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

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Extended results for Los Angeles
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)
Los Angeles: Daily Deaths per Million People

![Los Angeles每日死亡人数](图)
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)
Los Angeles: Estimates of $R_0(t)$

Los Angeles

$\delta = 0.010$  $\theta=0.10$  $\gamma=0.20$
Los Angeles: Percent Currently Infectious

Los Angeles
Peak I/N = 0.21%  Final I/N = 0.21%  δ = 0.010  θ = 0.10  γ = 0.20
Los Angeles: Growth Rate of Daily Deaths over Past Week (percent)

Los Angeles
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
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 $R_0(t) = \text{final empirical value}$. 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 $\alpha = 0$)
Los Angeles (7 days): Daily Deaths per Million People ($\alpha = .05$)

Los Angeles

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%\text{Infect}=5/7/10$

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

Los Angeles

$R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad %\text{Infect} = 5/7/10$

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

Los Angeles
$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect = 5/7/10
Robustness to Mortality Rate, $\delta$
Los Angeles: Cumulative Deaths per Million ($\delta = .01/\ .008/\ .012$)

Los Angeles

$R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/7/10$

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

Los Angeles

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect$= 5/7/10$

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

Los Angeles

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect = 5/7/10

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
Los Angeles: Re-Opening \((\alpha = 0.05)\)

Los Angeles

\[ R_0(t)=1.1, \ R_0(\text{suppress})=1.1, \ R_0(25/50)=1.3/1.5, \ \delta = 0.010, \ \alpha=0.05 \]
Results for alternative parameter values
Los Angeles (7 days): Daily Deaths per Million People ($\alpha = 0$)

Los Angeles

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$Infect $= 5/7/10$

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

Los Angeles

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$Infect = 5/7/10

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

Los Angeles

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  %Infect = 5/7/10

New York City

Italy
Los Angeles: Daily Deaths per Million People ($\delta = 0.8\%$)

Los Angeles
$R_0 = 1.5/1.1/1.1$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect= 7/8/12
Los Angeles: Cumulative Deaths per Million ($\delta = 0.8\%$)

Los Angeles
$R_0=1.5/1.1/1.1$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect= 7/ 8/12
Los Angeles: Daily Deaths per Million People (\( \delta = 1.2\% \))

\[ R_0 = 1.5/1.1/1.1 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 4/6/8 \]
Los Angeles: Cumulative Deaths per Million ($\delta = 1.2\%$)

Los Angeles

$R_0 = 1.5/1.1/1.1\quad \delta = 0.012\quad \theta = 0.1\quad \gamma = 0.2\quad \%\text{Infect} = 4/6/8$
Los Angeles: Daily Deaths per Million People ($\gamma = .2/.15$)

Los Angeles

$R_0 = 1.5/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 5/7/10

DATA THROUGH 24-AUG-2020
Los Angeles: Cumulative Deaths per Million \( \gamma = .2/.15 \)

Los Angeles

\( R_0 = 1.5/1.1/1.1 \)  \( \delta = 0.010 \)  \( \alpha = 0.05 \)  \( \theta = 0.1 \)  \%Infect = 5/7/10

DATA THROUGH 24-AUG-2020
Los Angeles: Daily Deaths per Million People ($\theta = .1/.07/.2$)

Los Angeles

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%Infect=5/7/10$

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

Los Angeles

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $%Infect=5/7/10$

DATA THROUGH 24-AUG-2020

$\theta = 0.07$
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)
Los Angeles: Daily deaths, actual and smoothed

Los Angeles: Daily deaths, \( d \)
\[
\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20
\]
Los Angeles: Change in Smoothed Daily Deaths

Los Angeles: Delta $d$

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

Los Angeles: Delta (Delta d)
$\delta = 0.010 \ \theta = 0.10 \ \gamma = 0.20$