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

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Extended results for Iowa
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)
Iowa: Daily Deaths per Million People
Iowa: 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)
Iowa: Estimates of $R_0(t)$

$Iowa$

$\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20$

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The graph shows the estimates of $R_0(t)$ for Iowa from March to October 2020, indicating the transmission rate over time. The values of $R_0(t)$ are shown on the y-axis, ranging from 0 to 3.5, with the specific values listed as 0.010, 0.10, and 0.20. The x-axis represents the months of the year, from March to October 2020.
Iowa: Percent Currently Infectious

Peak I/N = 0.28%  Final I/N = 0.16%  δ = 0.010  θ = 0.10  γ = 0.20
Iowa: 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:

     \[
     \log R_0(t) = a_0 - \alpha(Daily \ Deaths)
     \]

     \[\Rightarrow \alpha \approx .05\]

     *$R_0$ 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 $\alpha = 0$)
Iowa (7 days): Daily Deaths per Million People ($\alpha = .05$)

$I_{\text{Total}} = 1.4/1.1/1.1$  \quad $\delta = 0.010$  \quad $\alpha=0.05$  \quad $\theta=0.1$  \quad $\% \text{Infect}= 5/6/9$

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

\[ R_0 = 1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/6/9 \]

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

$Iowa$

$R_0 = 1.4/1.1/1.1 \, \delta = 0.010 \, \alpha = 0.05 \, \theta = 0.1 \, \%Infect = 5/6/9$

New York City

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

\[ R_0 = 1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/6/9 \]

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

Iowa

$R_0 = 1.4 / 1.1 / 1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect $= 5 / 6 / 9$

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

Iowa

$R_0 = 1.4/1.1/1.1$ $\delta = 0.010$ $\alpha = 0.05$ $\theta = 0.1$ %Infect = 5/6/9

DATA THROUGH 11-SEP-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 $R_0 = \text{“normal”}$
– Purple: we move 50% of the way from $R_0$(today) back to initial $R_0 = \text{“normal”}$

NOTE: Lines often cover each other up
Iowa: Re-Opening ($\alpha = .05$)

$Iowa$

$R_0(t)=1.1$, $R_0(suppress)=1.1$, $R_0(25/50)=1.3/1.5$, $\delta = 0.010$, $\alpha=0.05$

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

Iowa

$R_0(t) = 1.1$, $R_0(\text{suppress}) = 1.1$, $R_0(25/50) = 1.3/1.5$, $\delta = 0.010$, $\alpha = 0.00$

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

**Iowa**

$R_0=1.4/1.1/1.1$  \hspace{1em} $\delta = 0.010$  \hspace{1em} $\alpha=0.00$  \hspace{1em} $\theta=0.1$  \hspace{1em} %Infect= 5/ 6/ 9

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

$I_0=1.4/1.1/1.1$  $\delta = 0.010$  $\alpha=0.00$  $\theta=0.1$  %Infect= 5/ 6/ 9

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

$$R_0 = 1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 5/6/9$$
Iowa Daily Deaths per Million People ($\delta = 0.8\%$)

\[ R_0 = 1.4/1.1/1.1 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 6/8/11 \]
Iowa: Cumulative Deaths per Million ($\delta = 0.8\%$)

Iowa
$R_0 = 1.4/1.1/1.1 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 6/8/11$
Iowa: Daily Deaths per Million People ($\delta = 1.2\%$)

Iowa

$R_0 = 1.4/1.1/1.1$, $\delta = 0.012$, $\theta = 0.1$, $\gamma = 0.2$, %Infect = 4/5/7
Iowa: Cumulative Deaths per Million ($\delta = 1.2\%$)

Iowa

$R_0 = 1.4/1.1/1.1 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 4/5/7$
Iowa: Daily Deaths per Million People (γ = 0.2/0.15)

\[ R_0 = 1.4/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/6/9 \]

DATA THROUGH 11-SEP-2020
Iowa: Cumulative Deaths per Million $\gamma = 0.2/0.15$

$I_0 = 1.4/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 5/6/9

DATA THROUGH 11-SEP-2020

Cumulative deaths per million people

Iowa: Daily Deaths per Million People ($\theta = .1/.07/.2$)

$I_{\theta}=1.4/1.1/1.1$  $\alpha=0.05$  $\theta=0.1$  %Infect= 5/6/9

DATA THROUGH 11-SEP-2020
Iowa: Cumulative Deaths per Million People ($\theta = .1/.07/.2$)

Iowa

$R_0=1.4/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 5/ 6/ 9

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)
Iowa: Daily Deaths, Actual and Smoothed

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

Iowa: Delta d
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
**Iowa: Change in (Change in Smoothed Daily Deaths)**

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