths per Million People

[Bar chart showing daily deaths per million people in Austria from April to August 2020.]
Brief Summary of Model

- See the paper for a full exposition
- A 5-state SIRDC model with a time-varying $R_0$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta$</td>
<td>1.0%</td>
<td>Mortality rate from infections (IFR)</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.2</td>
<td>Rate at which people stop being infectious</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0.1</td>
<td>Rate at which cases (post-infection) resolve</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.05</td>
<td>Rate at which $R_0(t)$ decays with daily deaths</td>
</tr>
<tr>
<td>$R_0$</td>
<td>...</td>
<td>Initial base reproduction rate</td>
</tr>
<tr>
<td>$R_0(t)$</td>
<td>...</td>
<td>Base reproduction rate at date $t$ ($\beta_t/\gamma$)</td>
</tr>
</tbody>
</table>
Estimates of Time-Varying $R_0$

- Inferred from daily deaths, and
- the change in daily deaths, and
- the change in (the change in daily deaths)
(see end of slide deck for this data)
Austria: Estimates of $R_0(t)$

Austria

$\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20$
Austria: Percent Currently Infectious

Austria
Peak I/N = 0.12%  Final I/N = 0.02%  δ = 0.010  θ = 0.10  γ = 0.20
Austria: Growth Rate of Daily Deaths over Past Week (percent)

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Notes on Interpreting Results
Guide to Graphs

• **Warning**: Results are often very uncertain; this can be seen by comparing across multiple graphs. See the original paper.

• 7 days of forecasts: Rainbow color order!
  ROY-G-BIV (old to new, low to high)
  - Black=current
  - Red = oldest, Orange = second oldest, Yellow = third oldest...
  - Violet (purple) = one day earlier

• For robustness graphs, same idea
  - Black = baseline (e.g. $\delta = 1.0\%$)
  - Red = lowest parameter value (e.g. $\delta = 0.8\%$)
  - Green = highest parameter value (e.g. $\delta = 1.2\%$)
How does $R_0$ change over time?

- Inferred from death data when we have it

- For future, two approaches:
  
  1. Alternatively, we fit this equation:

     $$\log R_0(t) = a_0 - \alpha(Daily\ Deaths)$$

     $$\Rightarrow \alpha \approx .05$$

     $R_0$ declines by 5 percent for each new daily death, or rises by 5 percent when daily deaths decline

- Robustness: Assume $R_0(t) =$ final empirical value. Constant in future, so no $\alpha$ adjustment $\rightarrow \alpha = 0$
Repeated “Forecasts” from the past 7 days of data

- After peak, forecasts settle down.
- Before that, very noisy!
- If the region has not peaked, do not trust
- With $\alpha = .05$ (see robustness section for $\alpha = 0$)
Austria (7 days): Daily Deaths per Million People ($\alpha = .05$)

Austria

$R_0 = 1.5/0.2/0.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 1/1/1$

DATA THROUGH 24-AUG-2020
Austria (7 days): Cumulative Deaths per Million (Future, $\alpha = 0.05$)

\[ R_0 = 1.5/0.2/0.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1 \]

DATA THROUGH 24-AUG-2020
Austria (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0.05$)

New York City

Italy

Austria

$R_0 = 1.5/0.2/0.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1$
Robustness to Mortality Rate, $\delta$
Austria: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Data through 24-Aug-2020

Austria

$R_0 = 1.5/0.2/0.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 1/1/1
Austria: Daily Deaths per Million People ($\delta = 0.01/0.008/0.012$)

\[ R_0 = 1.5/0.2/0.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1 \]

DATA THROUGH 24-AUG-2020
Austria: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Austria

$R_0=1.5/0.2/0.2$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 1/1/1

DATA THROUGH 24-AUG-2020

$\delta = 0.008$
Reopening and Herd Immunity

– Black: assumes $R_0(today)$ remains in place forever
– Red: assumes $R_0(suppress) = 1/s(today)$
– Green: we move 25% of the way from $R_0(today)$ back to initial $R_0 = \text{“normal”}$
– Purple: we move 50% of the way from $R_0(today)$ back to initial $R_0 = \text{“normal”}$

NOTE: Lines often cover each other up
Austria: Re-Opening ($\alpha = .05$)

Austria

$R_0(t)=0.2$, $R_0($suppress$)=1.0$, $R_0(25/50)=0.7/1.1$, $\delta = 0.010$, $\alpha=0.05$
Austria: Re-Opening ($\alpha = 0$)

\[
R_0(t) = 0.2, \quad R_0(\text{suppress}) = 1.0, \quad R_0(25/50) = 0.7/1.1, \quad \delta = 0.010, \quad \alpha = 0.00
\]
Results for alternative parameter values
Austria (7 days): Daily Deaths per Million People ($\alpha = 0$)

Austria

$R_0 = 1.5/0.2/0.2 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1$

DATA THROUGH 24-AUG-2020
Austria (7 days): Cumulative Deaths per Million (Future, $\alpha = 0$)

Austria

$R_0 = 1.5/0.2/0.2 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1$

DATA THROUGH 24-AUG-2020
Austria (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0$)

Austria

$R_0=1.5/0.2/0.2$ $\delta = 0.010$ $\alpha=0.00$ $\theta=0.1$ $\%\text{Infect}=1/1/1$

Cumulative deaths per million people
Austria: Daily Deaths per Million People ($\delta = 0.8\%$)

Austria

$R_0 = 1.5/0.2/0.2$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $\%\text{Infect} = 1/1/1$

SOME ERRORS IN ESTIMATION...
Austria: Cumulative Deaths per Million ($\delta = 0.8\%$)

Austria

$R_0=1.5/0.2/0.2$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  $\%\text{Infect}=1/1/1$

SOME ERRORS IN ESTIMATION...
Austria: Daily Deaths per Million People ($\delta = 1.2\%$)

Austria

$R_0 = 1.5/0.2/0.2 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 1/1/1$

SOME ERRORS IN ESTIMATION...
Austria: Cumulative Deaths per Million ($\delta = 1.2\%$)

Austria

$R_0 = 1.5/0.2/0.2\quad \delta = 0.012\quad \theta = 0.1\quad \gamma = 0.2\quad \%\text{Infect} = 1/1/1$

SOME ERRORS IN ESTIMATION...
Austria: Daily Deaths per Million People ($\gamma = .2/15$)

\[
\begin{align*}
R_0 &= 1.5/0.2/0.2 \\
\delta &= 0.010 \\
\alpha &= 0.05 \\
\theta &= 0.1 \\
\%\text{Infect} &= 1/1/1
\end{align*}
\]

DATA THROUGH 24-AUG-2020
Austria: Cumulative Deaths per Million $\gamma = .2/ .15$)

Austria

$R_0 = 1.5/0.2/0.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 1/ 1/ 1

DATA THROUGH 24-AUG-2020

[Graph showing cumulative deaths per million people from March to January 2020 with annotations for $\gamma = 0.15$.]
Austria: Daily Deaths per Million People \( (\theta = .1/ .07/ .2) \)

\[
R_0 = 1.5/0.2/0.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1
\]

DATA THROUGH 24-AUG-2020
Austria: Cumulative Deaths per Million People ($\theta = .1/.07/.2$)

Austria

$R_0=1.5/0.2/0.2$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 1/ 1/ 1

DATA THROUGH 24-AUG-2020
Data Underlying Estimates of Time-Varying $R_0$

– Inferred from daily deaths, and
– the change in daily deaths, and
– the change in (the change in daily deaths)
Austria: Daily Deaths, Actual and Smoothed

Austria: Daily deaths, d
\[ \delta = 0.010 \quad \theta=0.10 \quad \gamma=0.20 \]
Austria: Change in Smoothed Daily Deaths

Austria: Delta d

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Austria: Change in (Change in Smoothed Daily Deaths)

Austria: Delta (Delta d)
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]