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

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Extended results for Kosovo
Based on data through October 9, 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:
  - Lower mortality rate, $\delta = 0.8\%$
  - Higher mortality rate, $\delta = 1.2\%$
  - Infections last longer, $\gamma = 0.15$
  - Cases resolve more quickly, $\theta = 0.2$
  - 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)
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)
Kosovo: Estimates of $R_0(t)$

Kosovo
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Kosovo: Percent Currently Infectious

**Kosovo**

Peak I/N = 0.35%  Final I/N = 0.03%  δ = 0.010  θ = 0.10  γ = 0.20
Kosovo: 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:

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

     \[\Rightarrow \alpha \approx 0.05\]

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

- Robustness: Assume $R_0(t) = \text{final empirical value}$. 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 $\alpha = 0$)
Kosovo (7 days): Daily Deaths per Million People ($\alpha = .05$)

Kosovo

$R_0 = 1.5/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect$ = 3/4/11$

DATA THROUGH 09-OCT-2020

[Diagram showing daily deaths per million people from July 2020 to May 2021, with peaks occurring in August 2020 and October 2020.]
Kosovo (7 days): Cumulative Deaths per Million (Future, $\alpha = .05$)

$R_0 = 1.5/1.3/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 3/4/11$

DATA THROUGH 09-OCT-2020
Kosovo (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0.05$)

Kosovo

$R_0=1.5/1.3/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 3/ 4/11
Robustness to Mortality Rate, $\delta$
Kosovo: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Kosovo

$R_0=1.5/1.3/1.1 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \% \text{Infect} = 3/4/11$

DATA THROUGH 09-OCT-2020
Kosovo: Daily Deaths per Million People ($\delta = .01/.008/.012$)

Kosovo

$R_0=1.5/1.3/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 3/ 4/11

DATA THROUGH 09-OCT-2020
Kosovo: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Kosovo

$R_0 = 1.5/1.3/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 3/4/11$

DATA THROUGH 09-OCT-2020
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 $R_0 = “normal”$
– Purple: we move 50% of the way from $R_0(today)$ back to initial $R_0 = “normal”$

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

Kosovo

$R_0(t)=1.3, \ R_0(\text{suppress})=1.0, \ R_0(25/50)=1.5/1.6, \ \delta = 0.010, \ \alpha=0.05$

(Light bars = New York City, for comparison)
Kosovo: Re-Opening ($\alpha = 0$)

Kosovo

$R_0(t) = 1.3$, $R_0(\text{suppress}) = 1.0$, $R_0(25/50) = 1.5/1.6$, $\delta = 0.010$, $\alpha = 0.00$

(Light bars = New York City, for comparison)
Results for alternative parameter values
Kosovo (7 days): Daily Deaths per Million People ($\alpha = 0$)

Kosovo

$R_0=1.5/1.3/1.3 \quad \delta = 0.010 \quad \alpha=0.00 \quad \theta=0.1 \quad \%\text{Infect}=3/4/39$

DATA THROUGH 09-OCT-2020
Kosovo (7 days): Cumulative Deaths per Million (Future, $\alpha = 0$)

Kosovo

$R_0 = 1.5/1.3/1.3$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  %Infec$t = 3/4/39$

DATA THROUGH 09-OCT-2020

Cumulative deaths per million people

Kosovo (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0$)

Kosovo
$R_0 = 1.5/1.3/1.3$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$ Infect = 3/4/39

New York City
Italy
Kosovo: Daily Deaths per Million People ($\delta = 0.8\%$)

Kosovo

$R_0 = 1.5/1.3/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $\%$ Infect = 4/5/14
Kosovo: Cumulative Deaths per Million ($\delta = 0.8\%$)

Kosovo

$R_0 = 1.5/1.3/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $\%$Infected = 4/5/14
Kosovo: Daily Deaths per Million People ($\delta = 1.2\%$)

Kosovo

$R_0=1.5/1.3/1.1$  $\delta = 0.012$  $\Theta = 0.1$  $\gamma = 0.2$  %Infect = 3/3/10
Kosovo: Cumulative Deaths per Million (δ = 1.2%)
Kosovo: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

DATA THROUGH 09-OCT-2020

Kosovo

$R_0 = 1.5/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 3/4/11

Daily deaths per million people
Kosovo: Cumulative Deaths per Million $\gamma = .2/.15$)

DATA THROUGH 09-OCT-2020

Kosovo

$R_0 = 1.5/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\% $Infect$ = 3/4/11$

$\gamma = 0.2$

$\gamma = 0.15$
Kosovo: Daily Deaths per Million People \((\theta = \frac{1}{1.07/0.2})\)

\[R_0 = 1.5/1.3/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 3/4/11\]

DATA THROUGH 09-OCT-2020
Kosovo: Cumulative Deaths per Million People ($\theta = .1/.07/.2$)

Kosovo

$R_0 = 1.5/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  \%Infect = 3/4/11

DATA THROUGH 09-OCT-2020

Cumulative deaths per million people

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)
Kosovo: Daily Deaths, Actual and Smoothed

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

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

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]