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 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)
New Mexico: Daily Deaths per Million People
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 = 0.10%  δ=0.010  θ=0.10  γ=0.20
New Mexico: 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)
  - 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 $R_0(t) = \text{final empirical value}$. 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 $\alpha = 0$)
New Mexico (7 days): Daily Deaths per Million People ($\alpha = .05$)

New Mexico

$R_0 = 1.5/0.9/1.0$ \hspace{1em} $\delta = 0.010$ \hspace{1em} $\alpha = 0.05$ \hspace{1em} $\theta = 0.1$ \hspace{1em} $\%$ Infect = 5/5/6

DATA THROUGH 11-SEP-2020
New Mexico (7 days): Cumulative Deaths per Million (Future, $\alpha = .05$)

New Mexico

$R_0=1.5/0.9/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 5/5/6

DATA THROUGH 11-SEP-2020
New Mexico (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0.05$)

New Mexico

$R_0 = 1.5/0.9/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/6$

Cumulative deaths per million people

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

New Mexico
$R_0 = 1.5/0.9/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect = 5/ 5/ 6

DATA THROUGH 11-SEP-2020
New Mexico: Daily Deaths per Million People ($\delta = 0.01/0.008/0.012$)

New Mexico

$R_0 = 1.5/0.9/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect $= 5/5/6$

DATA THROUGH 11-SEP-2020
New Mexico: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

New Mexico

$R_0 = 1.5/0.9/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/6$

DATA THROUGH 11-SEP-2020

Cumulative deaths per million people

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

$R_0(t) = 0.9$, $R_0$ (suppress) = 1.1, $R_0(25/50) = 1.2/1.4$, $\delta = 0.010$, $\alpha = 0.05$

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

New Mexico

$R_0(t)=0.9$,  $R_0(\text{suppress})=1.1$,  $R_0(25/50)=1.2/1.4$,  $\delta = 0.010$,  $\alpha=0.00$
Results for alternative parameter values
New Mexico (7 days): Daily Deaths per Million People ($\alpha = 0$)

New Mexico

$R_0 = 1.5/0.9/0.9 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \% \text{Infect} = 5/5/6$

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

New Mexico

$R_0 = 1.5/0.9/0.9 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect}= 5/5/6$

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

New Mexico

$R_0 = 1.5/0.9/0.9 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/6$

- New York City
- Italy

Cumulative deaths per million people

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

New Mexico

$R_0 = 1.5/0.9/1.0$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $%Infect = 6/7/7$
New Mexico: Cumulative Deaths per Million ($\delta = 0.8\%$)

New Mexico

$R_0=1.5/0.9/1.0$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $\%$ Infect $= 6/7/7$
New Mexico: Daily Deaths per Million People ($\delta = 1.2\%$)

New Mexico

$R_0 = 1.5/0.9/1.0$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  $\%$Infect$= 4/5/5$
New Mexico: Cumulative Deaths per Million ($\delta = 1.2\%$)

New Mexico

$R_0 = 1.5/0.9/1.0 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 4/5/5$
New Mexico: Daily Deaths per Million People ($\gamma = .2/.15$)

New Mexico

$R_0 = 1.5/0.9/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect $= 5/5/6$

DATA THROUGH 11-SEP-2020
New Mexico: Cumulative Deaths per Million $\gamma = .2/.15$)

New Mexico

$R_0 = 1.5/0.9/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 5/5/6

$\gamma \equiv 0.25$
New Mexico: Daily Deaths per Million People ($\theta = .1/.07/.2$)

New Mexico

$R_0=1.5/0.9/1.0 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}= 5/ 5/ 6$

DATA THROUGH 11-SEP-2020
New Mexico: Cumulative Deaths per Million People ($\theta = 0.1/0.07/0.2$)

\[
R_0 = 1.5/0.9/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect}= 5/5/6
\]

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)
New Mexico: Daily Deaths, Actual and Smoothed

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

New Mexico: Delta $d$

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

New Mexico: Delta (Delta d)

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