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

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Extended results for Argentina
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)
Argentina: Daily Deaths per Million People

Argentina

2020

Daily deaths per million people

Apr May Jun Jul Aug
Argentina: Daily Deaths per Million People (Smoothed)

Argentina

Daily deaths per million people (smoothed)

Apr May Jun Jul Aug 2020
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)
Argentina: Estimates of $R_0(t)$

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

Argentina
Peak I/N = 0.22%   Final I/N = 0.22%   δ = 0.010   θ = 0.10   γ = 0.20
Argentina: Growth Rate of Daily Deaths over Past Week (percent)

Argentina
\[ \delta = 0.010 \quad \theta = 0.10 \quad \gamma = 0.20 \]
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)
  o Black = current
  o Red = oldest, Orange = second oldest, Yellow = third oldest...
  o Violet (purple) = one day earlier

• For robustness graphs, same idea
  o Black = baseline (e.g. $\delta = 1.0\%$)
  o Red = lowest parameter value (e.g. $\delta = 0.8\%$)
  o 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 $R_0(t) = \text{final empirical value}$. 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 $\alpha = 0$)
Argentina (7 days): Daily Deaths per Million People ($\alpha = .05$)

$R_0 = 1.1/1.1/1.1$, $\delta = 0.010$, $\alpha = 0.05$, $\theta = 0.1$, $%\text{Infect} = 2/4/11$

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

$$R_0 = 1.1/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \% \text{Infect} = 2/4/11$$

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

Argentina

$R_0 = 1.1/1.1/1.1$, $\delta = 0.010$, $\alpha = 0.05$, $\theta = 0.1$, $\%$ Infect $= 2/4/11$
Robustness to Mortality Rate, $\delta$
Argentina: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Argentina

$R_0 = 1.1/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 2/4/11$

DATA THROUGH 24-AUG-2020
Argentina: Daily Deaths per Million People ($\delta = 0.01 / 0.008 / 0.012$)

Argentina

$R_0 = 1.1 / 1.1 / 1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 2 / 4 / 11$

DATA THROUGH 24-AUG-2020
Argentina: Cumulative Deaths per Million ($\delta = 0.01/0.008/0.012$)

DATA THROUGH 24-AUG-2020

Argentina

$R_0 = 1.1/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 2/4/11
Reopening and Herd Immunity

– Black: assumes $R_0(today)$ remains in place forever
– Red: assumes $R_0(suppress) = 1/s(todays)$
– Green: we move 25% of the way from $R_0(todays)$
  back to initial $R_0 = “normal”$
– Purple: we move 50% of the way from $R_0(todays)$
  back to initial $R_0 = “normal”$

NOTE: Lines often cover each other up
Argentina: Re-Opening ($\alpha = .05$)

Argentina

$R_0(t)=1.1$, $R_0(\text{suppress})=1.0$, $R_0(25/50)=1.3/1.6$, $\delta = 0.010$, $\alpha=0.05$
Argentina: Re-Opening ($\alpha = 0$)

Argentina
$R_0(t)=1.1$, $R_0(\text{suppress})=1.0$, $R_0(25/50)=1.4/1.6$, $\delta = 0.010$, $\alpha = 0.00$
Results for alternative parameter values
Argentina (7 days): Daily Deaths per Million People ($\alpha = 0$)

Argentina

$R_0 = 1.1/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 2/4/23$

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

Argentina

$R_0 = 1.1/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  $\%$ Infect $= 2/4/23$

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

Argentina

$R_0=1.1/1.1/1.1$  $\delta = 0.010$  $\alpha=0.00$  $\theta=0.1$  $\%$Infect= 2/ 4/23

New York City

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

Argentina

$R_0=1.1/1.1/1.1$ \hspace{0.5cm} $\delta = 0.008$ \hspace{0.5cm} $\theta=0.1$ \hspace{0.5cm} $\gamma=0.2$ \hspace{0.5cm} %Infect= 2/5/13
Argentina: Cumulative Deaths per Million ($\delta = 0.8\%$)

Argentina

$R_0 = 1.1/1.1/1.1$  \( \delta = 0.008 \)  \( \theta = 0.1 \)  \( \gamma = 0.2 \)  \%Infect = 2/5/13
Argentina: Daily Deaths per Million People ($\delta = 1.2\%$)

Argentina

$R_0=1.1/1.1/1.1 \quad \delta = 0.012 \quad \theta=0.1 \quad \gamma=0.2 \quad \%\text{Infect}= 2/3/10$
Argentina: Cumulative Deaths per Million ($\delta = 1.2\%$)

Argentina

$R_0=1.1/1.1/1.1$  $\delta = 0.012$  $\theta=0.1$  $\gamma=0.2$  \%Infect= 2/ 3/10
Argentina: Daily Deaths per Million People ($\gamma = 0.2/0.15$)

Argentina

$R_0=1.1/1.1/1.1$  \( \delta = 0.010 \)  \( \alpha=0.05 \)  \( \theta=0.1 \)  \%Infect= 2/ 4/11

DATA THROUGH 24-AUG-2020
Argentina: Cumulative Deaths per Million $\gamma = 0.2 / 0.15$

Argentina

$R_0 = 1.1 / 1.1 / 1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect = 2 / 4 / 11

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

$R_0=1.1/1.1/1.1 \quad \delta = 0.010 \quad \alpha=0.05 \quad \theta=0.1 \quad \%\text{Infect}= 2/4/11$

DATA THROUGH 24-AUG-2020
Argentina: Cumulative Deaths per Million People ($\theta = 1/0.07/0.2$)

Argentina

$R_0 = 1.1/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect$ = 2/4/11$

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)
Argentina: Daily Deaths, Actual and Smoothed

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

Argentina: Delta $d$

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

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