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

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Extended results for Illinois
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:
  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)
Illinois: Daily Deaths per Million People

Illinois

Daily deaths per million people

April 2020

May 2020

June 2020

July 2020

August 2020

September 2020
Illinois: 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)
Illinois: Estimates of $R_0(t)$

Illinois

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

Peak I/N = 0.50% Final I/N = 0.08% \( \delta = 0.010 \) \( \theta = 0.10 \) \( \gamma = 0.20 \)
Illinois: Growth Rate of Daily Deaths over Past Week (percent)

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Notes on Intepreting 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 $\alpha = 0$)
Illinois (7 days): Daily Deaths per Million People ($\alpha = .05$)

$R_0 = 1.8/1.0/1.0 \; \delta = 0.010 \; \alpha = 0.05 \; \theta = 0.1 \; \%\text{Infect} = 7/8/8$

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

$R_0 = 1.8/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 7/8/8

DATA THROUGH 11-SEP-2020

Cumulative deaths per million people

Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec  Jan  2020
Illinois (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0.05$)

Illinois

$R_0=1.8/1.0/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 7/8/8

Cumulative deaths per million people

Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan 2020
Robustness to Mortality Rate, $\delta$
Illinois: Cumulative Deaths per Million ($\delta = .01 / .008 / .012$)

Illinois
$R_0 = 1.8 / 1.0 / 1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 7 / 8 / 8$

DATA THROUGH 11-SEP-2020
Illinois: Daily Deaths per Million People ($\delta = .01/.008/.012$)

Illinois

$R_0 = 1.8/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect$= 7/8/8$

DATA THROUGH 11-SEP-2020

![Chart showing daily deaths per million people in Illinois from April to January 2020, with high peaks in May and a decline by November.]
Illinois: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

$R_0=1.8/1.0/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 7/8/8

DATA THROUGH 11-SEP-2020

Cumulative deaths per million people

Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec  Jan

2020
Reopening and Herd Immunity

- **Black**: assumes $R_0(today)$ remains in place forever
- **Red**: assumes $R_0(suppress) = \frac{1}{s(today)}$
- **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
Illinois: Re-Opening ($\alpha = .05$)

\[ R_0(t) = 1.0, \quad R_0(\text{suppress}) = 1.1, \quad R_0(25/50) = 1.2/1.5, \quad \delta = 0.010, \quad \alpha = 0.05 \]

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

Illinois

$R_0(t)=1.0, \; R_0(\text{suppress})=1.1, \; R_0(25/50)=1.2/1.5, \; \delta = 0.010, \; \alpha=0.00$

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

Illinois

$R_0 = 1.8/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%Infect = 7/8/8$

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

$R_0 = 1.8/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $%\text{Infect} = 7/8/8$

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

Illinois

$R_0=1.8/1.0/1.0$  $\delta = 0.010$  $\alpha=0.00$  $\theta=0.1$  $%\text{Infect}= 7/ 8/ 8$

- New York City
- Italy

Cumulative deaths per million people
Illinois: Daily Deaths per Million People ($\delta = 0.8\%$)

Illinois

$R_0 = 1.8/1.0/1.1 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 9/9/10$
Illinois: Cumulative Deaths per Million ($\delta = 0.8\%$)

\[
R_0 = 1.8/1.0/1.1 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 9/9/10
\]
Illinois: Daily Deaths per Million People ($\delta = 1.2\%$)

Illinois

$R_0 = 1.8/1.0/1.0$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  $\%$Infect = 6/6/7
Illinois: Cumulative Deaths per Million ($\delta = 1.2\%$)

R_0 = 1.8/1.0/1.0  \(\delta = 0.012\)  \(\theta = 0.1\)  \(\gamma = 0.2\)  %Infect = 6/6/7
Illinois: Daily Deaths per Million People ($\gamma = .2 / .15$)

Illinois

$R_0 = 1.8 / 1.0 / 1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 7 / 8 / 8$

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

Illinois

$R_0 = 1.8/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%Infect = 7/8/8$

$\gamma = 0.25$

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

Illinois

$R_0 = 1.8/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 7/8/8$

DATA THROUGH 11-SEP-2020

2020
Illinois: Cumulative Deaths per Million People ($\theta = .1/.07/.2$)

Illinois

$R_0=1.8/1.0/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $%\text{Infect}= 7/8/8$

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)
Illinois: Daily Deaths, Actual and Smoothed

Illinois: Daily deaths, \(d\)

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

Illinois: Delta d
\( \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \)
Illinois: Change in Smoothed Daily Deaths

Illinois: Delta (Delta d)
\( \delta = 0.010 \quad \theta=0.10 \quad \gamma=0.20 \)