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

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

Honduras

Daily deaths per million people

Apr May Jun Jul Aug

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

Honduras

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

Honduras
Peak I/N = 0.18%  Final I/N = 0.03%  δ = 0.010  θ=0.10  γ=0.20
Honduras: Growth Rate of Daily Deaths over Past Week (percent)

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

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

$$\Rightarrow \alpha \approx 0.05$$

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

Honduras

$R_0 = 1.1/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect = 2/2/2

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

\[ R_0 = 1.1/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \% \text{Infect} = 2/2/2 \]

Data through 24-Aug-2020
Honduras (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = .05$)

Honduras
$R_0=1.1/1.0/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 2/ 2/ 2
Robustness to Mortality Rate, $\delta$
Honduras: Cumulative Deaths per Million \( (\delta = .01/\ .008/\ .012) \)

\[
R_0 = 1.1/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 2/2/2
\]

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

Honduras

$R_0=1.1/1.0/1.0 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=2/2/2$

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

Honduras

$R_0=1.1/1.0/1.0 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=2/2/2$

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

Honduras

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

Honduras

$R_0(t)=1.0$, $R_0(\text{suppress})=1.0$, $R_0(25/50)=1.2/1.5$, $\delta = 0.010$, $\alpha=0.00$
Results for alternative parameter values
Honduras (7 days): Daily Deaths per Million People ($\alpha = 0$)

$R_0 = 1.1/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 2/2/2$

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

Honduras

$R_0=1.1/1.0/1.0$  $\delta = 0.010$  $\alpha=0.00$  $\theta=0.1$  %Infect= 2/2/2

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

Honduras

$R_0 = 1.1, 1.0, 1.0$ \hspace{1cm} $\delta = 0.010$ \hspace{1cm} $\alpha = 0.00$ \hspace{1cm} $\theta = 0.1$ \hspace{1cm} $\%\text{Infect} = 2/2/2$

Cumulative deaths per million people

Mar 2020 \hspace{1cm} May 2020 \hspace{1cm} Jul 2020 \hspace{1cm} Sep 2020 \hspace{1cm} Nov 2020 \hspace{1cm} Jan 2021 \hspace{1cm} Mar 2021
Honduras: Daily Deaths per Million People ($\delta = 0.8\%$)

Honduras

$R_0 = 1.1/1.0/1.0$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 2/2/3
Honduras: Cumulative Deaths per Million ($\delta = 0.8\%$)

Honduras

$R_0 = 1.1/1.0/1.0 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 2/2/3$
Honduras: Daily Deaths per Million People ($\delta = 1.2\%$)

Honduras

$R_0 = 1.1/1.0/1.0$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 1/1/2

Daily deaths per million people

Honduras: Cumulative Deaths per Million ($\delta = 1.2\%$)

Honduras

$R_0 = 1.1/1.0/1.0 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 1/1/2$
Honduras: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

**Honduras**

$R_0 = 1.1/1.0/1.0 \hspace{1cm} \delta = 0.010 \hspace{1cm} \alpha = 0.05 \hspace{1cm} \theta = 0.1 \hspace{1cm} \%I nfect = 2/2/2$
Honduras: Cumulative Deaths per Million $\gamma = 0.2/0.15$)

\[ R_0 = 1.1/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2/2/2 \]

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

Honduras

$R_0 = 1.1 / 1.0 / 1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2 / 2 / 2$

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

Data through 24-Aug-2020

$R_0 = 1.1/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 2/2/2
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)
Honduras: Daily Deaths, Actual and Smoothed

Honduras: Daily deaths, $d$

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

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

Honduras: Delta (Δd)

Δ = 0.010 \quad θ = 0.10 \quad γ = 0.20