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

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Extended results for Panama
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:
  o Lower mortality rate, $\delta = 0.8\%$
  o Higher mortality rate, $\delta = 1.2\%$
  o Infections last longer, $\gamma = 0.15$
  o Cases resolve more quickly, $\theta = 0.2$
  o 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)
Panama: 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)
Panama: Estimates of $R_0(t)$

Panama

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

Panama
Peak I/N = 0.34%  Final I/N = 0.13%  δ = 0.010  θ = 0.10  γ = 0.20
Panama: Growth Rate of Daily Deaths over Past Week (percent)

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

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

$$\implies \alpha \approx 0.05$$

$R_0$ 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 $\implies \alpha = 0$
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 $\alpha = 0$)
Panama (7 days): Daily Deaths per Million People ($\alpha = .05$)

Panama

$R_0=1.2/1.0/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 6/ 6/ 7

DATA THROUGH 09-OCT-2020
Panama (7 days): Cumulative Deaths per Million (Future, $\alpha = .05$)

Panama

$R_0=1.2/1.0/1.0 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}= 6/6/7$

DATA THROUGH 09-OCT-2020
Panama (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = .05$)

Panama

$R_0 = 1.2/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 6/6/7$

New York City

Italy

Cumulative deaths per million people

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

Panama

$R_0=1.2/1.0/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 6/ 6/ 7

DATA THROUGH 09-OCT-2020
Panama: Daily Deaths per Million People ($\delta = .01/.008/.012$)
Panama: Cumulative Deaths per Million ($\delta = \cdot01/\cdot008/\cdot012$)

Panama

$R_0=1.2/1.0/1.0$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  %Infect= 6/6/7

DATA THROUGH 09-OCT-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
Panama: Re-Opening ($\alpha = 0.05$)

Panama

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

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

Panama

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

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

\[
R_0 = 1.2/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \text{%Infect} = 6/6/7
\]

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

Panama

$R_0 = 1.2/1.0/1.0 \; \delta = 0.010 \; \alpha = 0.00 \; \theta = 0.1 \; \%\text{Infect}= 6/6/7$

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

Panama

$R_0 = 1.2/1.0/1.0$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$ Infect $= 6/6/7$
Panama: Daily Deaths per Million People ($\delta = 0.8\%$)

Panama

$R_0=1.2/1.0/1.1$  $\delta = 0.008$  $\theta=0.1$  $\gamma=0.2$  %Infect= 7/8/9
Panama: Cumulative Deaths per Million ($\delta = 0.8\%$)

Panama

$R_0 = 1.2/1.0/1.1$ \hspace{0.5cm} $\delta = 0.008$ \hspace{0.5cm} $\theta = 0.1$ \hspace{0.5cm} $\gamma = 0.2$ \hspace{0.5cm} $\%\text{Infect} = 7/8/9$
Panama: Daily Deaths per Million People ($\delta = 1.2\%$)

Panama

$R_0 = 1.2/1.0/1.0 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 5/5/6
Panama: Cumulative Deaths per Million ($\delta = 1.2\%$)

Panama

$R_0 = 1.2/1.0/1.0$  \( \delta = 0.012 \)  \( \theta = 0.1 \)  \( \gamma = 0.2 \)  \%Infect = 5/5/6
Panama: Daily Deaths per Million People ($\gamma = 0.2 / 0.15$)

Panama

$R_0 = 1.2 / 1.0 / 1.0$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect = 6 / 6 / 7

DATA THROUGH 09-OCT-2020
Panama: Cumulative Deaths per Million $\gamma = .2/1.15$)

Panama

$R_0 = 1.2/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad % \text{Infect} = 6/6/7$

DATA THROUGH 09-OCT-2020

Cumulative deaths per million people

Panama: Daily Deaths per Million People ($\theta = .1/.07/.2$)

Panama

$R_0 = 1.2/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad %\text{Infect} = 6/6/7$

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

Panama

\[ R_0 = 1.2/1.0/1.0 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \% \text{Infect} = 6/6/7 \]

\[ \theta = 0.2 \]
\[ \theta = 0.1 \]
\[ \theta = 0.07 \]

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)
Panama: Daily Deaths, Actual and Smoothed

Panama: Daily deaths, d
\[ d = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
Panama: Change in Smoothed Daily Deaths

Panama: Delta $d$

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

Panama: Delta (Delta d)
\[ \delta = 0.010 \quad \theta=0.10 \quad \gamma=0.20 \]