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

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Extended results for Houston (Harris Co.)
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)
Houston (Harris Co.): Daily Deaths per Million People

Houston (Harris Co.)

Daily deaths per million people

Apr May Jun Jul Aug

2020
Houston (Harris Co.): 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)
Houston (Harris Co.): Estimates of $R_0(t)$

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Houston (Harris Co.): Percent Currently Infectious

Houston (Harris Co.)
Peak I/N = 0.42%  Final I/N = 0.40%  δ = 0.010  θ = 0.10  γ = 0.20
Houston (Harris Co.): Growth Rate of Daily Deaths over Past Week (percent, past week)

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

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

  $$\Rightarrow \alpha \approx .05$$

  $R_0$ 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 \( \alpha = 0 \))
Houston (Harris Co.) (7 days): Cumulative Deaths per Million (Future, α)

Houston (Harris Co.)

$R_0 = 1.3/0.9/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect $= 5/7/10$

DATA THROUGH 24-AUG-2020
Houston (Harris Co.) (7 days): Cumulative Deaths per Million, Log Scale

Houston (Harris Co.)
\[ R_0 = 1.3/0.9/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/7/10 \]
Robustness to Mortality Rate, $\delta$
Houston (Harris Co.): Cumulative Deaths per Million ($\delta = 0.01/0.008/0.012$)

Houston (Harris Co.)

$R_0 = 1.3/0.9/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect = 5/7/10

DATA THROUGH 24-AUG-2020
Houston (Harris Co.): Daily Deaths per Million People ($\delta = 0.01/0.008/0.012$)

R$_0$ = 1.3/0.9/1.1  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 5/7/10

Data through 24-Aug-2020
Houston (Harris Co.): Cumulative Deaths per Million ($\delta = 0.01/0.008/0.012$)

Houston (Harris Co.)

$R_0 = 1.3/0.9/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 5/7/10

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

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

Houston (Harris Co.)

$R_0(t)=0.9$, $R_0$ (suppress)$=1.1$, $R_0(25/50)=1.2/1.5$, $\delta = 0.010$, $\alpha=0.05$
Houston (Harris Co.): Re-Opening ($\alpha = 0$)

Houston (Harris Co.)

$R_0(t) = 1.0, \ R_0(\text{suppress}) = 1.1, \ R_0(25/50) = 1.2/1.5, \ \delta = 0.010, \ \alpha = 0.00$
Results for alternative parameter values
Houston (Harris Co.) (7 days): Daily Deaths per Million People ($\alpha = 0$)

Houston (Harris Co.)

$R_0 = 1.3/1.0/1.0$  $\delta = 0.010$  $\alpha=0.00$  $\theta=0.1$  $\%\text{Infect}=5/7/8$

DATA THROUGH 24-AUG-2020
Houston (Harris Co.) (7 days): Cumulative Deaths per Million (Future, α)

\[ R_0 = 1.3/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 5/7/8 \]

DATA THROUGH 24-AUG-2020
Houston (Harris Co.) (7 days): Cumulative Deaths per Million, Log Scale

Cumulative deaths per million people

Houston (Harris Co.)

$R_0 = 1.3/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 5/7/8$

New York City

Italy

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

$R_0 = 1.3/1.0/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  %Infect $= 7/8/13$
Houston (Harris Co.): Cumulative Deaths per Million ($\delta = 0.8\%$)

Houston (Harris Co.)

$R_0 = 1.3/1.0/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 7/8/13
Houston (Harris Co.): Daily Deaths per Million People ($\delta = 1.2\%$)

Houston (Harris Co.)

$R_0 = 1.3/0.9/1.1 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 4/6/9$
Houston (Harris Co.): Cumulative Deaths per Million ($\delta = 1.2\%$)

Houston (Harris Co.)

$R_0 = 1.3/0.9/1.1$  
$\delta = 0.012$  
$\theta = 0.1$  
$\gamma = 0.2$  
$\%Infect = 4/6/9$
Houston (Harris Co.): Daily Deaths per Million People ($\gamma = .2/.15$)

$R_0 = 1.3/0.9/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infected = 5/7/10

DATA THROUGH 24-AUG-2020
Houston (Harris Co.): Cumulative Deaths per Million $\gamma = .2/.15$
Houston (Harris Co.): Daily Deaths per Million People ($\theta = 1/0.07/0.2$)

Houston (Harris Co.)

$R_0=1.3/0.9/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 5/7/10

DATA THROUGH 24-AUG-2020
Houston (Harris Co.): Cumulative Deaths per Million People ($\theta = 0.1/0.07$)

$R_0 = 1.3/0.9/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%Infect = 5/7/10$

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)
Houston (Harris Co.): Daily deaths, d

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Houston (Harris Co.): Change in Smoothed Daily Deaths

Houston (Harris Co.): Delta d
δ = 0.010  θ = 0.10  γ = 0.20

2020
Houston (Harris Co.): Change in (Change in Smoothed Daily Deaths)

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