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

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Extended results for Connecticut
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)
Brief Summary of Model

• See the paper for a full exposition

• A 5-state SIRDC model with a time-varying $R_0$

| Parameter | Baseline | Description |
|-----------|----------|-------------|
| $\delta$  | 1.0%     | Mortality rate from infections (IFR) |
| $\gamma$  | 0.2      | Rate at which people stop being infectious |
| $\theta$  | 0.1      | Rate at which cases (post-infection) resolve |
| $\alpha$  | 0.05     | Rate at which $R_0(t)$ decays with daily deaths |
| $R_0$     | ...      | Initial base reproduction rate |
| $R_0(t)$  | ...      | Base reproduction rate at date $t$ ($\beta_t/\gamma$) |
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)
Connecticut: Estimates of $R_0(t)$

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

Graph showing $R_0(t)$ values for Connecticut over the months of March to November 2020.
Connecticut: Percent Currently Infectious

Connecticut
Peak I/N = 1.61%  Final I/N = 0.03%  δ = 0.010  θ = 0.10  γ = 0.20
Connecticut: Growth Rate of Daily Deaths over Past Week (percent)

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

Connecticut

$R_0=2.2/1.4/1.2$ $\delta = 0.010$ $\alpha=0.05$ $\theta=0.1$ $\%$Infect=13/13/16

DATA THROUGH 09-OCT-2020
Connecticut (7 days): Cumulative Deaths per Million (Future, $\alpha = 0.05$)

Connecticut

$R_0 = 2.2 / 1.4 / 1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 13 / 13 / 16$

DATA THROUGH 09-OCT-2020
Connecticut (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0.05$)

Cumulative deaths per million people

Connecticut
$R_0=2.2/1.4/1.2 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}=13/13/16$

New York City
Italy
Robustness to Mortality Rate, $\delta$
Connecticut: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Connecticut

$R_0=2.2/1.4/1.2$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%$ In$fect=13/13/16$

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

Connecticut

$R_0 = 2.2/1.4/1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 13/13/16$

DATA THROUGH 09-OCT-2020
Connecticut: Cumulative Deaths per Million ($\delta = \frac{1}{1000} / \frac{1}{1000} / \frac{1}{100}$)

DATA THROUGH 09-OCT-2020

Connecticut

$R_0 = 2.2 / 1.4 / 1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 13 / 13 / 16$

$\delta = 0.001$
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
Connecticut: Re-Opening ($\alpha = 0.05$)

Connecticut

$R_0(t) = 1.4$, $R_0(\text{suppress}) = 1.2$, $R_0(25/50) = 1.6/1.8$, $\delta = 0.010$, $\alpha = 0.05$

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

Connecticut

$R_0(t)=1.4, \ R_0(\text{suppress})=1.2, \ R_0(25/50)=1.6/1.8, \ \delta = 0.010, \ \alpha=0.00$

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

Connecticut

$R_0 = 2.2/1.4/1.4$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$Infect=13/13/24

DATA THROUGH 09-OCT-2020
Connecticut (7 days): Cumulative Deaths per Million (Future, $\alpha = 0$)

Connecticut

$R_0 = 2.2/1.4/1.4 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 13/13/24$

DATA THROUGH 09-OCT-2020
Connecticut (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = 0$)

Connecticut

$R_0 = 2.2/1.4/1.4 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 13/13/24$
Connecticut: Daily Deaths per Million People ($\delta = 0.8\%$)

Connecticut

$R_0=2.2/1.4/1.2$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  $\%$Infect=16/17/20
Connecticut: Cumulative Deaths per Million ($\delta = 0.8\%$)

Connecticut

$R_0 = 2.2/1.4/1.2 \quad \delta = 0.008 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 16/17/20$
Connecticut: Daily Deaths per Million People ($\delta = 1.2\%$)

Connecticut
$R_0=2.2/1.3/1.1$  $\delta = 0.012$  $\theta=0.1$  $\gamma=0.2$  $\%Infect=11/11/13$
Connecticut: Cumulative Deaths per Million ($\delta = 1.2\%$)

Connecticut

$R_0 = 2.2/1.3/1.1 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect}=11/11/13$
Connecticut: Daily Deaths per Million People ($\gamma = .2/.15$)

Connecticut

$R_0=2.2/1.4/1.2$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%$Infect=13/13/16

DATA THROUGH 09-OCT-2020
Connecticut: Cumulative Deaths per Million $\gamma = .2/.15$)

Connecticut

$R_0 = 2.2/1.4/1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 13/13/16$

$\gamma = 0.15$

$\gamma = 0.2$

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

Connecticut

$R_0 = 2.2/1.4/1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 13/13/16$

DATA THROUGH 09-OCT-2020
Connecticut: Cumulative Deaths per Million People ($\theta = .1/.07/.2$)

Connecticut

$R_0 = 2.2/1.4/1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 13/13/16$

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)
Connecticut: Change in Smoothed Daily Deaths

Connecticut: Delta $d$

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

Connecticut: Delta (Delta d)

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