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

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

Daily deaths per million people

Mar Apr May Jun Jul Aug

2020
Iran: 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)
Iran: Estimates of $R_0(t)$

Iran

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

Peak I/N = 0.13% Final I/N = 0.08% \( \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \)
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 $\alpha = 0$)
Iran (7 days): Daily Deaths per Million People ($\alpha = .05$)

$R_0 = 1.4/0.9/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 3/3/3$

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

$R_0 = 1.4/0.9/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%$Infect $= 3/3/3$

DATA THROUGH 24-AUG-2020
Iran (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = .05$)

Iran

$R_0=1.4/0.9/1.0 \ \delta = 0.010 \ \alpha=0.05 \ \theta=0.1 \ \%Infect= 3/3/3$

Cumulative deaths per million people

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

DATA THROUGH 24-AUG-2020

Iran

$R_0=1.4/0.9/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 3/3/3
Iran: Daily Deaths per Million People ($\delta = 0.01/0.008/0.012$)

Iran

$R_0 = 1.4/0.9/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 3/3/3

DATA THROUGH 24-AUG-2020
Iran: Cumulative Deaths per Million ($\delta = .01/0.008/0.012$)

$R_0 = 1.4/0.9/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 3/3/3 \quad \delta = 0.008$

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
Iran: Re-Opening ($\alpha = .05$)

Iran

$R_0(t)=0.9$, $R_0($suppress$)=1.0$, $R_0(25/50)=1.2/1.5$, $\delta = 0.010$, $\alpha=0.05$
Iran: Re-Opening ($\alpha = 0$)

$R_0(t) = 0.9$, $R_0$ (suppress) = 1.0, $R_0(25/50) = 1.2/1.4$, $\delta = 0.010$, $\alpha = 0.00$
Results for alternative parameter values
Iran (7 days): Daily Deaths per Million People ($\alpha = 0$)

$$R_0 = 1.4/0.9/0.9 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 3/3/3$$

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

\[ R_0 = 1.4/0.9/0.9 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 3/3/3 \]

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

Iran

$R_0=1.4/0.9/0.9$  $\delta = 0.010$  $\alpha=0.00$  $\theta=0.1$  $\%\text{Infect}=3/3/3$

New York City

Italy

Cumulative deaths per million people

Mar Apr May Jun Jul Aug Sep Oct Nov Dec 2020
Iran: Daily Deaths per Million People ($\delta = 0.8\%$)

Iran

$R_0=1.4/0.9/1.0$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  $\%\text{Infect}=3/4/4$
Iran: Cumulative Deaths per Million ($\delta = 0.8\%$)

Iran

$R_0=1.4/0.9/1.0$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect= 3/ 4/ 4
Iran: Daily Deaths per Million People ($\delta = 1.2\%$)

$R_0 = 1.4/0.9/1.0$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  $\%$Infect $= 2/2/3$
Iran: Cumulative Deaths per Million ($\delta = 1.2\%$)

Cumulative deaths per million people

Iran

$R_0=1.4/0.9/1.0$  $\delta = 0.012$  $\theta=0.1$  $\gamma=0.2$  $% Infection= 2/2/3$
Iran: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

![Graph showing daily deaths per million people in Iran with data through 24-Aug-2020.](image-url)

$R_0 = 1.4/0.9/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 3/3/3
Iran: Cumulative Deaths per Million $\gamma = .2/.15$)

$R_0=1.4/0.9/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%Infect=3/3/3$

DATA THROUGH 24-AUG-2020

Cumulative deaths per million people
Iran: Daily Deaths per Million People ($\theta = .1/.07/.2$)

Daily deaths per million people

DATA THROUGH 24-AUG-2020

$R_0=1.4/0.9/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 3/3/3
Iran: Cumulative Deaths per Million People ($\theta = .1 / .07 / .2$)

$R_0 = 1.4 / 0.9 / 1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infected = 3 / 3 / 3

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)
Iran: Daily Deaths, Actual and Smoothed

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

Iran: Delta d

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

Iran: Delta (Δd)

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