

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

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Extended results for Bolivia  
Based on data through October 9, 2020

## Outline of Slides

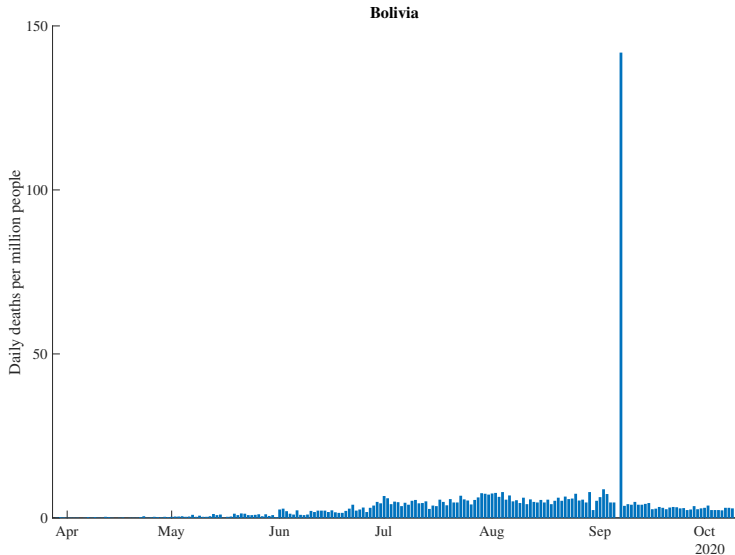
- Basic data from Johns Hopkins CSSE (raw and smoothed)
- Brief summary of the model
- Baseline results ( $\delta = 1.0\%$ ,  $\gamma = 0.2$ ,  $\theta = 0.1$ )
- Simulation of re-opening – possibilities for raising  $R_0$
- Results with alternative parameter values:
  - Lower mortality rate,  $\delta = 0.8\%$
  - 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  $R_0(t)$



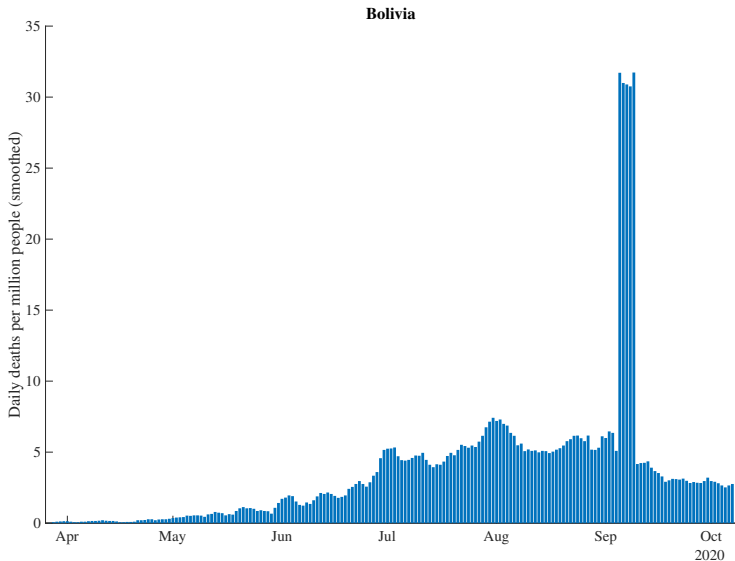
## Underlying data from Johns Hopkins CSSE

- Raw data
- Smoothed = 7 day centered moving average
- No “excess deaths” correction (change as of Aug 6 run)

## Bolivia: Daily Deaths per Million People



## Bolivia: 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  $R_0$

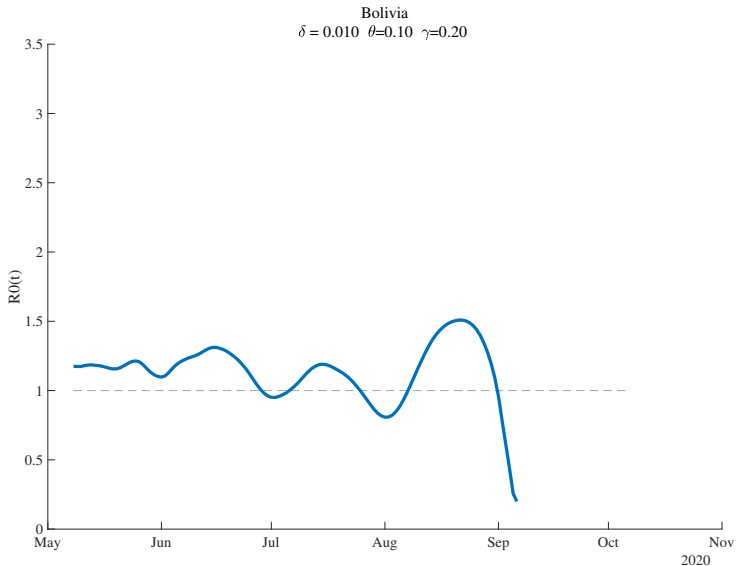
Parameter	Baseline	Description
$\delta$	1.0%	Mortality rate from infections (IFR)
$\gamma$	0.2	Rate at which people stop being infectious
$\theta$	0.1	Rate at which cases (post-infection) resolve
$\alpha$	0.05	Rate at which $R_0(t)$ decays with daily deaths
$R_0$	...	Initial base reproduction rate
$R_0(t)$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



## Estimates of Time-Varying $R_0$

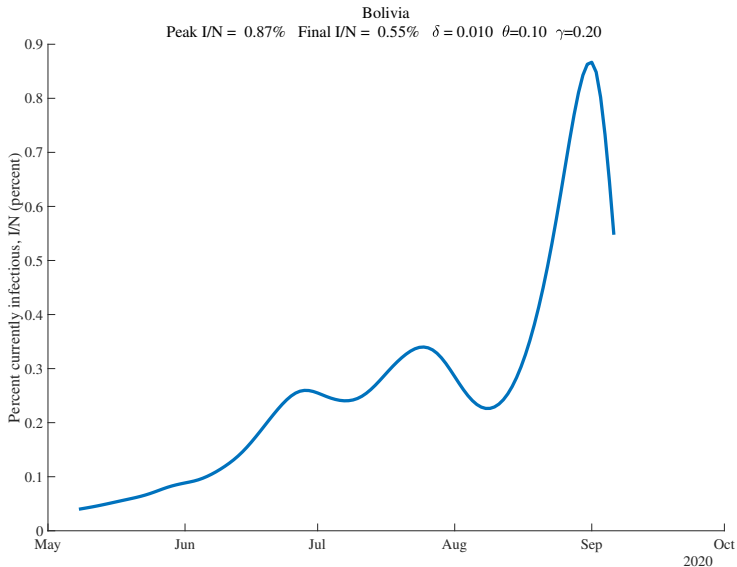
- Inferred from daily deaths, and
  - the change in daily deaths, and
  - the change in (the change in daily deaths)
- (see end of slide deck for this data)

## Bolivia: Estimates of $R_0(t)$

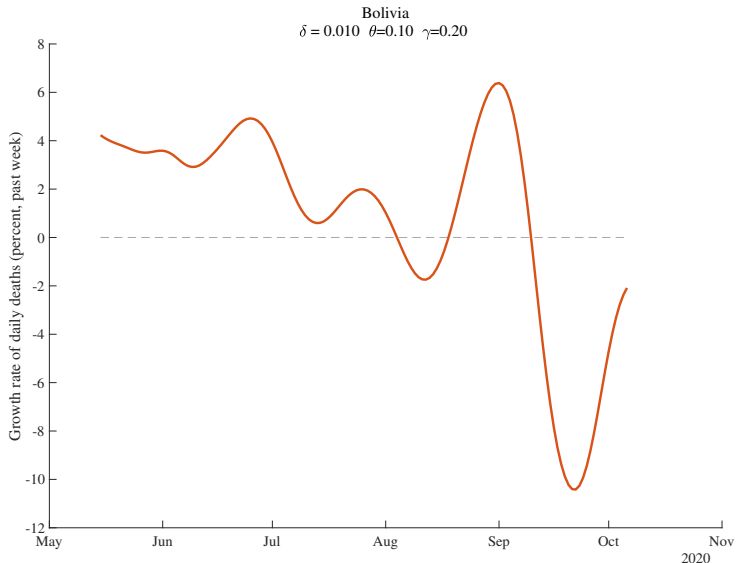


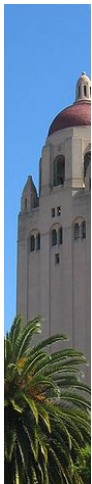


## Bolivia: Percent Currently Infectious



## Bolivia: Growth Rate of Daily Deaths over Past Week (percent)





## Notes on Intepreting 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*

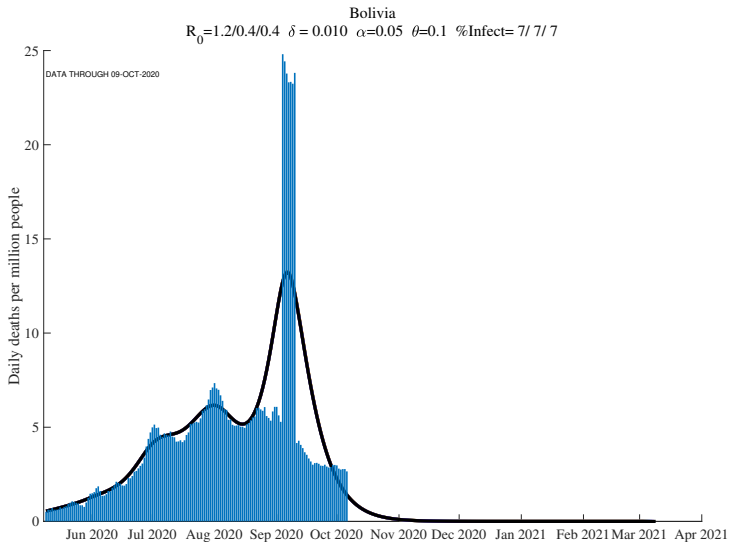
- Robustness: Assume  $R_0(t) =$  final empirical value. Constant in future, so no  $\alpha$  adjustment  $\rightarrow \alpha = 0$



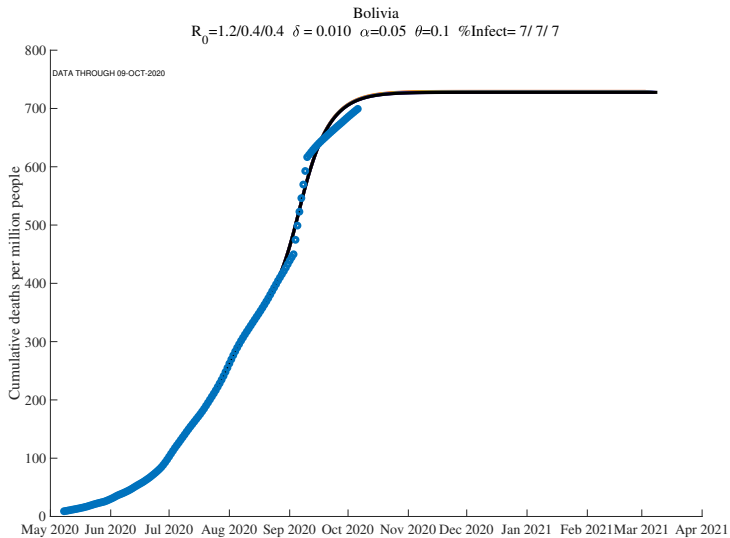
## Repeated “Forecasts” from the past 7 days of data

- 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  $\alpha = 0$ )

## Bolivia (7 days): Daily Deaths per Million People ( $\alpha = .05$ )

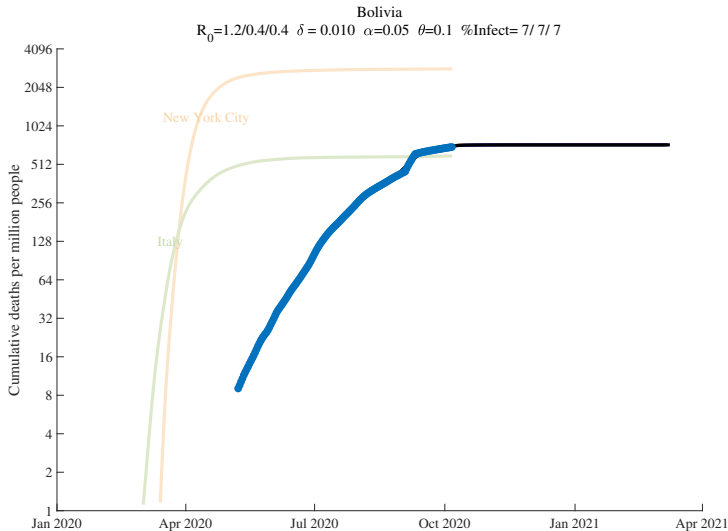


## Bolivia (7 days): Cumulative Deaths per Million (Future, $\alpha = .05$ )





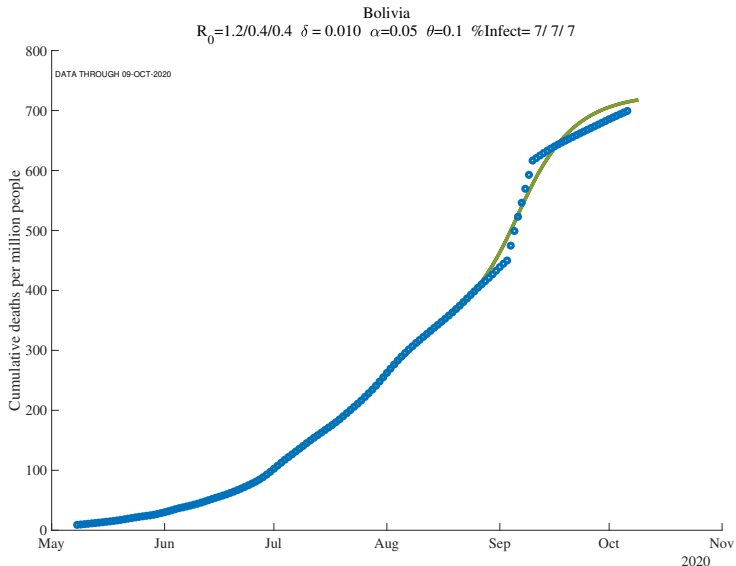
## Bolivia (7 days): Cumulative Deaths per Million, Log Scale ( $\alpha = .05$ )



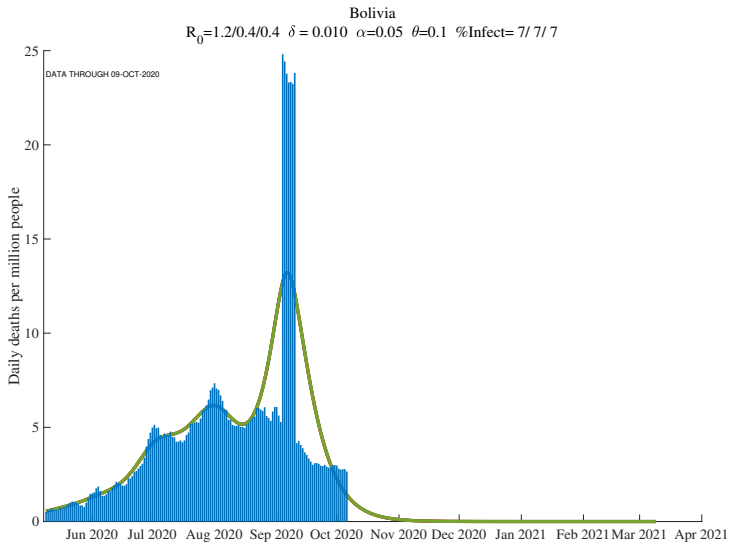


## Robustness to Mortality Rate, $\delta$

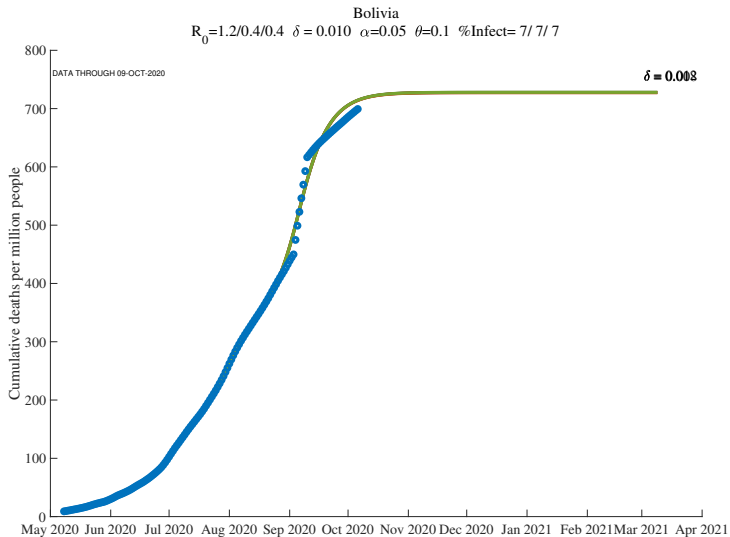
## Bolivia: Cumulative Deaths per Million ( $\delta = .01/.008/.012$ )



## Bolivia: Daily Deaths per Million People ( $\delta = .01/.008/.012$ )



## Bolivia: Cumulative Deaths per Million ( $\delta = .01/.008/.012$ )



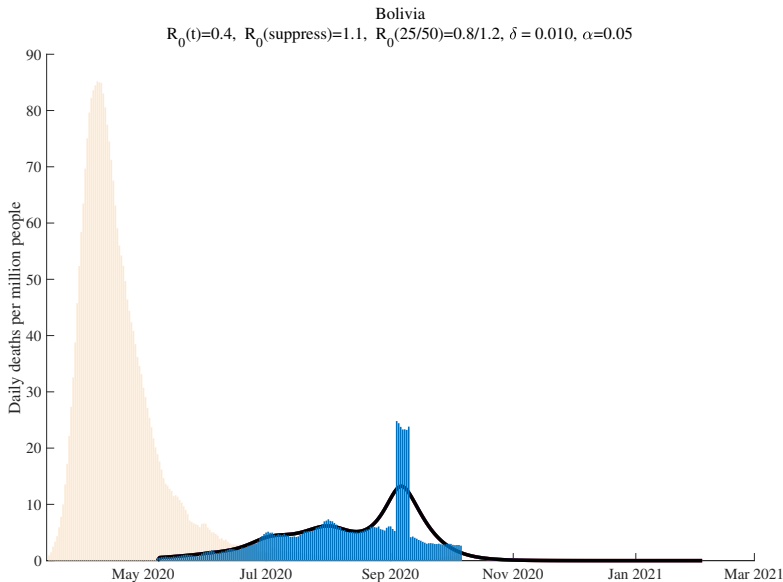


## Reopening and Herd Immunity

- 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  $R_0 = \text{“normal”}$

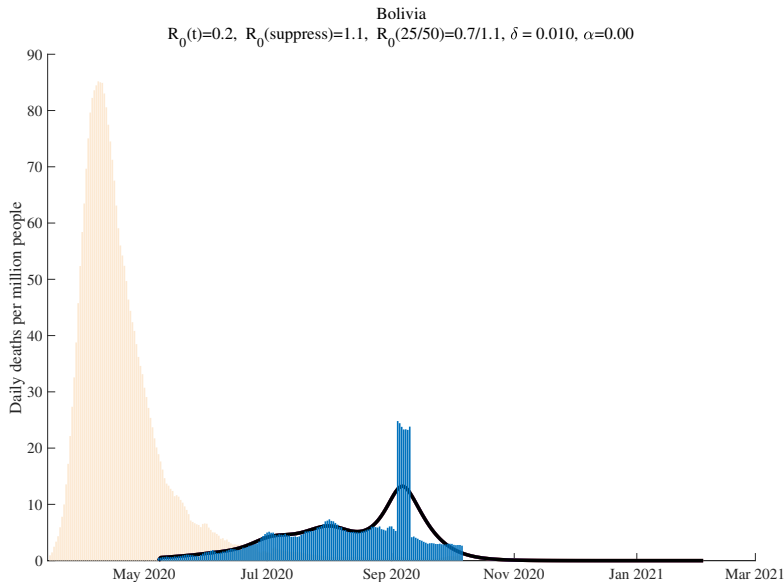
NOTE: Lines often cover each other up

## Bolivia: Re-Opening ( $\alpha = .05$ )



(Light bars = New York City, for comparison)

## Bolivia: Re-Opening ( $\alpha = 0$ )



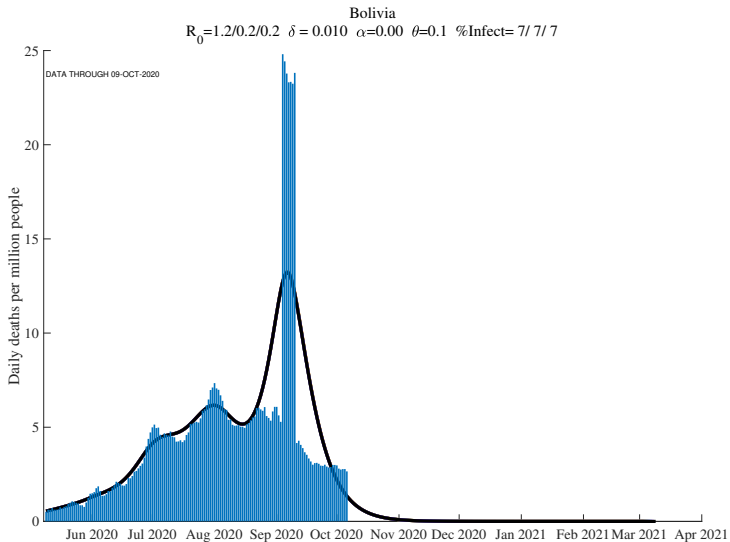
(Light bars = New York City, for comparison)



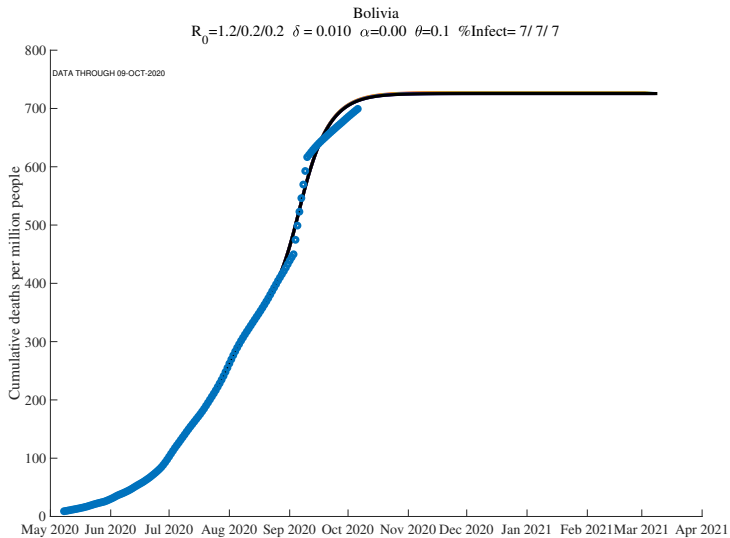


## Results for alternative parameter values

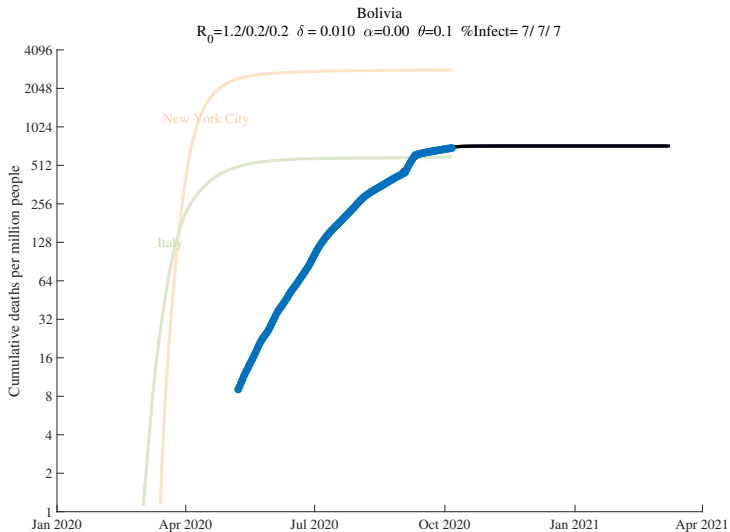
## Bolivia (7 days): Daily Deaths per Million People ( $\alpha = 0$ )



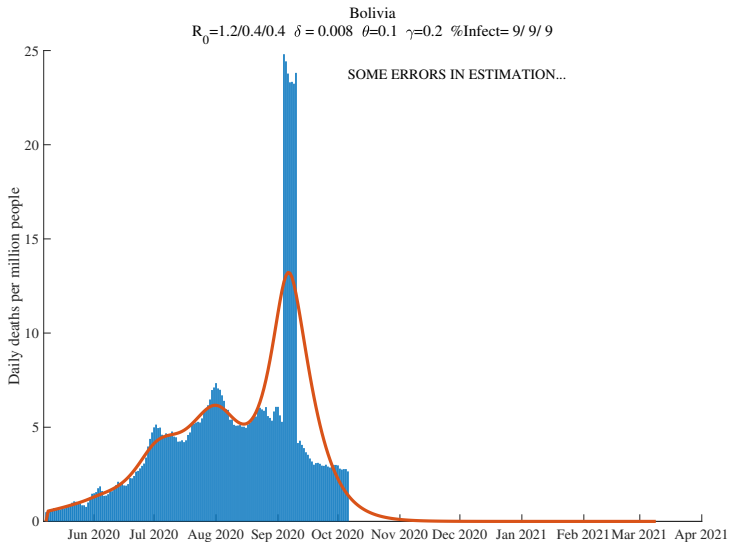
## Bolivia (7 days): Cumulative Deaths per Million (Future, $\alpha = 0$ )



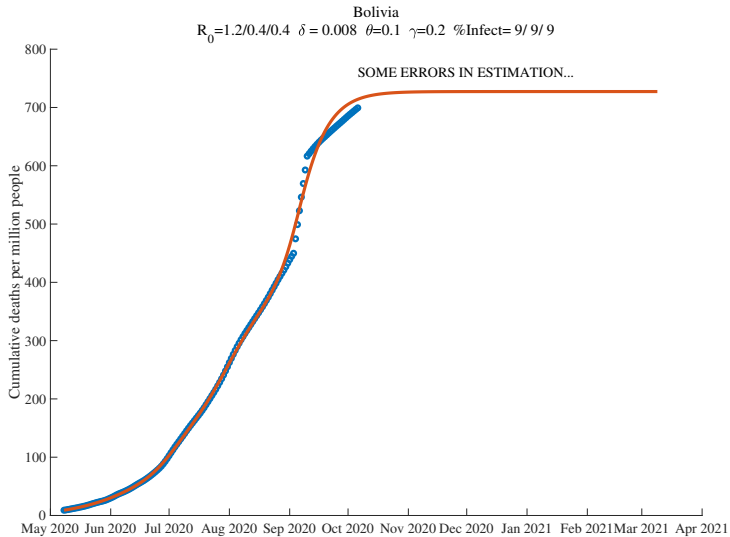
## Bolivia (7 days): Cumulative Deaths per Million, Log Scale ( $\alpha = 0$ )



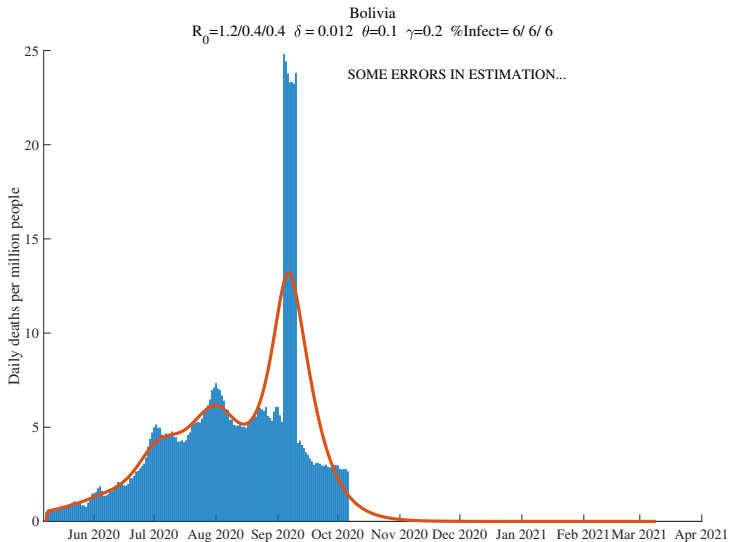
## Bolivia: Daily Deaths per Million People ( $\delta = 0.8\%$ )



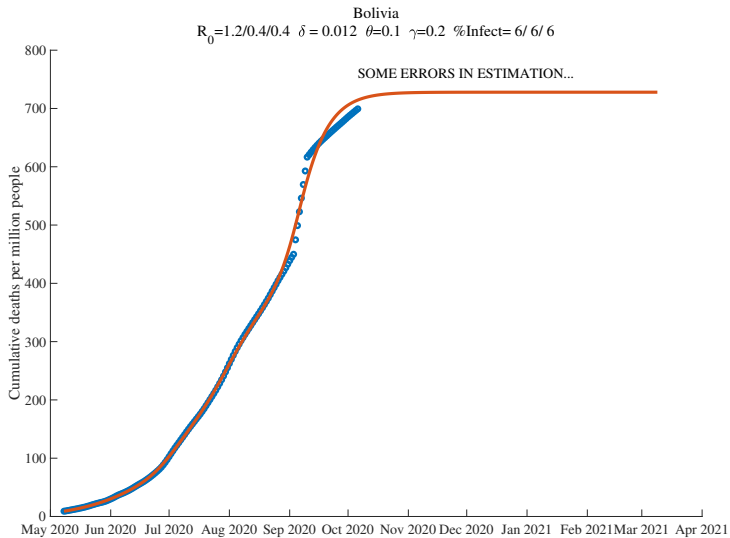
## Bolivia: Cumulative Deaths per Million ( $\delta = 0.8\%$ )



## Bolivia: Daily Deaths per Million People ( $\delta = 1.2\%$ )

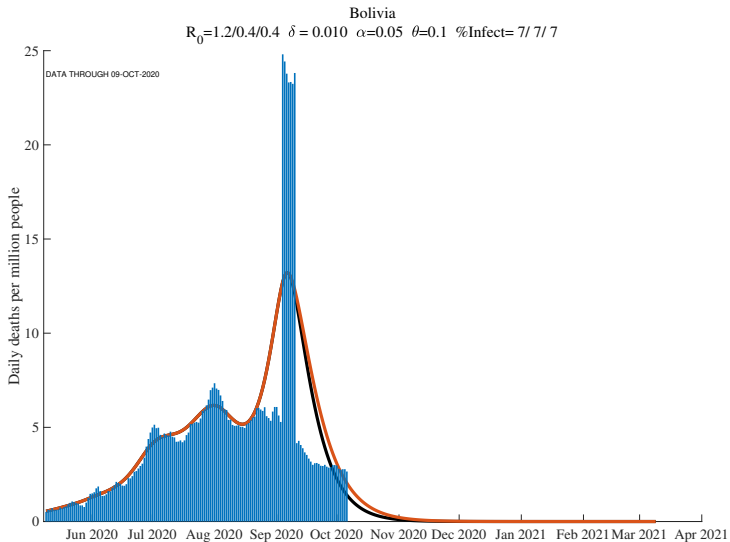


## Bolivia: Cumulative Deaths per Million ( $\delta = 1.2\%$ )

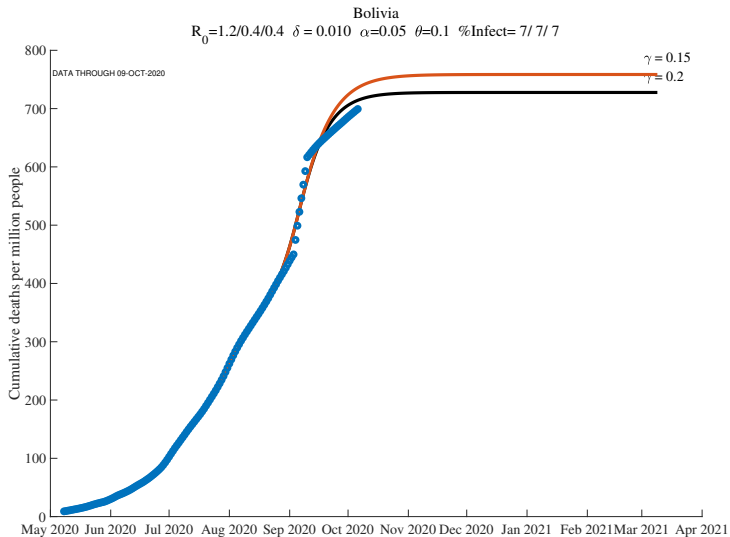




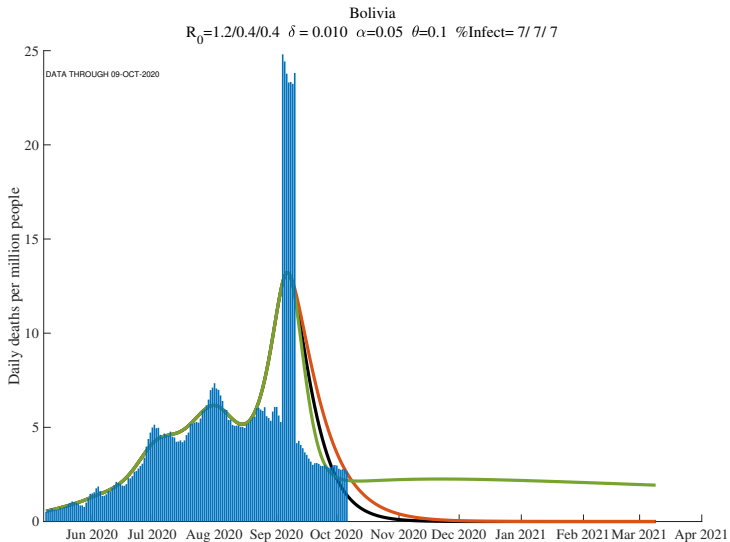
## Bolivia: Daily Deaths per Million People ( $\gamma = .2/.15$ )



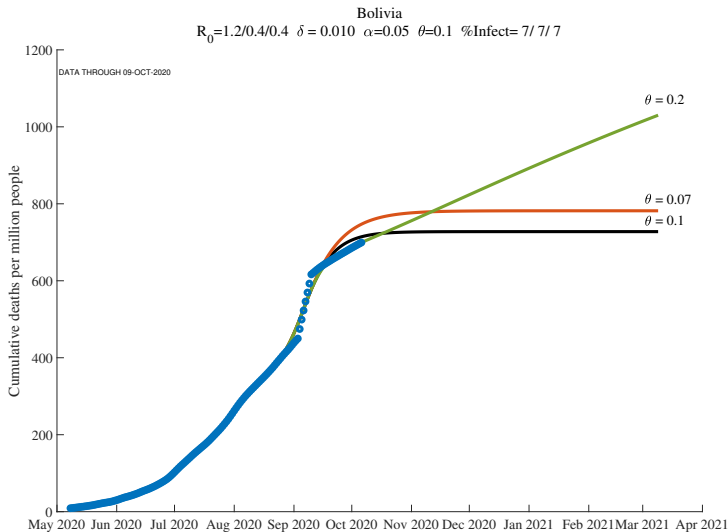
## Bolivia: Cumulative Deaths per Million $\gamma = .2/.15$



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



## Bolivia: Cumulative Deaths per Million People ( $\theta = .1/.07/.2$ )

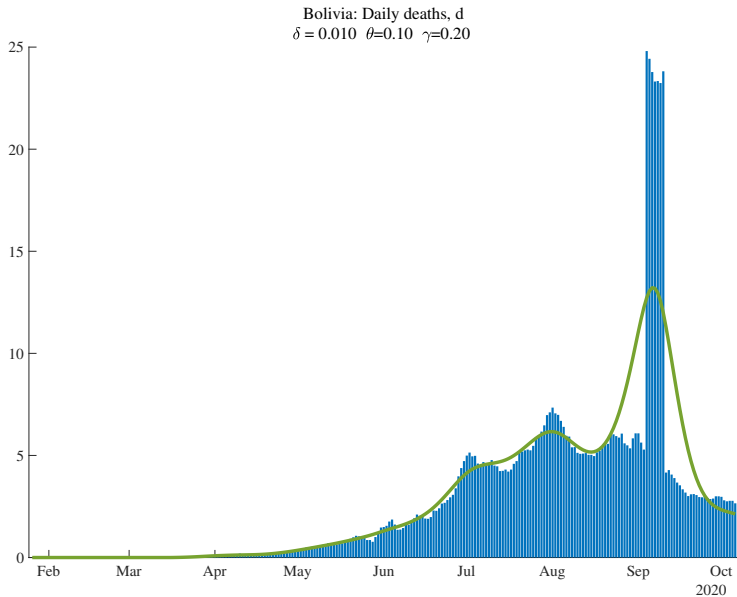




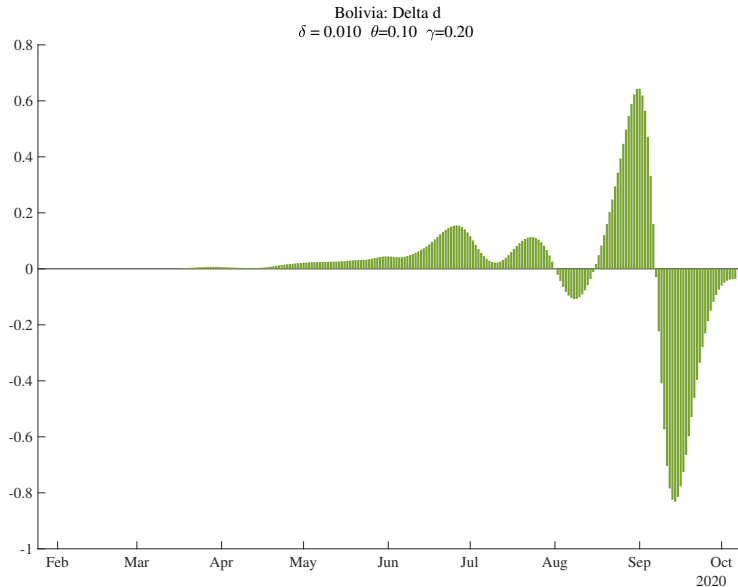
## Data Underlying Estimates of Time-Varying $R_0$

- Inferred from daily deaths, and
- the change in daily deaths, and
- the change in (the change in daily deaths)

## Bolivia: Daily Deaths, Actual and Smoothed



## Bolivia: Change in Smoothed Daily Deaths



## Bolivia: Change in (Change in Smoothed Daily Deaths)

