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

Jesús Fernández-Villaverde and Chad Jones

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

Oklahoma

Daily deaths per million people

Apr May Jun Jul Aug

2020
Oklahoma: 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)
Oklahoma: Estimates of $R_0(t)$

Oklahoma

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

Oklahoma
Peak I/N = 0.14%   Final I/N = 0.14%   $\delta=0.010$   $\theta=0.10$   $\gamma=0.20$
Oklahoma: Growth Rate of Daily Deaths over Past Week (percent)

Oklahoma

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
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 $R_0(t) =$ 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 $\alpha = 0$)
Oklahoma (7 days): Daily Deaths per Million People ($\alpha = .05$)

$R_0 = 1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2/4/7$

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

\[ R_0 = 1.4/1.1/1.1, \quad \delta = 0.010, \quad \alpha = 0.05, \quad \theta = 0.1, \quad \%\text{Infect} = 2/4/7 \]

DATA THROUGH 24-AUG-2020
Oklahoma (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0.05$)

\( R_0 = 1.4/1.1/1.1 \)  \( \delta = 0.010 \)  \( \alpha = 0.05 \)  \( \theta = 0.1 \)  \%Infect = 2/4/7
Robustness to Mortality Rate, $\delta$
Oklahoma: Cumulative Deaths per Million ($\delta = .01/\cdot008/\cdot012$)

Oklahoma

$R_0=1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%Infect= 2/ 4/ 7$

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

Oklahoma

$R_0 = 1.4/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%\text{Infect}=2/4/7$

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

**Oklahoma**

$R_0=1.4/1.1/1.1$ $\delta = 0.010$ $\alpha=0.05$ $\theta=0.1$

%Infect= 2/ 4/ 7

DATA THROUGH 24-AUG-2020

Cumulative deaths per million people

Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan 2020

0 | 100 | 200 | 300 | 400 | 500 | 600 | 700
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
Oklahoma: Re-Opening ($\alpha = 0.05$)

Oklahoma

$R_0(t)=1.1$, $R_0$(suppress)$=1.0$, $R_0(25/50)=1.3/1.6$, $\delta = 0.010$, $\alpha=0.05$
Oklahoma: Re-Opening ($\alpha = 0$)

\[
R_0(t)=1.1, \quad R_0(\text{suppress})=1.0, \quad R_0(25/50)=1.3/1.6, \quad \delta = 0.010, \quad \alpha=0.00
\]
Results for alternative parameter values
Oklahoma (7 days): Daily Deaths per Million People ($\alpha = 0$)

Oklahoma

$R_0 = 1.4/1.1/1.1$  \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 2/4/11

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

Oklahoma

$R_0 = 1.4/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%\text{Infect} = 2/4/11$

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

R$_0$ = 1.4/1.1/1.1  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  %Infect = 2/4/11
Oklahoma: Daily Deaths per Million People ($\delta = 0.8\%$)

R$_0$ = 1.4/1.1/1.1  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 3/4/8

\[ \text{Daily deaths per million people} \]
Oklahoma: Cumulative Deaths per Million (δ = 0.8%)
Oklahoma: Cumulative Deaths per Million ($\delta = 1.2\%$)
Oklahoma: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

Oklahoma

$R_0=1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=2/4/7$

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

Oklahoma

$R_0 = 1.4/1.1/1.1 \delta = 0.010 \alpha = 0.05 \theta = 0.1 \%Infect = 2/4/7$

DATA THROUGH 24-AUG-2020

$\gamma = 0.15$

$\gamma = 0.2$
Oklahoma: Daily Deaths per Million People \((\theta = 0.1/0.07/0.2)\)

\[ R_0 = 1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2/4/7 \]
Oklahoma: Cumulative Deaths per Million People ($\theta = .1/ .07/ .2$)

Oklahoma

$R_0 = 1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 2/4/7$

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)
Oklahoma: Daily Deaths, Actual and Smoothed

\[ d = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Oklahoma: Change in Smoothed Daily Deaths

Oklahoma: Delta $d$

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

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