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

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

Daily deaths per million people

Mexico
Mexico: 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)
Mexico: Estimates of $R_0(t)$

Mexico

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

Peak I/N = 0.28%  Final I/N = 0.28%  δ = 0.010  θ = 0.10  γ = 0.20
Mexico: 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 $\alpha = 0$)
Mexico (7 days): Daily Deaths per Million People ($\alpha = 0.05$)

Mexico

$R_0 = 1.2/1.3/1.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect $= 7/10/18$

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

Mexico

$R_0 = 1.2/1.3/1.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  $\%\text{Infect} = 7/10/18$

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

Mexico

$R_0 = 1.2/1.3/1.2$  \(\delta = 0.010\)  \(\alpha = 0.05\)  \(\theta = 0.1\)  \%Infect = 7/10/18
Robustness to Mortality Rate, $\delta$
Mexico: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Mexico

$R_0$=1.2/1.3/1.2  $\delta = 0.010$  $\alpha =0.05$  $\theta =0.1$  %Infect= 7/10/18

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

\[ R_0 = 1.2/1.3/1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \%\text{Infect} = 7/10/18 \]

Data through 09-Oct-2020
Mexico: Cumulative Deaths per Million \( (\delta = .01/.008/.012) \)

\[
R_0 = 1.2/1.3/1.2 \quad \delta = 0.010 \quad \alpha = 0.05 \quad \theta = 0.1 \quad \% \text{Infect} = 7/10/18
\]

DATA THROUGH 09-OCT-2020
Reopening and Herd Immunity

– Black: assumes $R_0(\text{today})$ remains in place forever
– Red: assumes $R_0(\text{suppress}) = \frac{1}{s(\text{today})}$
– 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
Mexico: Re-Opening ($\alpha = .05$)

Mexico

$R_0(t)=1.3$, $R_0\text{ (suppress)}=1.1$, $R_0\text{ (25/50)}=1.5/1.6$, $\delta = 0.010$, $\alpha=0.05$

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

Mexico

$R_0(t)=1.4$, $R_0$ (suppress) = 1.2, $R_0(25/50) = 1.5/1.7$, $\delta = 0.010$, $\alpha = 0.00$

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

Mexico

$\mathcal{R}_0 = 1.2/1.4/1.4$  \( \delta = 0.010 \)  \( \alpha = 0.00 \)  \( \theta = 0.1 \)  \%Infect = 7/15/46

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

Mexico

$R_0 = 1.2/1.4/1.4$ $\delta = 0.010$ $\alpha = 0.00$ $\theta = 0.1$  %Infect = 7/15/46

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

Mexico
$R_0 = 1.2 / 1.4 / 1.4$  $\delta = 0.010$  $\alpha = 0.00$  $\theta = 0.1$  %Infect = 7/15/46

New York City
Italy

Cumulative deaths per million people

Mexico: Daily Deaths per Million People ($\delta = 0.8\%$)
Mexico: Cumulative Deaths per Million ($\delta = 0.8\%$)

Mexico

$R_0=1.2/1.3/1.3$ \hspace{1em} $\delta = 0.008$ \hspace{1em} $\theta=0.1$ \hspace{1em} $\gamma=0.2$ \hspace{1em} %Infect= 9/13/21
Mexico: Daily Deaths per Million People ($\delta = 1.2\%$)

Mexico

$R_0=1.2/1.3/1.2 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 6/8/15$

Daily deaths per million people
Mexico: Cumulative Deaths per Million ($\delta = 1.2\%$)

Mexico

$R_0 = 1.2/1.3/1.2 \quad \delta = 0.012 \quad \theta = 0.1 \quad \gamma = 0.2 \quad \%\text{Infect} = 6/8/15$
Mexico: Daily Deaths per Million People ($\gamma = .2/.15$)

Mexico

$R_0=1.2/1.3/1.2$  $\delta = 0.010$  $\alpha=0.05$  $\theta=0.1$  $\%$Infect= 7/10/18

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

Mexico

$R_0=1.2/1.3/1.2$ $\delta = 0.010$ $\alpha=0.05$ $\theta=0.1$ $\%\text{Infect}=7/10/18$

DATA THROUGH 09-OCT-2020
Mexico: Daily Deaths per Million People ($\theta = .1/0.07/0.2$)

DATA THROUGH 09-OCT-2020

$R_0 = 1.2/1.3/1.2$  $\delta = 0.010$  $\alpha = 0.05$  $\theta = 0.1$  %Infect = 7/10/18
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)
Mexico: Daily Deaths, Actual and Smoothed

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

Mexico: Delta $d$

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

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