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

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Extended results for Alabama
Based on data through September 11, 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)
Alabama: Daily Deaths per Million People (Smoothed)

Daily deaths per million people (smoothed)

Alabama
**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)
Alabama: Estimates of $R_0(t)$

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

Peak I/N = 0.27%  Final I/N = 0.09%  δ = 0.010  θ = 0.10  γ = 0.20
Alabama: Growth Rate of Daily Deaths over Past Week (percent)

Alabama
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
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 $R_0(t) = \text{final empirical value. Constant in future, so no } \alpha \text{ adjustment } \rightarrow \alpha = 0$
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 $\alpha = 0$)
Alabama (7 days): Daily Deaths per Million People ($\alpha = .05$)

Alabama

$R_0 = 1.3/0.4/0.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5$

DATA THROUGH 11-SEP-2020
Alabama (7 days): Cumulative Deaths per Million (Future, $\alpha = 0.05$)

$$R_0 = 1.3/0.4/0.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5$$

DATA THROUGH 11-SEP-2020
Alabama (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = .05$)

Alabama

$R_0=1.3/0.4/0.4 \hspace{0.5cm} \delta = 0.010 \hspace{0.5cm} \alpha=0.05 \hspace{0.5cm} \theta=0.1 \hspace{0.5cm} \%Infect=5/5/5$

Cumulative deaths per million people

New York City

Italy
Robustness to Mortality Rate, $\delta$
Alabama: Cumulative Deaths per Million ($\delta = .01/0.008/0.012$)

Alabama

$R_0 = 1.3/0.4/0.4$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 5/5/5

DATA THROUGH 11-SEP-2020
Alabama: Daily Deaths per Million People ($\delta = .01/.008/.012$)

\[ R_0 = 1.3/0.4/0.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5 \]

DATA THROUGH 11-SEP-2020
Alabama: Cumulative Deaths per Million ($\delta = 0.01/0.008/0.012$)

Alabama

$R_0 = 1.3/0.4/0.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5$

DATA THROUGH 11-SEP-2020
Reopening and Herd Immunity

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

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

\[ R_0(t)=0.4, \ R_0(\text{suppress})=1.1, \ R_0(25/50)=0.8/1.2, \ \delta = 0.010, \ \alpha=0.05 \]
Alabama: Re-Opening ($\alpha = 0$)

Alabama

$R_0(t)=0.4$, $R_0\text{(suppress)}=1.1$, $R_0(25/50)=0.8/1.2$, $\delta = 0.010$, $\alpha=0.00$

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

Alabama

$R_0 = 1.3/0.4/0.4$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  %Infect = 5/5/5

DATA THROUGH 11-SEP-2020
Alabama (7 days): Cumulative Deaths per Million (Future, $\alpha = 0$)

Alabama

$R_0 = 1.3/0.4/0.4$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$Infect$ = 5/5/5$

DATA THROUGH 11-SEP-2020
Alabama (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0$)

Alabama

$R_0 = 1.3/0.4/0.4$ \hspace{1em} $\delta = 0.010$ \hspace{1em} $\alpha = 0.00$ \hspace{1em} $\theta = 0.1$ \hspace{1em} $\%$Infect = 5/5/5

New York City

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

\[
R_0 = 1.3/0.4/0.4 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \% \text{Infect} = 6/6/6
\]
Alabama: Cumulative Deaths per Million ($\delta = 0.8\%$)

Alabama

$R_0 = 1.3/0.4/0.4 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 6/6/6$
Alabama: Daily Deaths per Million People ($\delta = 1.2\%$)

Alabama

$R_0 = 1.3/0.4/0.4 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 4/4/4$
Alabama: Cumulative Deaths per Million ($\delta = 1.2\%$)

Alabama

$R_0 = 1.3/0.4/0.4 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 4/4/4$
Alabama: Daily Deaths per Million People ($\gamma = .2/.15$)

Alabama

$R_0 = 1.3/0.4/0.4$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 5/5/5$

Data through 11-Sep-2020
Alabama: Cumulative Deaths per Million $\gamma = .2/.15$)

Alabama

$R_0 = 1.3/0.4/0.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5$

$\gamma = 0.25$

DATA THROUGH 11-SEP-2020
Alabama: Daily Deaths per Million People ($\theta = .1/.07/.2$)

Alabama

$R_0=1.3/0.4/0.4 \; \delta = 0.010 \; \alpha=0.05 \; \theta=0.1 \; \%\text{Infect}= 5/5/5$

DATA THROUGH 11-SEP-2020
Alabama: Cumulative Deaths per Million People ($\theta = .1/.07/.2$)

Alabama

$R_0=1.3/0.4/0.4 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}= 5/5/5$

Data through 11-Sep-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)
Alabama: Daily Deaths, Actual and Smoothed

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

Alabama: Delta d
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]