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

Jesús Fernández-Villaverde and Chad Jones

Extended results for Maryland
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:
  • 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)
Maryland: Estimates of $R_0(t)$

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

Maryland
Peak I/N = 0.53%  Final I/N = 0.05%  $\delta = 0.010$  $\theta = 0.10$  $\gamma = 0.20$
Maryland: Growth Rate of Daily Deaths over Past Week (percent)

\[
\text{Maryland} \\
\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20
\]
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 $R_0(t) = \text{final empirical value}$. 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 $\alpha = 0$)
Maryland (7 days): Daily Deaths per Million People ($\alpha = 0.05$)

Maryland

$R_0 = 1.8/0.8/0.9 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 6/6/6$

DATA THROUGH 24-AUG-2020
Maryland (7 days): Cumulative Deaths per Million (Future, $\alpha = .05$)

Maryland

$R_0=1.8/0.8/0.9 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}= 6/6/6$

DATA THROUGH 24-AUG-2020
Maryland (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = .05$)

Maryland

$R_0=1.8/0.8/0.9$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%\text{Infect}=6/6/6$

Cumulative deaths per million people

New York City

Italy
Robustness to Mortality Rate, $\delta$
Maryland: Cumulative Deaths per Million \( (\delta = .01/.008/.012) \)

\[
R_0 = 1.8/0.8/0.9 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 6/6/6
\]

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

Maryland

$R_0=1.8/0.8/0.9 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 6/6/6$

DATA THROUGH 24-AUG-2020

Daily deaths per million people

0 2 4 6 8 10 12
Apr May Jun Jul Aug Sep Oct Nov Dec Jan 2020
Maryland: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

$R_0=1.8/0.8/0.9 \quad \delta=0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=6/6/6$

DATA THROUGH 24-AUG-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
Maryland: Re-Opening ($\alpha = .05$)

Maryland

$R_0(t)=0.8, \ R_0(\text{suppress})=1.1, \ R_0(25/50)=1.1/1.4, \ \delta = 0.010, \ \alpha=0.05$
Maryland: Re-Opening ($\alpha = 0$)

Maryland

$R_0(t)=0.8, \ R_0(\text{suppress})=1.1, \ R_0(25/50)=1.1/1.4, \ \delta = 0.010, \ \alpha=0.00$
Results for alternative parameter values
Maryland (7 days): Daily Deaths per Million People ($\alpha = 0$)

Maryland

$R_0 = 1.8/0.8/0.8$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$Infect = 6/ 6/ 6

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

Maryland

$R_0 = 1.8/0.8/0.8 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 6/6/6$

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

Maryland

$R_0 = 1.8/0.8/0.8 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 6/6/6$

New York City

Italy

Cumulative deaths per million people

Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan 2020
Maryland: Daily Deaths per Million People \((\delta = 0.8\%)\)

### Maryland

\[ R_0 = 1.8/0.8/0.9 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 8/8/8 \]
Maryland: Cumulative Deaths per Million ($\delta = 0.8\%$)

Maryland

$R_0 = 1.8/0.8/0.9 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 8/8/8$
Maryland: Daily Deaths per Million People ($\delta = 1.2\%$)

Maryland

$R_0 = 1.8/0.8/0.9 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 5/5/5$
Maryland: Cumulative Deaths per Million ($\delta = 1.2\%$)

Maryland

$R_0 = 1.8/0.8/0.9$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 5/5/5
Maryland: Daily Deaths per Million People ($\gamma = .2/.15$)

Maryland

$R_0 = 1.8/0.8/0.9$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  \%Infect $= 6/6/6$

DATA THROUGH 24-AUG-2020
Maryland: Cumulative Deaths per Million $\gamma = 0.2/0.15$

Maryland

$R_0 = 1.8/0.8/0.9 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 6/6/6$

$\gamma = 0.25$

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

Maryland

$R_0 = 1.8 / 0.8 / 0.9$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 6/6/6
Maryland: Cumulative Deaths per Million People ($\theta = .1/.07/.2$)

Maryland

$R_0=1.8/0.8/0.9$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%$Infect= 6/ 6/ 6

DATA THROUGH 24-AUG-2020

Cumulative deaths per million people

Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec  Jan  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)
Maryland: Daily Deaths, Actual and Smoothed

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

Maryland: Delta $d$

$\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20$
Maryland: Change in (Change in Smoothed Daily Deaths)

Maryland: Delta (Δd)
δ = 0.010  θ=0.10  γ=0.20

2020