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

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Extended results for New York City (plus)
Based on data through October 9, 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 York City (plus): Daily Deaths per Million People
New York City (plus): 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 York City (plus): Estimates of $R_0(t)$

New York City (plus)

$\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20$
New York City (plus): Percent Currently Infectious

New York City (plus)
Peak I/N = 4.09%  Final I/N = 0.03%  δ = 0.010  θ = 0.10  γ = 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:
  - 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 $\alpha = 0$)
New York City (plus) (7 days): Daily Deaths per Million People ($\alpha = 0.05$)

New York City (plus)

$R_0 = 2.2/1.6/1.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 24/25/27$

DATA THROUGH 09-OCT-2020
New York City (plus) (7 days): Cumulative Deaths per Million (Future, α)

\[ R_0 = 2.2/1.6/1.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 24/25/27 \]
New York City (plus) (7 days): Cumulative Deaths per Million, Log Scale

New York City (plus)

\[ R_0 = 2.2/1.6/1.4, \quad \delta = 0.010, \quad \alpha = 0.05, \quad \theta = 0.1, \quad \text{%Infect} = 24/25/27 \]
Robustness to Mortality Rate, $\delta$
New York City (plus): Cumulative Deaths per Million ($\delta = .01/.008/.012$)

$R_0=2.2/1.6/1.4$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%$Infect=24/25/27

DATA THROUGH 09-OCT-2020
New York City (plus): Daily Deaths per Million People ($\delta = .01/.008/.012$)

New York City (plus)
$R_0 = 2.2/1.6/1.4$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect = 24/25/27

DATA THROUGH 09-OCT-2020
New York City (plus): Cumulative Deaths per Million ($\delta = .01/.008/.012$)

$$R_0 = 2.2/1.6/1.4 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=24/25/27$$

DATA THROUGH 09-OCT-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 (plus): Re-Opening ($\alpha = .05$)

New York City (plus)

$R_0(t)=1.6, \ R_0^{\text{suppress}}=1.3, \ R_0^{(25/50)}=1.7/1.9, \ \delta = 0.010, \ \alpha=0.05$

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

New York City (plus)

$R_0(t)=1.6$, $R_0(\text{suppress})=1.3$, $R_0(25/50)=1.7/1.9$, $\delta = 0.010$, $\alpha=0.00$

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

New York City (plus)

$R_0 = 2.2/1.6/1.6 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 24/25/32$

DATA THROUGH 09-OCT-2020
New York City (plus) (7 days): Cumulative Deaths per Million (Future, α)

\[ R_0 = 2.2/1.6/1.6 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 24/25/32 \]

DATA THROUGH 09-OCT-2020
New York City (plus): Cumulative Deaths per Million, Log Scale

New York City (plus)

$R_0 = 2.2/1.6/1.6$, $\delta = 0.010$, $\alpha = 0.00$, $\theta = 0.1$, %Infect = 24/25/32
New York City (plus): Daily Deaths per Million People ($\delta = 0.8\%$)

R\textsubscript{0}=2.3/1.7/1.5  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect=31/31/34
New York City (plus): Cumulative Deaths per Million ($\delta = 0.8\%$)

New York City (plus)

$R_0 = 2.3/1.7/1.5$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $\%\text{Infect} = 31/31/34$
New York City (plus): Daily Deaths per Million People ($\delta = 1.2\%$)

New York City (plus)

$R_0=2.2/1.5/1.3$  $\delta = 0.012$  $\theta=0.1$  $\gamma=0.2$  $\%Infect=20/21/23$
New York City (plus): Cumulative Deaths per Million ($\delta = 1.2\%$)

$R_0 = 2.2/1.5/1.3 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 20/21/23$
New York City (plus): Daily Deaths per Million People ($\gamma = .2/.15$)

New York City (plus)

$R_0 = 2.2/1.6/1.4$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 24/25/27

DATA THROUGH 09-OCT-2020
New York City (plus): Cumulative Deaths per Million $\gamma = .2 / .15$

New York City (plus)

$R_0 = 2.2 / 1.6 / 1.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 24 / 25 / 27$

DATA THROUGH 09-OCT-2020
New York City (plus): Daily Deaths per Million People ($\theta = .1/.07/.2$)

\[ R_0 = 2.2/1.6/1.4 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 24/25/27 \]

DATA THROUGH 09-OCT-2020
New York City (plus): Cumulative Deaths per Million People ($\theta = .1/0.07$)

New York City (plus)

$R_0 = 2.2/1.6/1.4 \; \delta = 0.010 \; \alpha = 0.05 \; \theta = 0.1 \; \%\text{Infect} = 24/25/27$

DATA THROUGH 09-OCT-2020

Cumulative deaths per million people


Cumulative deaths per million people:

- 0
- 500
- 1000
- 1500
- 2000
- 2500
- 3000

\(\theta = 0.07\)
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 (plus): Daily Deaths, Actual and Smoothed

New York City (plus): Daily deaths, $d$

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

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