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

Houston (Harris Co.)

Daily deaths per million people

Apr May Jun Jul Aug Sep
0 2 4 6 8 10 12 14
0 2 4 6 8 10 12 14
Apr May Jun Jul Aug Sep
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 $R_0(t)$

Houston (Harris Co.)

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

Houston (Harris Co.)
Peak I/N = 0.41%  Final I/N = 0.13%  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:

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

     $$\Rightarrow \alpha \approx 0.05$$

     $R_0$ declines by 5 percent for each new daily death, or rises by 5 percent when daily deaths decline

- Robustness: Assume $R_0(t) =$ 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): Daily Deaths per Million People ($\alpha = .05$)

Houston (Harris Co.)

$R_0 = 1.3/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5$

DATA THROUGH 11-SEP-2020
Houston (Harris Co.) (7 days): Cumulative Deaths per Million (Future, α)

$R_0 = 1.3/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 5/5/5$

Data through 11-Sep-2020
Houston (Harris Co.) (7 days): Cumulative Deaths per Million, Log Scale

Houston (Harris Co.)

$R_0=1.3/0.7/0.8 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=5/5/5$

New York City

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

Houston (Harris Co.)

$R_0 = 1.3/0.7/0.8$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect = 5/5/5

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

Data through 11-Sep-2020

$R_0 = 1.3/0.7/0.8$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $%\text{Infect} = 5/5/5$
Houston (Harris Co.): Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Houston (Harris Co.)

$R_0 = 1.3/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5$

DATA THROUGH 11-SEP-2020
Reopening and Herd Immunity

– Black: assumes $R_0(\text{today})$ remains in place forever
– Red: assumes $R_0(\text{suppress}) = 1/s(\text{today})$
– Green: we move 25% of the way from $R_0(\text{today})$ back to initial $R_0 = \text{“normal”}$
– Purple: we move 50% of the way from $R_0(\text{today})$ back to initial $R_0 = \text{“normal”}$

NOTE: Lines often cover each other up
Houston (Harris Co.): Re-Opening ($\alpha = 0.05$)

Houston (Harris Co.)
$R_0(t) = 0.7$, $R_0$ (suppress) = 1.1, $R_0(25/50)$ = 1.0/1.3, $\delta = 0.010$, $\alpha = 0.05$

(Light bars = New York City, for comparison)
Houston (Harris Co.): Re-Opening \((\alpha = 0)\)

\[
R_0(t) = 0.6, \quad R_0(\text{suppress}) = 1.1, \quad R_0(25/50) = 1.0/1.3, \quad \delta = 0.010, \quad \alpha = 0.00
\]

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

Houston (Harris Co.)

$R_0 = 1.3/0.6/0.6$ \hspace{0.5cm} $\delta = 0.010$ \hspace{0.5cm} $\alpha = 0.00$ \hspace{0.5cm} $\theta = 0.1$ \hspace{0.5cm} %Infect = 5/5/5

DATA THROUGH 11-SEP-2020
Houston (Harris Co.) (7 days): Cumulative Deaths per Million (Future, α)

R₀ = 1.3/0.6/0.6  δ = 0.010  α = 0.00  θ = 0.1  %Infect = 5/5/5

DATA THROUGH 11-SEP-2020
Houston (Harris Co.) (7 days): Cumulative Deaths per Million, Log Scale

Houston (Harris Co.)

\[ R_0 = 1.3/0.6/0.6 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5 \]
Houston (Harris Co.): Daily Deaths per Million People ($\delta = 0.8\%$)

Houston (Harris Co.)
$R_0 = 1.3/0.7/0.8$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 7/7/7
Houston (Harris Co.): Cumulative Deaths per Million ($\delta = 0.8\%$)

Houston (Harris Co.)

$R_0 = 1.3/0.7/0.8$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $%Infect = 7/7/7$
Houston (Harris Co.): Daily Deaths per Million People ($\delta = 1.2\%$)

Houston (Harris Co.)

$R_0 = 1.3/0.7/0.8$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  $\%\text{Infect} = 4/5/5$
Houston (Harris Co.): Cumulative Deaths per Million ($\delta = 1.2\%$)

Houston (Harris Co.)

$R_0 = 1.3/0.7/0.8 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 4/5/5$
Houston (Harris Co.): Daily Deaths per Million People (\(\gamma = 0.2/0.15\))

Houston (Harris Co.)

\(R_0 = 1.3/0.7/0.8\)  \(\delta = 0.010\)  \(\alpha = 0.05\)  \(\theta = 0.1\)  \%Infect = 5/5/5

DATA THROUGH 11-SEP-2020
Houston (Harris Co.): Cumulative Deaths per Million $\gamma = .2/ .15$

Houston (Harris Co.)
$R_0 = 1.3/0.7/0.8 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 5/5/5$

DATA THROUGH 11-SEP-2020

$\gamma = 0.15$
Houston (Harris Co.): Daily Deaths per Million People ($\theta = .1/.07/.2$)

Houston (Harris Co.)

$R_0=1.3/0.7/0.8 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=5/5/5$

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

Houston (Harris Co.)

$R_0 = 1.3 / 0.7 / 0.8$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 5 / 5 / 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)
Houston (Harris Co.): Daily Deaths, Actual and Smoothed

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

Houston (Harris Co.): Delta \( \delta \)

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

Houston (Harris Co.): Delta (Delta d)
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]