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 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)
Argentina: Daily Deaths per Million People

![Argentina: Daily Deaths per Million People](image_url)
Argentina: 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)
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 = 0.24% Final I/N = 0.24% \( \delta = 0.010 \) \( \theta = 0.10 \) \( \gamma = 0.20 \)
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)
  - 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 $R_0(t) = \text{final empirical value}$. 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 ($\alpha = 0.05$)

Argentina

$R_0 = 1.1/1.1/1.1$, $\delta = 0.010$, $\alpha = 0.05$, $\theta = 0.1$, %Infect = 3/4/11

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

Argentina

$R_0 = 1.1/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$Infect$= 3/4/11$

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

Argentina

$R_0 = 1.1/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 3/4/11$

New York City

Italy
Robustness to Mortality Rate, $\delta$
Argentina: Cumulative Deaths per Million ($\delta = 0.01/0.008/0.012$)

Argentina

$R_0 = 1.1/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%$ Infect $= 3/4/11$

DATA THROUGH 11-SEP-2020
Argentina: Daily Deaths per Million People ($\delta = 0.01/0.008/0.012$)

$R_0 = 1.1/1.1/1.1$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%Infect=3/4/11$

DATA THROUGH 11-SEP-2020
Argentina: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

**Argentina**

$R_0=1.1/1.1/1.1$  \( \delta = 0.010 \)  \( \alpha=0.05 \)  \( \theta=0.1 \)  \%Infect= 3/4/11

DATA THROUGH 11-SEP-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
Argentina: Re-Opening ($\alpha = .05$)

Argentina

$R_0(t)=1.1, \ R_0(\text{suppress})=1.0, \ R_0(25/50)=1.3/1.5, \ \delta = 0.010, \ \alpha=0.05$

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

Argentina

$R_0(t) = 1.1$, $R_0\text{ (suppress)} = 1.0$, $R_0(25/50) = 1.3/1.5$, $\delta = 0.010$, $\alpha = 0.00$

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

\begin{align*}
R_0 &= 1.1/1.1/1.1 \\
\delta &= 0.010 \\
\alpha &= 0.00 \\
\theta &= 0.1 \\
\%\text{Infect} &= 3/5/13
\end{align*}

DATA THROUGH 11-SEP-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 = 3/5/13

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

Argentina

$R_0 = 1.1/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.00 \quad \theta = 0.1 \quad \%\text{Infect} = 3/5/13$
Argentina: Daily Deaths per Million People ($\delta = 0.8\%$)

Argentina

$R_0 = 1.1/1.1/1.1$  $\delta = 0.008$  $\theta = 0.1$  $\gamma = 0.2$  %Infect = 4/ 6/14
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= 4/6/14
Argentina: Daily Deaths per Million People ($\delta = 1.2\%$)

Argentina

$R_0 = 1.1/1.1/1.1 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 2/4/10$
Argentina: Cumulative Deaths per Million ($\delta = 1.2\%$)

Argentina

$R_0=1.1/1.1/1.1 \quad \delta = 0.012 \quad \theta=0.1 \quad \gamma=0.2 \quad \%\text{Infect}=2/4/10$
Argentina: Daily Deaths per Million People ($\gamma = .2 / .15$)

Argentina

$R_0 = 1.1 / 1.1 / 1.1$  \( \delta = 0.010 \)  \( \alpha = 0.05 \)  \( \theta = 0.1 \)  \%Infect = 3/4/11

DATA THROUGH 11-SEP-2020
Argentina: Cumulative Deaths per Million $\gamma = .2/.15$)

Argentina

$R_0 = 1.1/1.1/1.1$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infected $= 3/4/11$

DATA THROUGH 11-SEP-2020

Cumulative deaths per million people


$\gamma = 0.15$
$\gamma = 0.2$
Argentina: Daily Deaths per Million People ($\theta = .1 / .07 / .2$)

\[ R_0 = 1.1/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%Infect = 3/4/11 \]

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

DATA THROUGH 11-SEP-2020

$R_0 = 1.1/1.1/1.1 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 3/4/11$
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 $d$

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

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