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

Jesús Fernández-Villaverde and Chad Jones

Extended results for Armenia
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)
Armenia: Daily Deaths per Million People

Armenia
Armenia: Daily Deaths per Million People (Smoothed)
## 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)
Armenia: Estimates of $R_0(t)$

Armenia

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

Peaks and Final values:
- Peak I/N = 0.19%
- Final I/N = 0.09%

Model parameters:
- $\delta=0.010$
- $\theta=0.10$
- $\gamma=0.20$
Armenia: Growth Rate of Daily Deaths over Past Week (percent)

Armenia

$\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20$
Notes on Intepreting 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 $R_0(t) = \text{final empirical value}$. 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 $\alpha = 0$)
Armenia (7 days): Daily Deaths per Million People ($\alpha = .05$)

Armenia

$R_0=1.6/1.3/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 4/ 5/12

DATA THROUGH 09-OCT-2020
Armenia (7 days): Cumulative Deaths per Million (Future, $\alpha = .05$)

Armenia

$R_0 = 1.6/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect = 4/5/12

DATA THROUGH 09-OCT-2020
Armenia (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = .05$)

Armenia

$R_0 = 1.6/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 4/5/12
Robustness to Mortality Rate, $\delta$
Armenia: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Armenia

$R_0=1.6/1.3/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 4/5/12

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

DATA THROUGH 09-OCT-2020

Armenia

$R_0 = 1.6/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 4/5/12
Armenia: Cumulative Deaths per Million ($\delta = 0.01/0.008/0.012$)

DATA THROUGH 09-OCT-2020

Armenia

$R_0=1.6/1.3/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%$Infect= 4/5/12
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
Armenia: Re-Opening ($\alpha = 0.05$)

Armenia

$R_0(t)=1.3, \ R_0\text{(suppress)}=1.1, \ R_0(25/50)=1.5/1.7, \ \delta = 0.010, \ \alpha=0.05$

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

Armenia

$R_0(t)=1.4$, $R_0\text{ (suppress)}=1.1$, $R_0(25/50)=1.5/1.7$, $\delta = 0.010$, $\alpha=0.00$

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

Armenia

$R_0=1.6/1.4/1.4$  $\delta = 0.010$  $\alpha=0.00$  $\theta=0.1$  $\%$Infect= 4/7/46

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

Armenia

$R_0 = 1.6/1.4/1.4$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$Infect = 4/7/46

DATA THROUGH 09-OCT-2020

Cumulative deaths per million people

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

Armenia

$R_0 = 1.6/1.4/1.4 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 4/7/46$

New York City

Italy
Armenia: Daily Deaths per Million People ($\delta = 0.8\%$)

Armenia

$R_0=1.6/1.3/1.2$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect= 4/ 7/15
Armenia: Cumulative Deaths per Million ($\delta = 0.8\%$)

Armenia

$R_0=1.6/1.3/1.2 \quad \delta = 0.008 \quad \theta=0.1 \quad \gamma=0.2 \quad \%\text{Infect}= 4/7/15$
Armenia: Daily Deaths per Million People ($\delta = 1.2\%$)

$R_0=1.6/1.3/1.1$  $\delta = 0.012$  $\theta=0.1$  $\gamma=0.2$  %Infect= 3/ 4/11
Armenia: Cumulative Deaths per Million ($\delta = 1.2\%$)

Armenia

$R_0 = 1.6/1.3/1.1$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 3/4/11
Armenia: Daily Deaths per Million People ($\gamma = \frac{2}{15}$)

Armenia

$R_0 = 1.6/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\% Infect = 4/5/12$

DATA THROUGH 09-OCT-2020
Armenia: Cumulative Deaths per Million $\gamma = 0.2/0.15$

Armenia

$R_0 = 1.6/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%Infected = 4/5/12$

$\gamma = 0.15$

$\gamma = 0.2$

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

DATA THROUGH 09-OCT-2020

$R_0 = 1.6/1.3/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect $= 4/5/12$
Armenia: Cumulative Deaths per Million People ($\theta = 0.1/0.07/0.2$)

Armenia

$R_0=1.6/1.3/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%Infect=4/5/12$

DATA THROUGH 09-OCT-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)
Armenia: Daily Deaths, Actual and Smoothed

Armenia: Daily deaths, d
\( \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \)
Armenia: Change in Smoothed Daily Deaths

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

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