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

Jesús Fernández-Villaverde and Chad Jones

Extended results for Florida
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)
Florida: Daily Deaths per Million People
### 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)
Florida: Estimates of $R_0(t)$

Florida
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Florida: Percent Currently Infectious

Peak I/N = 0.44%  Final I/N = 0.19%  δ = 0.010  θ = 0.10  γ = 0.20
Florida: Growth Rate of Daily Deaths over Past Week (percent)

Florida

$\delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20$
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:
  - 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 $\alpha = 0$)
Florida (7 days): Daily Deaths per Million People ($\alpha = .05$)

Florida

$R_0=1.4/1.0/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%Infect=6/7/9$

DATA THROUGH 11-SEP-2020
Florida (7 days): Cumulative Deaths per Million (Future, $\alpha = .05$)

Florida

$R_0=1.4/1.0/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%Infect=6/7/9$

DATA THROUGH 11-SEP-2020

Cumulative deaths per million people

Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec  Jan  2020
Florida (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0.05$)

Florida

$R_0 = 1.4/1.0/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%Infect = 6/7/9$
Robustness to Mortality Rate, $\delta$
Florida: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Florida

$R_0=1.4/1.0/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 6/7/9

DATA THROUGH 11-SEP-2020
Florida: Daily Deaths per Million People (δ = 0.01/0.008/0.012)

江西省：每日每百万人口死亡人数（δ = 0.01/0.008/0.012）

R₀ = 1.4/1.0/1.1  δ = 0.010  θ = 0.1  %Infect = 6/7/9

图示数据截至2020年9月11日
Florida: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Florida

$R_0 = 1.4/1.0/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 6/7/9$

DATA THROUGH 11-SEP-2020

Cumulative deaths per million people
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
Florida: Re-Opening ($\alpha = .05$)

Florida

$R_0(t)=1.0$, $R_0(\text{suppress})=1.1$, $R_0(25/50)=1.2/1.5$, $\delta = 0.010$, $\alpha=0.05$

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

Florida

$R_0(t) = 1.0$, $R_0(suppress) = 1.1$, $R_0(25/50) = 1.2/1.5$, $\delta = 0.010$, $\alpha = 0.00$

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

$R_0 = 1.4 / 1.0 / 1.0$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$Infect = 6 / 7 / 8

DATA THROUGH 11-SEP-2020
Florida (7 days): Cumulative Deaths per Million (Future, $\alpha = 0$)

Florida

$R_0 = 1.4/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  %Infect = 6/7/8

DATA THROUGH 11-SEP-2020
Florida (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0$)

Florida

$R_0 = 1.4/1.0/1.0$  \( \delta = 0.010 \)  \( \alpha = 0.00 \)  \( \theta = 0.1 \)  \%Infect = 6/7/8

New York City

Italy
Florida: Daily Deaths per Million People ($\delta = 0.8\%$)

Florida

$R_0=1.4/1.0/1.1$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  $\%$Infect= 8/ 9/11
Florida: Cumulative Deaths per Million ($\delta = 0.8\%$)

Florida

$R_0 = 1.4/1.0/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  $\%$ Infect $= 8/9/11$
Florida: Daily Deaths per Million People ($\delta = 1.2\%$)

Florida

$R_0 = 1.4/1.0/1.1$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  %Infect $= 5/6/8$
Florida: Cumulative Deaths per Million ($\delta = 1.2\%$)

Florida

$R_0 = 1.4/1.0/1.1$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 5/6/8
Florida: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

Florida

$R_0=1.4/1.0/1.1 \ \delta = 0.010 \ \alpha=0.05 \ \theta=0.1 \ \%\text{Infect}= 6/7/9$

Data through 11-Sep-2020
Florida: Cumulative Deaths per Million $\gamma = .2/.15$)

Florida
$R_0=1.4/1.0/1.1 \delta = 0.010 \alpha=0.05 \theta=0.1 \%Infect= 6/7/9$

DATA THROUGH 11-SEP-2020

Cumulative deaths per million people

Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan

2020
Florida: Daily Deaths per Million People ($\theta = .1/0.07/0.2$)

Florida

$R_0 = 1.4/1.0/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect = 6/7/9

DATA THROUGH 11-SEP-2020
Florida: Cumulative Deaths per Million People ($\theta = .1/.07/.2$)

Florida

$R_0 = 1.4/1.0/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect = 6/7/9

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)
Florida: Daily Deaths, Actual and Smoothed

Florida: Daily deaths, $d$

\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Florida: Change in Smoothed Daily Deaths

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

Florida: Delta (Δd)
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]