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

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Extended results for Trinidad and Tobago
Based on data through October 9, 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)
Trinidad and Tobago: Daily Deaths per Million People
Trinidad and Tobago: 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)
Trinidad and Tobago: Estimates of $R_0(t)$

Trinidad and Tobago
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Trinidad and Tobago: Percent Currently Infectious

Trinidad and Tobago
Peak I/N = 0.09%  Final I/N = 0.05%  δ = 0.010  θ = 0.10  γ = 0.20
Trinidad and Tobago: Growth Rate of Daily Deaths over Past Week (percent, past week)

Trinidad and Tobago

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

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

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

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

Trinidad and Tobago

$R_0 = 1.4/1.2/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%Infect = 1/1/9$

DATA THROUGH 09-OCT-2020
Trinidad and Tobago (7 days): Cumulative Deaths per Million (Future, Oct 2020)

Trinidad and Tobago

$R_0 = 1.4/1.2/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/9$

DATA THROUGH 09-OCT-2020
Trinidad and Tobago (7 days): Cumulative Deaths per Million, Log Scale

Trinidad and Tobago

$R_0 = 1.4/1.2/1.1$  \( \delta = 0.010 \)  \( \alpha = 0.05 \)  \( \theta = 0.1 \)  \( \%\text{Infect} = 1/1/9 \)
Robustness to Mortality Rate, $\delta$
Trinidad and Tobago: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Trinidad and Tobago

$R_0=1.4/1.2/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%\text{Infect}=1/1/9$

DATA THROUGH 09-OCT-2020
Trinidad and Tobago: Daily Deaths per Million People \((\delta = .01/.008/.012)\)

\[ R_0 = 1.4/1.2/1.1 \]

\[ \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/9 \]

DATA THROUGH 09-OCT-2020
Trinidad and Tobago: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

DATA THROUGH 09-OCT-2020

Cumulative deaths per million people

Trinidad and Tobago

$R_0=1.4/1.2/1.1 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect} = 1/1/9$
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
Trinidad and Tobago: Re-Opening \( (\alpha = .05) \)

Trinidad and Tobago

\[ R_0(t)=1.2, \ R_0(\text{suppress})=1.0, \ R_0(25/50)=1.4/1.6, \ \delta = 0.010, \ \alpha=0.05 \]

(Light bars = New York City, for comparison)
Trinidad and Tobago: Re-Opening ($\alpha = 0$)

Trinidad and Tobago

$R_0(t)=1.2$, $R_0$ (suppress)=1.0, $R_0(25/50)=1.4/1.6$, $\delta = 0.010$, $\alpha=0.00$

(Light bars = New York City, for comparison)
Results for alternative parameter values
Trinidad and Tobago (7 days): Daily Deaths per Million People ($\alpha = 0$)

Trinidad and Tobago

$R_0 = 1.4/1.2/1.2$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$Infect = 1/1/30

DATA THROUGH 09-OCT-2020
Trinidad and Tobago (7 days): Cumulative Deaths per Million (Future, Oct 2020)

Trinidad and Tobago

\[ R_0 = 1.4/1.2/1.2 \delta = 0.010 \alpha = 0.00 \theta = 0.1 \%Infect = 1/1/30 \]

DATA THROUGH 09-OCT-2020
Trinidad and Tobago (7 days): Cumulative Deaths per Million, Log Scale

Trinidad and Tobago

$R_0 = 1.4/1.2/1.2 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 1/\ 1/30$
Trinidad and Tobago: Daily Deaths per Million People ($\delta = 0.8\%$)

Trinidad and Tobago

$R_0=1.4/1.2/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $\%$Infect = 1/2/11
Trinidad and Tobago: Cumulative Deaths per Million ($\delta = 0.8\%$)

Trinidad and Tobago

$R_0 = 1.4/1.2/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $\%$Infect = 1/2/11
Trinidad and Tobago: Daily Deaths per Million People ($\delta = 1.2\%$)

Trinidad and Tobago

$R_0 = 1.4/1.2/1.1 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 1/1/8$
Trinidad and Tobago: Cumulative Deaths per Million ($\delta = 1.2\%$)
Trinidad and Tobago: Daily Deaths per Million People ($\gamma = .2/.15$)

Trinidad and Tobago

$R_0 = 1.4/1.2/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = $1/1/9$

DATA THROUGH 09-OCT-2020
Trinidad and Tobago: Cumulative Deaths per Million $\gamma = .2 / .15$.

Trinidad and Tobago

$R_0 = 1.4 / 1.2 / 1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infected = 1/1/9

DATA THROUGH 09-OCT-2020
Trinidad and Tobago: Daily Deaths per Million People ($\theta = .1/ .07/ .2$)

Trinidad and Tobago

$R_0 = 1.4/1.2/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 1/1/9$

DATA THROUGH 09-OCT-2020
Trinidad and Tobago: Cumulative Deaths per Million People ($\theta = .1/.07$)

Trinidad and Tobago

$R_0 = 1.4/1.2/1.1 \ \delta = 0.010 \ \alpha = 0.05 \ \theta = 0.1 \ \%\text{Infect} = 1/1/9$

DATA THROUGH 09-OCT-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)
Trinidad and Tobago: Daily Deaths, Actual and Smoothed

Trinidad and Tobago: Daily deaths, \( d \)
\( \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \)
Trinidad and Tobago: Change in Smoothed Daily Deaths

Trinidad and Tobago: Delta $d$

$\delta = 0.010 \ \theta = 0.10 \ \gamma = 0.20$
Trinidad and Tobago: Change in (Change in Smoothed Daily Deaths)

Trinidad and Tobago: Delta (Delta d)

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