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

Jesús Fernández-Villaverde and Chad Jones

Extended results for New York City (only)
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)
**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 York City (only): Estimates of $R_0(t)$

\[
\text{New York City (only)} \\
\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20
\]
New York City (only): Percent Currently Infectious

New York City (only)
Peak I/N = 5.11%  Final I/N = 0.02%  δ = 0.010  θ = 0.10  γ = 0.20
New York City (only): 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 $R_0(t) =$ 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 York City (only) (7 days): Daily Deaths per Million People ($\alpha = .05$)

$$R_0 = 2.4/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 29/29/29$$

DATA THROUGH 24-AUG-2020
New York City (only) (7 days): Cumulative Deaths per Million (Future, \( \alpha \))

\[ R_0 = 2.4/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 29/29/29 \]

DATA THROUGH 24-AUG-2020
New York City (only) (7 days): Cumulative Deaths per Million, Log Scale

New York City (only)
$R_0=2.4/1.0/1.0$  $\delta=0.010$  $\alpha=0.05$  $\theta=0.1$  $\%\text{Infect}=29/29/29$
Robustness to Mortality Rate, $\delta$
New York City (only): Cumulative Deaths per Million ($\delta = .01 / .008 / .012$)

New York City (only)

$R_0 = 2.4 / 1.0 / 1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 29 / 29 / 29$

DATA THROUGH 24-AUG-2020
New York City (only): Daily Deaths per Million People ($\delta = 0.01/0.008/0.012$)

New York City (only)

$R_0 = 2.4/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect $= 29/29/29$

DATA THROUGH 24-AUG-2020
New York City (only): Cumulative Deaths per Million ($\delta = 0.01/0.008/0.012$)

New York City (only)

$R_0=2.4/1.0/1.0 \ \delta = 0.010 \ \alpha=0.05 \ \theta=0.1 \ \%\text{Infect}=29/29/29$

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 York City (only): Re-Opening ($\alpha = .05$)

New York City (only)
$R_0(t)=1.0$, $R_0(suppress)=1.4$, $R_0(25/50)=1.3/1.7$, $\delta = 0.010$, $\alpha=0.05$
New York City (only): Re-Opening ($\alpha = 0$)

New York City (only)

$R_0(t)=0.9$, $R_0$ (suppress) $=1.4$, $R_0(25/50)=1.3/1.7$, $\delta = 0.010$, $\alpha=0.00$
Results for alternative parameter values
New York City (only) (7 days): Daily Deaths per Million People ($\alpha = 0$)

New York City (only)

$R_0 = 2.4/0.9/0.9 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 29/29/29$

DATA THROUGH 24-AUG-2020
New York City (only) (7 days): Cumulative Deaths per Million (Future, $\alpha$)

New York City (only)

$R_0 = 2.4/0.9/0.9 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 29/29/29$

DATA THROUGH 24-AUG-2020

Cumulative deaths per million people
New York City (only) (7 days): Cumulative Deaths per Million, Log Scale

New York City (only)

$R_0 = 2.4/0.9/0.9 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 29/29/29$
New York City (only): Daily Deaths per Million People ($\delta = 0.8\%$)

New York City (only)

$R_0=2.4/1.1/1.1$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect=36/36/36
New York City (only): Cumulative Deaths per Million ($\delta = 0.8\%$)

New York City (only)
$R_0 = 2.4/1.1/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $%\text{Infect}=36/36/36$
New York City (only): Daily Deaths per Million People ($\delta = 1.2\%$)

New York City (only)
$R_0=2.4/0.9/0.9$  $\delta = 0.012$  $\theta=0.1$  $\gamma=0.2$  $%\text{Infect}=24/24/24$
New York City (only): Cumulative Deaths per Million ($\delta = 1.2\%$)

New York City (only)

$R_0 = 2.4/0.9/0.9 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 24/24/24$
New York City (only): Daily Deaths per Million People ($\gamma = .2/.15$)

New York City (only)

$R_0=2.4/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect=29/29/29

DATA THROUGH 24-AUG-2020
New York City (only): Cumulative Deaths per Million $\gamma = .2/1.5$)

New York City (only)

$R_0 = 2.4/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 29/29/29$

$\gamma = 0.25$

DATA THROUGH 24-AUG-2020
New York City (only): Daily Deaths per Million People ($\theta = .1/.07/.2$)

New York City (only)

$R_0=2.4/1.0/1.0 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=29/29/29$

DATA THROUGH 24-AUG-2020
New York City (only): Cumulative Deaths per Million People ($\theta = 1/0.07$)

New York City (only)

$R_0=2.4/1.0/1.0 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=29/29/29$

DATA THROUGH 24-AUG-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 York City (only): Daily Deaths, Actual and Smoothed

New York City (only): Daily deaths, \( d \)

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
New York City (only): Change in Smoothed Daily Deaths

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
New York City (only): Change in (Change in Smoothed Daily Deaths)

New York City (only): Delta (Delta d)
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]