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

Jesús Fernández-Villaverde and Chad Jones

Extended results for Miami
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)
Miami: 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)
Miami: Estimates of $R_0(t)$

$R_0(t)$ Miami

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

Miami
Peak I/N = 0.69%  Final I/N = 0.51%  δ = 0.010  θ = 0.10  γ = 0.20
Miami: Growth Rate of Daily Deaths over Past Week (percent)

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

$R_0 = 1.7/1.1/1.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 10/12/19$

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

$R_0=1.7/1.1/1.2 \, \delta = 0.010 \, \alpha=0.05 \, \theta=0.1 \, \% \text{Infect}=10/12/19$

DATA THROUGH 24-AUG-2020
Miami (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0.05$)

Miami

$R_0 = 1.7/1.1/1.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect=10/12/19
Robustness to Mortality Rate, $\delta$
Miami: Cumulative Deaths per Million ($\delta = .01/0.008/0.012$)

Miami

$R_0 = 1.7/1.1/1.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect = 10/12/19

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

$R_0 = 1.7/1.1/1.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 10/12/19$

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

Data through 24-Aug-2020

$R_0 = 1.7/1.1/1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 10/12/19$

Cumulative deaths per million people

March April May June July August September October November December 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
Miami: Re-Opening ($\alpha = .05$)

Miami

$R_0(t)=1.1$, $R_0(\text{suppress})=1.1$, $R_0(25/50)=1.3/1.5$, $\delta = 0.010$, $\alpha=0.05$
Miami: Re-Opening ($\alpha = 0$)

Miami

$R_0(t) = 1.0$, $R_0(\text{suppress}) = 1.1$, $R_0(25/50) = 1.3/1.5$, $\delta = 0.010$, $\alpha = 0.00$
Results for alternative parameter values
Miami (7 days): Daily Deaths per Million People ($\alpha = 0$)

$R_0 = 1.7/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 10/12/14$

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

Miami

$R_0 = 1.7/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$ Infect = 10/12/14

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

$R_0=1.7/1.0/1.0$ $\delta = 0.010$ $\alpha = 0.00$ $\theta = 0.1$ $\%$ Infect = 10/12/14
Miami: Daily Deaths per Million People ($\delta = 0.8\%$)

Miami

$R_0=1.7/1.1/1.3 \quad \delta = 0.008 \quad \theta=0.1 \quad \gamma=0.2 \quad \%\text{Infect}=12/15/23$
Miami: Cumulative Deaths per Million ($\delta = 0.8\%$)

Miami

$R_0 = 1.7/1.1/1.3 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad %\text{Infect} = 12/15/23$
Miami: Daily Deaths per Million People ($\delta = 1.2\%$)

Miami

$R_0 = 1.7/1.0/1.2$  $\delta = 0.012$  $\theta = 0.1$  $\gamma = 0.2$  $\%\text{Infect} = 8/10/16$
Miami: Cumulative Deaths per Million ($\delta = 1.2\%$)

Miami

$R_0=1.7/1.0/1.2 \quad \delta = 0.012 \quad \theta=0.1 \quad \gamma=0.2 \quad \%\text{Infect}=8/10/16$
Miami: Daily Deaths per Million People ($\gamma = .2/.15$)

$R_0=1.7/1.1/1.2$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%\text{Infect}=10/12/19$

DATA THROUGH 24-AUG-2020
Miami: Cumulative Deaths per Million $\gamma = .2 / .15$)
Miami: Daily Deaths per Million People ($\theta = .1/.07/.2$)

$R_0 = 1.7/1.1/1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \%Infect = 10/12/19$

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

Miami

$R_0=1.7/1.1/1.2$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect=10/12/19

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)
Miami: Daily Deaths, Actual and Smoothed

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

Miami: Delta $d$

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

Miami: Delta (Δd)

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