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

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

[Graph showing daily deaths per million people in Iraq from April to September 2020.]
Iraq: 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)
Iraq: Estimates of $R_0(t)$

\[ R_0(t) = 0.010 \]

Iraq
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Iraq: Percent Currently Infectious

Peak I/N = 0.14%   Final I/N = 0.09%   δ = 0.010   θ=0.10   γ=0.20
Iraq: 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)
  o Black = current
  o Red = oldest, Orange = second oldest, Yellow = third oldest...
  o Violet (purple) = one day earlier

• For robustness graphs, same idea
  o Black = baseline (e.g. \( \delta = 1.0\% \))
  o Red = lowest parameter value (e.g. \( \delta = 0.8\% \))
  o 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:

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

$\Rightarrow \alpha \approx 0.05$

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

$R_0 = 1.5/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 2/3/5

DATA THROUGH 11-SEP-2020
Iraq (7 days): Cumulative Deaths per Million (Future, $\alpha = 0.05$)

\[ R_0 = 1.5/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \text{%Infect} = 2/3/5 \]
Iraq (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = .05$)

\[R_0 = 1.5/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \% \text{Infect} = 2/3/5\]
Robustness to Mortality Rate, $\delta$
Iraq: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

\[ R_0 = 1.5/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2/3/5 \]

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

\[ R_0 = 1.5/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2/3/5 \]

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

\[ R_0 = 1.5 / 1.0 / 1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \% \text{Infect} = 2 / 3 / 5 \]

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 $R_0 = “normal”$
– Purple: we move 50% of the way from $R_0(today)$ back to initial $R_0 = “normal”$

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

$Iraq$

$R_0(t)=1.0, \ R_0(\text{suppress})=1.0, \ R_0(25/50)=1.3/1.5, \ \delta = 0.010, \ \alpha=0.05$

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

Iraq

$R_0(t)=1.0, \ R_0(\text{suppress})=1.0, \ R_0(25/50)=1.3/1.5, \ \delta = 0.010, \ \alpha=0.00$

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

\[
R_0 = 1.5/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 2/3/4
\]

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

$R_0 = 1.5/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%\text{Infect} = 2/3/4$

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

Iraq
\[ R_0 = 1.5/1.0/1.0 \] \[ \delta = 0.010 \] \[ \alpha = 0.00 \] \[ \theta = 0.1 \] \[ \%\text{Infect} = 2/3/4 \]
Iraq: Daily Deaths per Million People ($\delta = 0.8\%$)

R$_0$=1.5/1.0/1.1  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect= 3/3/6
Iraq: Cumulative Deaths per Million ($\delta = 0.8\%$)

\[
R_0 = 1.5/1.0/1.1 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 3/3/6
\]
Iraq: Daily Deaths per Million People ($\delta = 1.2\%$)

\[ R_0 = 1.5/1.0/1.0 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 2/2/4 \]
Iraq: Cumulative Deaths per Million ($\delta = 1.2\%$)

Iraq

$R_0 = 1.5/1.0/1.0$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 2/2/4
Iraq: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

Iraq

$R_0 = 1.5/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect = 2/3/5

DATA THROUGH 11-SEP-2020
Iraq: Cumulative Deaths per Million \( \gamma = 0.2 / 0.15 \)

\[ R_0 = 1.5 / 1.0 / 1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \% \text{Infect} = 2 / 3 / 5 \]
Iraq: Daily Deaths per Million People ($\theta = .1/.07/.2$)

Iraq

$R_0=1.5/1.0/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 2/3/5

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

$R_0 = 1.5 / 1.0 / 1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad %\text{Infect} = 2 / 3 / 5$

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)
Iraq: Daily Deaths, Actual and Smoothed

Iraq: Daily deaths, \( d \)

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

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

Iraq: Delta (Δd)

Δ = 0.010  θ = 0.10  γ = 0.20