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 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)
Iraq: Daily Deaths per Million People

![Graph showing daily deaths per million people in Iraq from April to August 2020.](image-url)
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 $R_0(t)$

$Iraq$

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

Peak I/N = 0.14%   Final I/N = 0.10%   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)
  - 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:

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

     \[\Rightarrow \alpha \approx 0.05\]

     $R_0$ 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 ($\alpha = .05$)

\[ R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2/3/7 \]

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

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 2/ 3/ 7

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

Iraq

$R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2/3/7$

Cumulative deaths per million people

New York City

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

\[ R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2/3/7 \]

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

\[ R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \text{%Infect} = 2/3/7 \]

DATA THROUGH 24-AUG-2020

Daily deaths per million people

**Iraq: Cumulative Deaths per Million**

\[ \delta = 0.01/0.008/0.012 \]

**Iraq**

\[ R_0 = 1.5/1.1/1.1 \]

\[ \delta = 0.010 \]

\[ \alpha = 0.05 \]

\[ \theta = 0.1 \]

%Infect = 2/3/7

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

$Iraq$

$R_0(t)=1.1, \ R_0(\text{suppress})=1.0, \ R_0(25/50)=1.3/1.5, \ \delta = 0.010, \ \alpha=0.05$
Iraq: Re-Opening ($\alpha = 0$)

Iraq

$R_0(t) = 1.1, \ R_0(\text{suppress}) = 1.0, \ R_0(25/50) = 1.3/1.6, \ \delta = 0.010, \ \alpha = 0.00$
Results for alternative parameter values
Iraq (7 days): Daily Deaths per Million People \( (\alpha = 0) \)

\[ R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 2/3/14 \]
Iraq (7 days): Cumulative Deaths per Million (Future, $\alpha = 0$)

$Iraq$

$R_0 = 1.5/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \% \text{Infect} = 2/3/14$

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

**Iraq**

$R_0 = 1.5/1.1/1.1$, $\delta = 0.010$, $\alpha = 0.00$, $\theta = 0.1$, %Infect = 2/3/14

New York City

Italy

Cumulative deaths per million people

Iraq: Daily Deaths per Million People ($\delta = 0.8\%$)

Iraq

$R_0 = 1.5/1.1/1.1 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad %\text{Infect} = 2/3/9$
Iraq: Cumulative Deaths per Million ($\delta = 0.8\%$)

Iraq

$R_0 = 1.5/1.1/1.1$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  $\%$ Infect $= 2/3/9$
Iraq: Daily Deaths per Million People ($\delta = 1.2\%$)

\[ R_0 = 1.5/1.1/1.1 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 2/2/6 \]
Iraq: Cumulative Deaths per Million ($\delta = 1.2\%$)

\[ R_0 = 1.5/1.1/1.1 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 2/2/6 \]
Iraq: Daily Deaths per Million People ($\gamma = 2/1.15$)

$Iraq$

$R_0=1.5/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\% Infections = 2/3/7$

DATA THROUGH 24-AUG-2020
Iraq: Cumulative Deaths per Million $\gamma = .2 / .15$)

Iraq

$R_0 = 1.5/1.1/1.1$ \hspace{1cm} $\delta = 0.010$ \hspace{1cm} $\alpha = 0.05$ \hspace{1cm} $\theta = 0.1$ \hspace{1cm} $\%$ Infection $= 2/3/7$

DATA THROUGH 24-AUG-2020

$\gamma = 0.15$

$\gamma = 0.2$

Cumulative deaths per million people

Jun 2020 \hspace{1cm} Jul 2020 \hspace{1cm} Aug 2020 \hspace{1cm} Sep 2020 \hspace{1cm} Oct 2020 \hspace{1cm} Nov 2020 \hspace{1cm} Dec 2020 \hspace{1cm} Jan 2021 \hspace{1cm} Feb 2021 \hspace{1cm} Mar 2021
Iraq: Daily Deaths per Million People ($\theta = 1 / .07 / .2$)

$R_0 = 1.5 / 1.1 / 1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 2 / 3 / 7$

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

![Graph showing cumulative deaths per million people in Iraq with different values of $\theta$.]

- $R_0 = 1.5/1.1/1.1$
- $\delta = 0.010$
- $\alpha = 0.05$
- $\theta = 0.1$
- %Infect = 2/3/7

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)
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

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

Iraq: Delta (Delta d)

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