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

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

Maryland

Daily deaths per million people

Apr  May  Jun  Jul  Aug  Sep  Oct

2020
Maryland: Daily Deaths per Million People (Smoothed)

Maryland
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 = 0.03%  δ = 0.010  θ=0.10  γ=0.20
Maryland: 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)
  
  o Black = current
  
  o **Red** = oldest, **Orange** = second oldest, **Yellow** = third oldest...
  
  o **Violet (purple)** = one day earlier

• For robustness graphs, same idea
  
  o Black = baseline (e.g. $\delta = 1.0\%$)
  
  o **Red** = lowest parameter value (e.g. $\delta = 0.8\%$)
  
  o **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:

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

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

   $R_0$ 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 ($\alpha = .05$)

Maryland

$R_0 = 1.8/0.7/0.7$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 7/7/7$

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

Maryland

$R_0 = 1.8/0.7/0.7 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 7/7/7$

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

Maryland

$R_0 = 1.8/0.7/0.7$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\% Infect = 7/7/7$
Robustness to Mortality Rate, $\delta$
Maryland: Cumulative Deaths per Million ($\delta = .01/0.008/.012$)

Maryland

$R_0 = 1.8/0.7/0.7$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect $= 7/7/7$

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

**Daily deaths per million people**

Maryland

$R_0 = 1.8/0.7/0.7$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\% Infect = 7/7/7$

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

$R_0 = 1.8/0.7/0.7 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 7/7/7$

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
Maryland: Re-Opening \( (\alpha = .05) \)

\[
R_0(t) = 0.7, \quad R_0(\text{suppress}) = 1.1, \quad R_0(25/50) = 1.0/1.3, \quad \delta = 0.010, \quad \alpha = 0.05
\]

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

Maryland

$R_0(t)=0.6$, $R_0\text{(suppress)}=1.1$, $R_0(25/50)=1.0/1.3$, $\delta = 0.010$, $\alpha=0.00$

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

Maryland

$R_0 = 1.8/0.6/0.6 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 7/7/7$

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

Maryland

$R_0 = 1.8/0.6/0.6$ \quad $\delta = 0.010$ \quad $\alpha = 0.00$ \quad $\theta = 0.1$ \quad %Infect = 7/7/7

DATA THROUGH 09-OCT-2020
Maryland (7 days): Cumulative Deaths per Million, Log Scale $\left( \alpha = 0 \right)$

Maryland

$R_0 = 1.8/0.6/0.6 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 7/7/7$

New York City

Italy

Cumulative deaths per million people

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

Maryland

$R_0 = 1.8/0.7/0.7 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 8/8/8$
Maryland: Cumulative Deaths per Million ($\delta = 0.8\%$)

Maryland

$R_0=1.8/0.7/0.7 \quad \delta = 0.008 \quad \theta=0.1 \quad \gamma=0.2 \quad \%\text{Infect}= 8/8/8$
Maryland: Daily Deaths per Million People ($\delta = 1.2\%$)

Maryland

$R_0 = 1.8 / 0.6 / 0.7$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 6 / 6 / 6
Maryland: Cumulative Deaths per Million ($\delta = 1.2\%$)

Maryland

$R_0 = 1.8/0.6/0.7 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 6/6/6$
Maryland: Daily Deaths per Million People ($\gamma = .2/.15$)

Maryland

$R_0 = 1.8/0.7/0.7$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 7/7/7$

DATA THROUGH 09-OCT-2020
Maryland: Cumulative Deaths per Million $\gamma = .2/.15$)

Maryland

$R_0=1.8/0.7/0.7 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=7/7/7$

$\gamma = 0.25$

DATA THROUGH 09-OCT-2020
Maryland: Daily Deaths per Million People ($\theta = 0.1/0.07/0.2$)

Maryland

$R_0 = 1.8/0.7/0.7$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 7/7/7$

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

DATA THROUGH 09-OCT-2020

Maryland

$R_0 = 1.8/0.7/0.7\quad \delta = 0.010\quad \alpha = 0.05\quad \theta = 0.1\quad \%\text{Infected} = 7/7/7$

$\theta \equiv 0.07$
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, $d$

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

Maryland: Delta $d$

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

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