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

Jesús Fernández-Villaverde and Chad Jones

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

Oman
Oman: 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)
Oman: Estimates of $R_0(t)$

Oman

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

Peak I/N = 0.11%  Final I/N = 0.06%  \( \delta = 0.010 \)  \( \theta = 0.10 \)  \( \gamma = 0.20 \)
Oman: 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:

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

$\Rightarrow \alpha \approx .05$

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

Oman

$R_0 = 1.1/0.7/0.8$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect $= 1/1/1$

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

\[ R_0 = 1.1/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \text{%Infect} = 1/1/1 \]

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

R\_0 = 1.1/0.7/0.8  $\delta = 0.010  \alpha = 0.05  \theta = 0.1  \text{%Infect} = 1/1/1
Robustness to Mortality Rate, $\delta$
Oman: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

$R_0=1.1/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1$

DATA THROUGH 24-AUG-2020
**Oman: Daily Deaths per Million People**

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

\[ R_0 = 1.1/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1 \]

DATA THROUGH 24-AUG-2020
Oman: Cumulative Deaths per Million ($\delta = 0.01/0.008/0.012$)

$R_0 = 1.1/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1$

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

$$R_0(t)=0.7, \; R_0(\text{suppress})=1.0, \; R_0(25/50)=1.0/1.4, \; \delta = 0.010, \; \alpha=0.05$$
Oman: Re-Opening ($\alpha = 0$)

**Oman**

$R_0(t)=0.7$, $R_0$ (suppress) = 1.0, $R_0(25/50)$ = 1.0/1.4, $\delta = 0.010$, $\alpha=0.00$
Results for alternative parameter values
Oman (7 days): Daily Deaths per Million People ($\alpha = 0$)

Oman

$R_0 = 1.1/0.7/0.7$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%\text{Infect} = 1/1/1$

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

$R_0 = 1.1/0.7/0.7 \quad \delta = 0.01 \quad \alpha = 0.0 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1$

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

\[ R_0 = 1.1/0.7/0.7 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1 \]
Oman: Daily Deaths per Million People ($\delta = 0.8\%$)

\begin{align*}
\text{Daily deaths per million people} & \\
\text{Oman} & \\
R_0 & = 1.1/0.7/0.8 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 2/2/2
\end{align*}
Oman: Cumulative Deaths per Million ($\delta = 0.8\%$)
Oman: Daily Deaths per Million People (δ = 1.2%)
Oman: Cumulative Deaths per Million ($\delta = 1.2\%$)

\[ R_0 = 1.1/0.7/0.8 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 1/1/1 \]
Oman: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

$R_0 = 1.1/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1$

Data through 24-Aug-2020
Oman: Cumulative Deaths per Million $\gamma = .2 / .15$)

\[ R_0 = 1.1 / 0.7 / 0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1 / 1 / 1 \]

\[ \gamma = 0.25 \]
Oman: Daily Deaths per Million People ($\theta = .1/.07/.2$)

\[ R_0 = 1.1/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/1 \]

DATA THROUGH 24-AUG-2020
Oman: Cumulative Deaths per Million People ($\theta = 1/0.07/0.2$)

R$_0$=1.1/0.7/0.8  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect= 1/ 1/ 1

DATA THROUGH 24-AUG-2020

$\theta = 0.2$

$\theta \equiv \theta_{0.7}$
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)
Oman: Daily Deaths, Actual and Smoothed

Oman: Daily deaths, $d$

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

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

Oman: Delta (Δd)

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