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

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Extended results for New Mexico
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:
  o Lower mortality rate, $\delta = 0.8\%$
  o Higher mortality rate, $\delta = 1.2\%$
  o Infections last longer, $\gamma = 0.15$
  o Cases resolve more quickly, $\theta = 0.2$
  o 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)
New Mexico: Daily Deaths per Million People

![Bar chart showing daily deaths per million people in New Mexico from April to August 2020. The x-axis represents the months of the year, and the y-axis represents the daily deaths per million people. The chart shows a fluctuation in deaths throughout the months, with a peak in May and a trough in July.](chart.png)
New Mexico: 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)
New Mexico: Estimates of $R_0(t)$

New Mexico

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

New Mexico
Peak I/N = 0.27%  Final I/N = 0.13%  δ = 0.010  θ = 0.10  γ = 0.20

Percent currently infectious, I/N (percent)
New Mexico: Growth Rate of Daily Deaths over Past Week (percent)

New Mexico
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
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:

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

\[\Rightarrow \alpha \approx 0.05\]

$R_0$ 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 $\alpha = 0$)
New Mexico (7 days): Daily Deaths per Million People ($\alpha = .05$)

New Mexico

$R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/6/8$

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

New Mexico

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\% $ Infect $ = 5/6/8$

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

New Mexico

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%$Infect = 5/6/8

New York City

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

New Mexico

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%$Infect$=5/6/8$

Data through 24-Aug-2020
New Mexico: Daily Deaths per Million People ($\delta = .01/.008/.012$)

New Mexico

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 5/6/8$

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

New Mexico

$R_0 = 1.5/1.1/1.1, \delta = 0.010, \alpha = 0.05, \theta = 0.1, \%\text{Infect} = 5/6/8$

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
New Mexico: Re-Opening ($\alpha = .05$)

New Mexico

$R_0(t)=1.1$, $R_0$ (suppress) = 1.1, $R_0(25/50)=1.3/1.5$, $\delta = 0.010$, $\alpha = 0.05$
New Mexico: Re-Opening ($\alpha = 0$)

New Mexico

$R_0(t)=1.1, \ R_0(\text{suppress})=1.1, \ R_0(25/50)=1.3/1.5, \ \delta = 0.010, \ \alpha=0.00$
Results for alternative parameter values
New Mexico (7 days): Daily Deaths per Million People ($\alpha = 0$)

New Mexico

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $%\text{Infect} = 5/6/9$

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

New Mexico

$R_0 = 1.5/1.1/1.1$  \(\delta = 0.010\)  \(\alpha = 0.00\)  \(\theta = 0.1\)  \%Infect = 5/6/9

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

Cumulative deaths per million people

New Mexico

$R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%$ Infect $= 5/6/9$

New York City

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

New Mexico

$R_0=1.5/1.1/1.1$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect= 6/ 7/10
New Mexico: Cumulative Deaths per Million ($\delta = 0.8\%$)

New Mexico

$R_0 = 1.5/1.1/1.1 \delta = 0.008 \ \theta = 0.1 \ \gamma = 0.2 \ \%Infect = 6/7/10$
New Mexico: Daily Deaths per Million People ($\delta = 1.2\%$)

New Mexico

$R_0 = 1.5/1.1/1.1$  \(\delta = 0.012\)  \(\theta = 0.1\)  \(\gamma = 0.2\)  \%Infect = 4/5/7
New Mexico: Cumulative Deaths per Million ($\delta = 1.2\%$)

New Mexico

$R_0=1.5/1.1/1.1 \quad \delta = 0.012 \quad \theta=0.1 \quad \gamma=0.2 \quad \%\text{Infect}=4/5/7$
New Mexico: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

New Mexico

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 5/6/8$

Data through 24-Aug-2020
New Mexico: Cumulative Deaths per Million $\gamma = 0.2 / 0.15$"
New Mexico: Daily Deaths per Million People ($\theta = .1/.07/.2$)

New Mexico

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 5/6/8$

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

New Mexico

$R_0 = 1.5/1.1/1.1$, $\delta = 0.010$, $\alpha = 0.05$, $\theta = 0.1$, %Infect = 5/6/8

DATA THROUGH 24-AUG-2020

$\theta = 0.07$

$\theta = 0.1$

$\theta = 0.2$

Cumulative deaths per million people

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)
New Mexico: Daily Deaths, Actual and Smoothed

New Mexico: Daily deaths, $d$

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

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]