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

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Extended results for Libya

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, $\theta = 0.07$

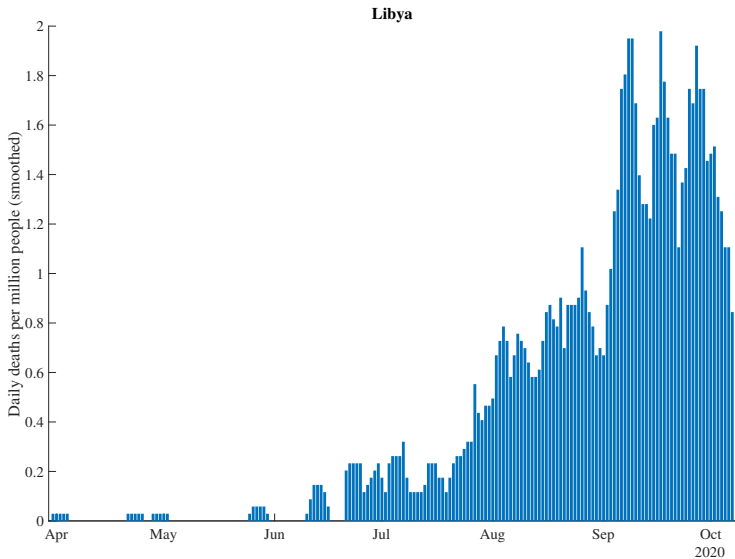- Data underlying estimates of $R_0(t)$

Underlying data from
Johns Hopkins CSSE

– Raw data

– Smoothed = 7 day centered moving average

– No "excess deaths" correction (change as of Aug 6 run)

Libya: Daily Deaths per Million People
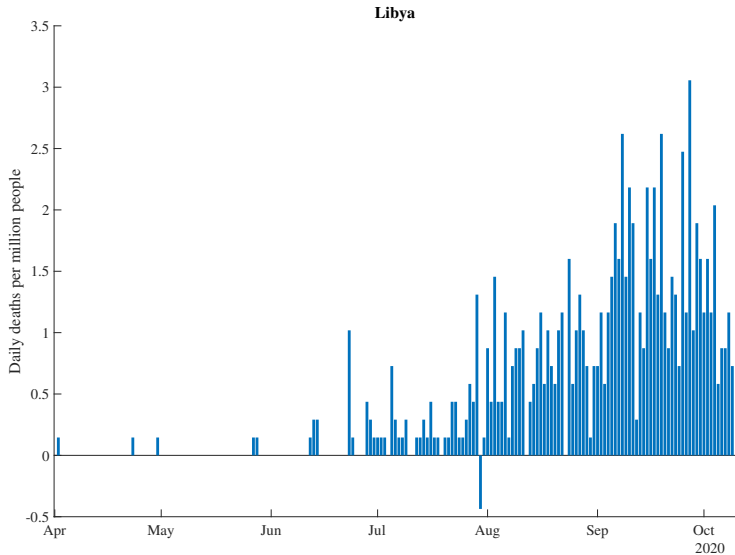
Libya

Libya: Daily Deaths per Million People (Smoothed)

Libya

Brief Summary of Model

- See the paper for a full exposition

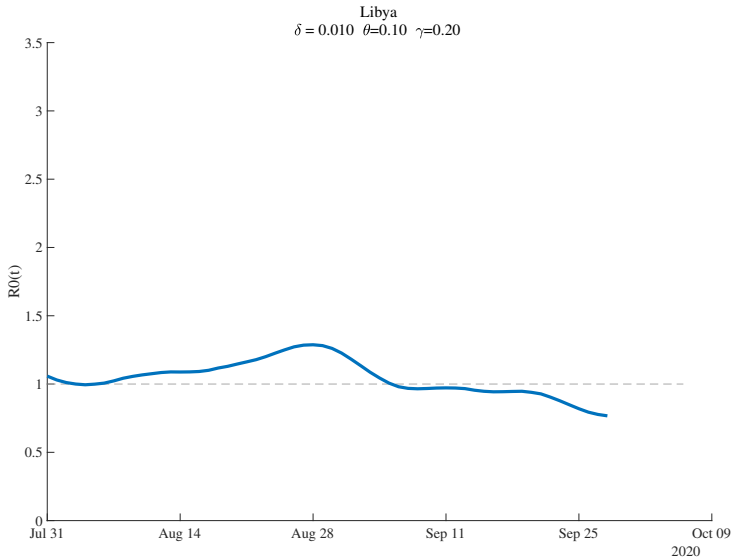- A 5-state SIRDC model with a time-varying R_0

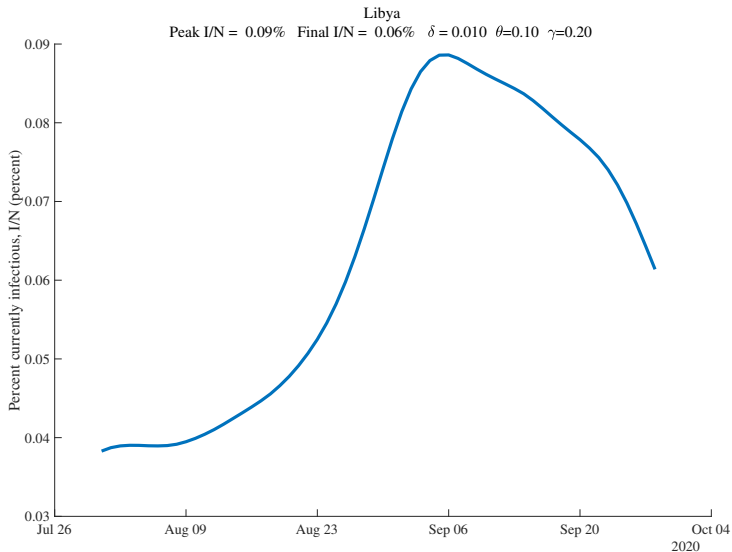| Parameter	Baseline	Description
δ	1.0%	Mortality rate from infections (IFR)
γ	0.2	Rate at which people stop being infectious
θ	0.1	Rate at which cases (post-infection) resolve
α	0.05	Rate at which $R_0(t)$ decays with daily deaths
R_0	...	Initial base reproduction rate
$R_0(t)$	...	Base reproduction rate at date t (β_t/γ)

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)

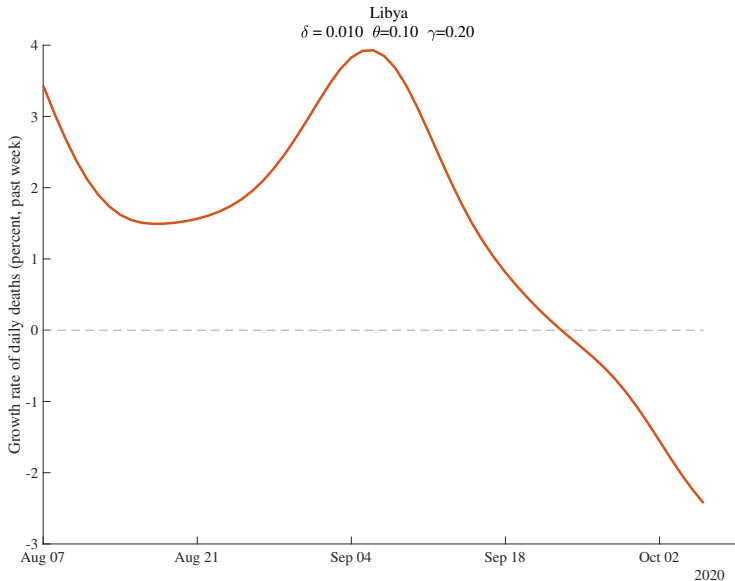(see end of slide deck for this data)

Libya: Estimates of $R_0(t)$

Libya
$\delta = 0.010$ $\theta = 0.10$ $\gamma = 0.20$

Libya: Percent Currently Infectious

Libya
Peak I/N = 0.09%   Final I/N = 0.06% $\delta = 0.010$ $\theta = 0.10$ $\gamma = 0.20$

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

Libya
$\delta = 0.010$ $\theta = 0.10$ $\gamma = 0.20$

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,
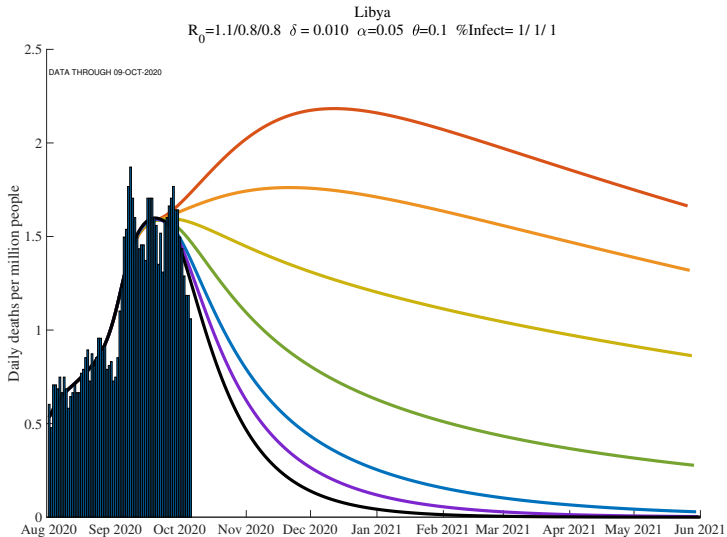*or rises by 5 percent when daily deaths decline*

- Robustness: Assume $R_0(t) = $ final empirical value. Constant in future, so no α adjustment $\rightarrow \alpha = 0$
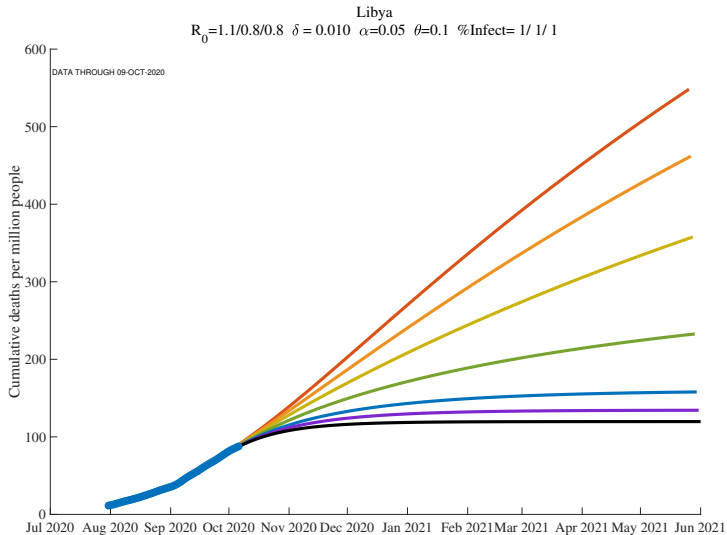
Repeated "Forecasts" from the past 7 days of data

- 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 $\alpha = 0$)

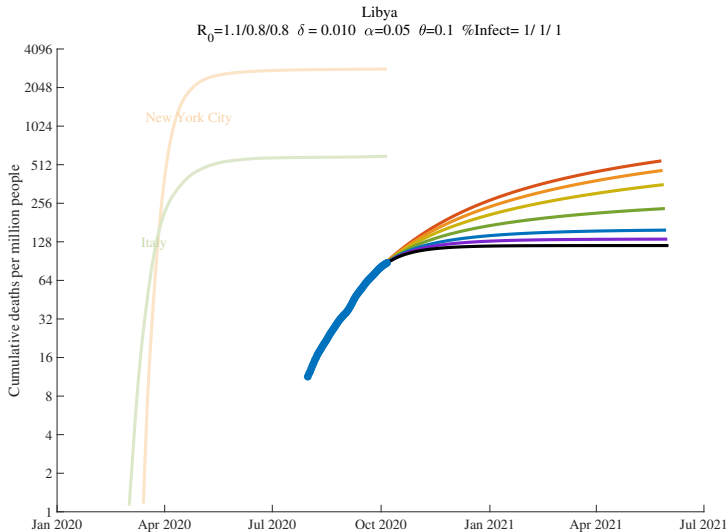**Libya (7 days): Daily Deaths per Million People ($\alpha = .05$)**

Libya
R_0=1.1/0.8/0.8 $\delta = 0.010$ α=0.05 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

Daily deaths per million people

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

Libya
R_0=1.1/0.8/0.8 $\delta = 0.010$ α=0.05 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

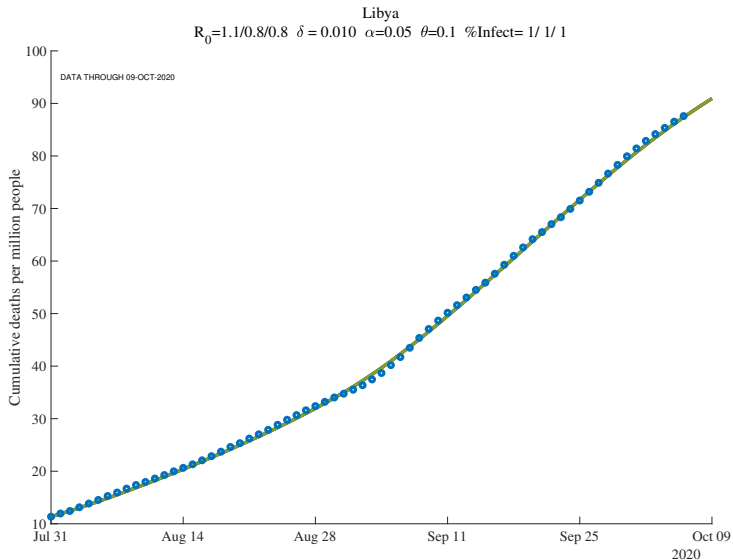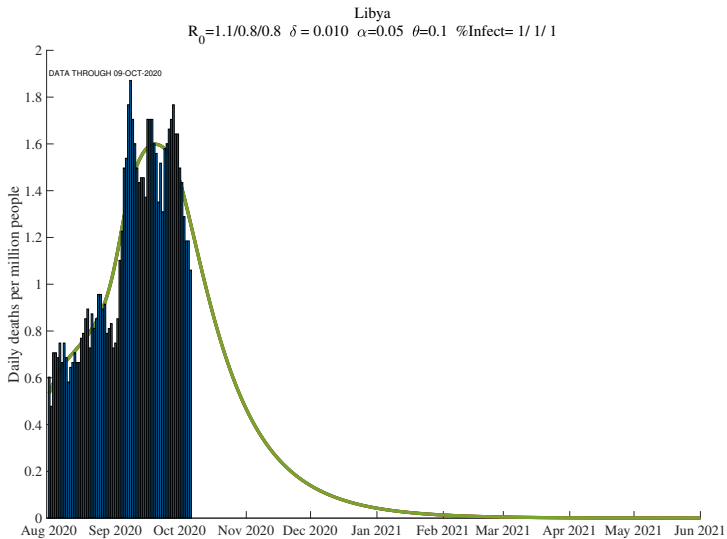**Libya (7 days): Cumulative Deaths per Million, Log Scale ($\alpha = .05$)**

Robustness to Mortality Rate, δ

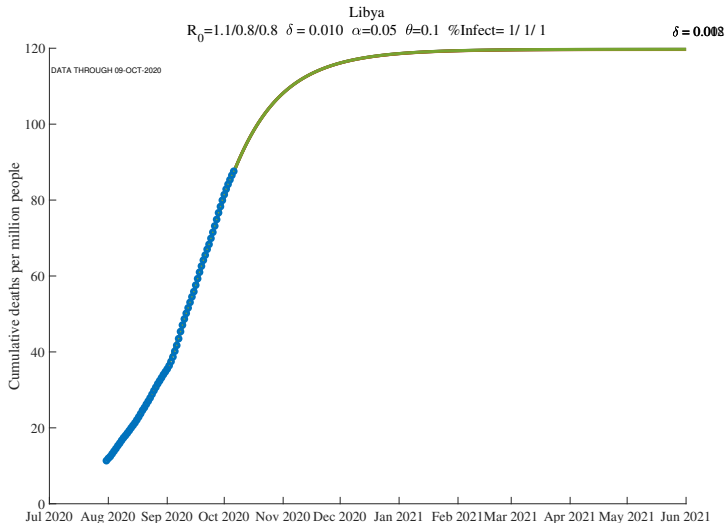## Libya: Cumulative Deaths per Million ($\delta = .01/.008/.012$)

Libya
R_0=1.1/0.8/0.8 δ = 0.010 α=0.05 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

Cumulative deaths per million people

Jul 31   Aug 14   Aug 28   Sep 11   Sep 25   Oct 09
2020

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

Libya
R_0=1.1/0.8/0.8 δ = 0.010 α=0.05 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

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

Libya
R_0=1.1/0.8/0.8 $\delta = 0.010$ α=0.05 θ=0.1 %Infect= 1/ 1/ 1

$\delta = 0.008$

DATA THROUGH 09-OCT-2020

Cumulative deaths per million people

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

Libya
$R_0(t)=0.8$, $R_0(\text{suppress})=1.0$, $R_0(25/50)=1.1/1.4$, $\delta = 0.010$, $\alpha=0.05$
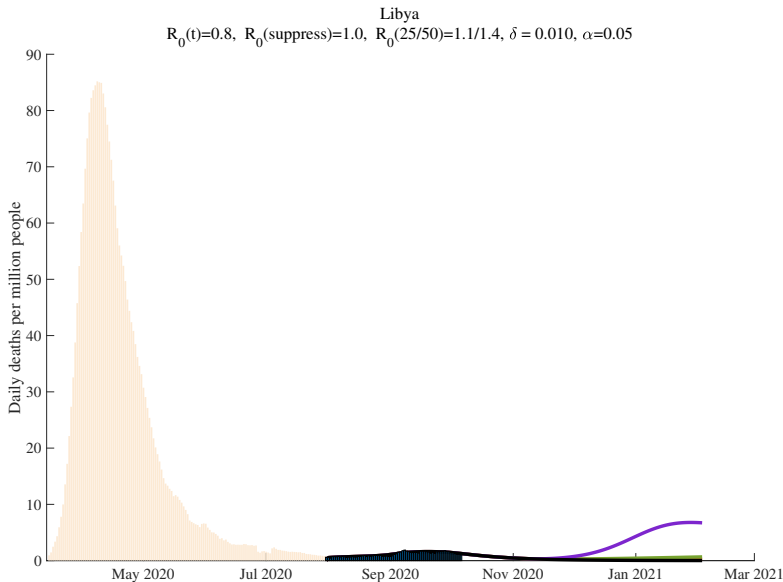
(Light bars = New York City, for comparison)

Libya

$R_0(t)=0.8$, R_0(suppress)=1.0, $R_0(25/50)=1.1/1.4$, $\delta = 0.010$, $\alpha=0.00$
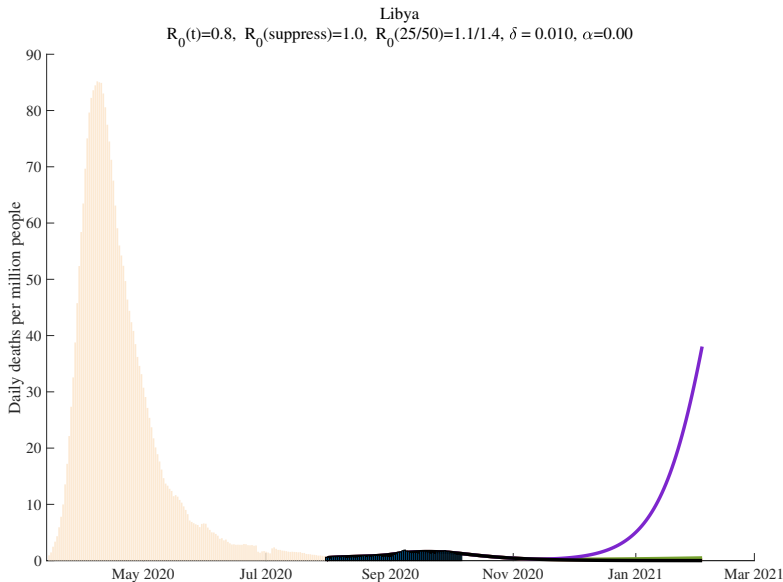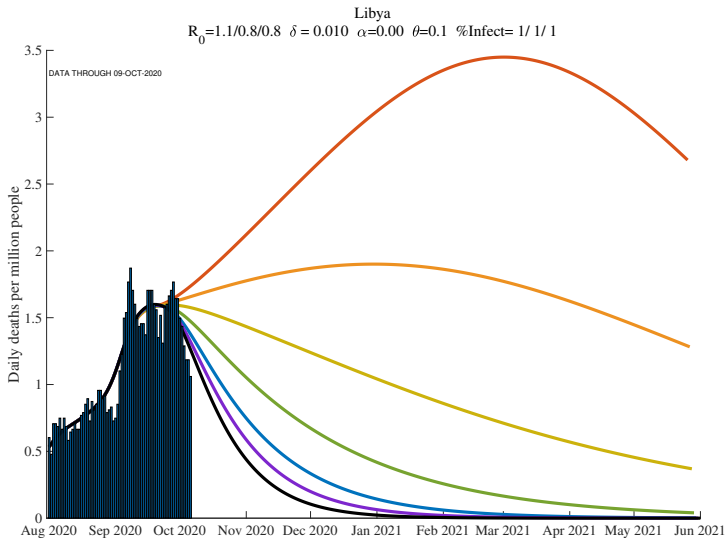
(Light bars = New York City, for comparison)
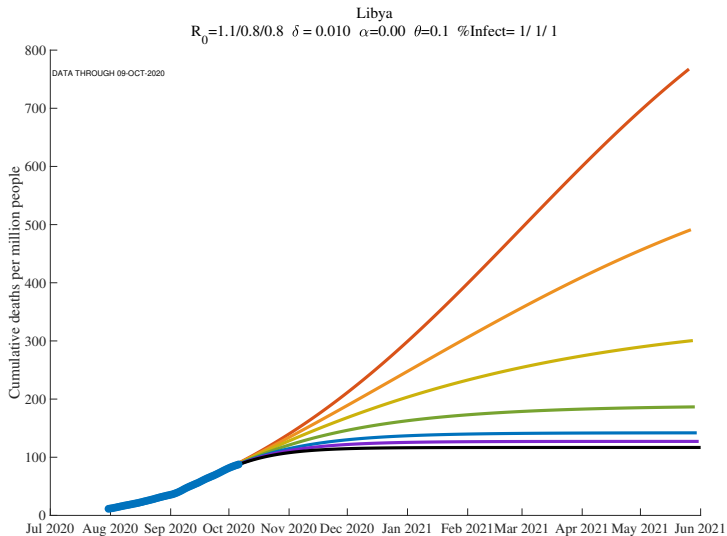
Results for alternative parameter values

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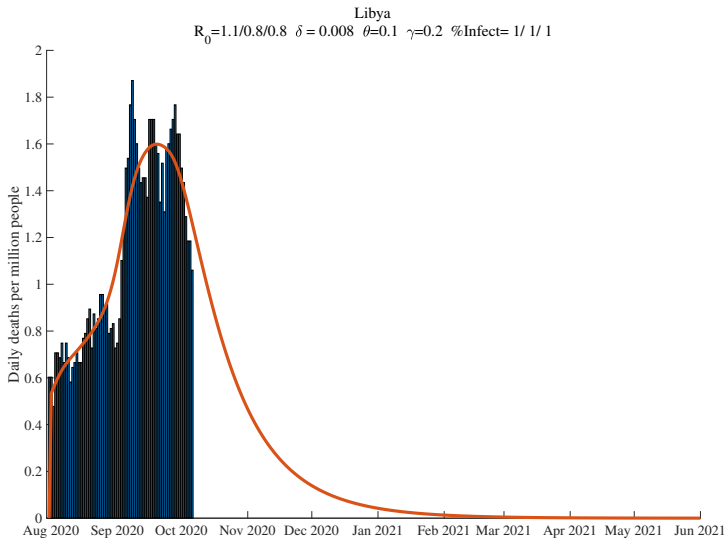

Libya
R_0=1.1/0.8/0.8 δ = 0.010 α=0.00 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

Libya
R_0=1.1/0.8/0.8 $\delta = 0.010$ α=0.00 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

Libya
R_0=1.1/0.8/0.8 $\delta = 0.010$ α=0.00 θ=0.1 %Infect= 1/ 1/ 1

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

Libya
R_0=1.1/0.8/0.8 $\delta = 0.008$ θ=0.1 γ=0.2 %Infect= 1/ 1/ 1

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

Libya
R_0=1.1/0.8/0.8 $\delta = 0.008$ θ=0.1 γ=0.2 %Infect= 1/ 1/ 1
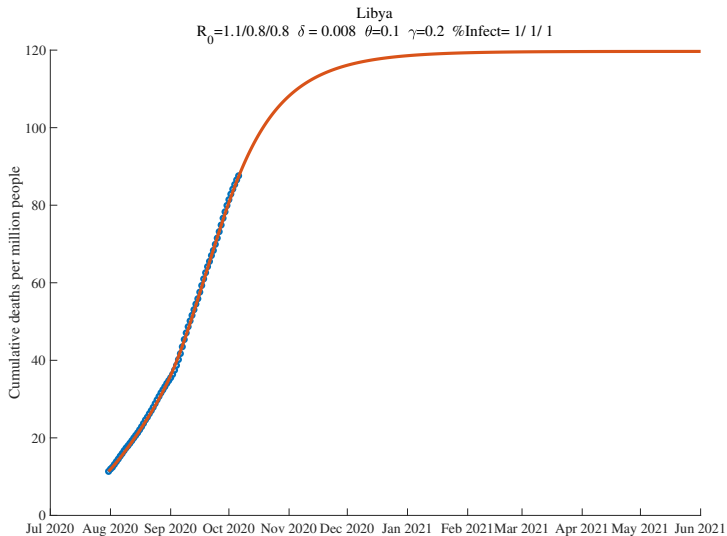
Libya: Daily Deaths per Million People ($\delta = 1.2\%$)

Libya
R_0=1.1/0.8/0.8 $\delta = 0.012$ θ=0.1 γ=0.2 %Infect= 1/ 1/ 1
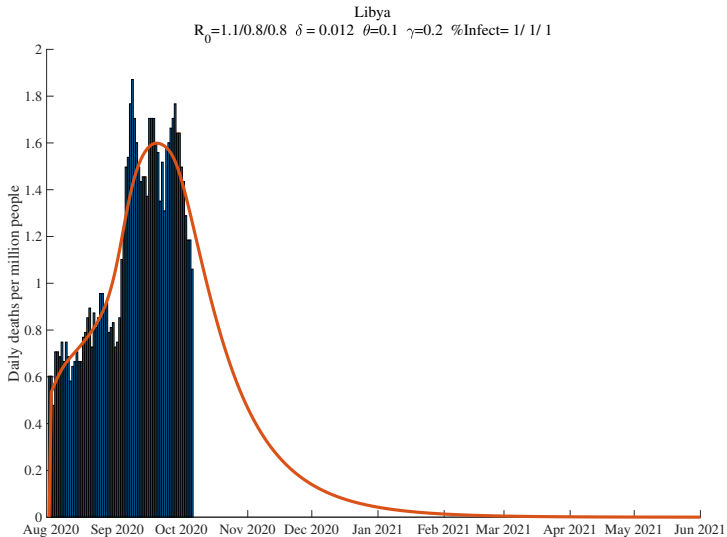
Libya
R_0=1.1/0.8/0.8 $\delta = 0.012$ θ=0.1 γ=0.2 %Infect= 1/ 1/ 1
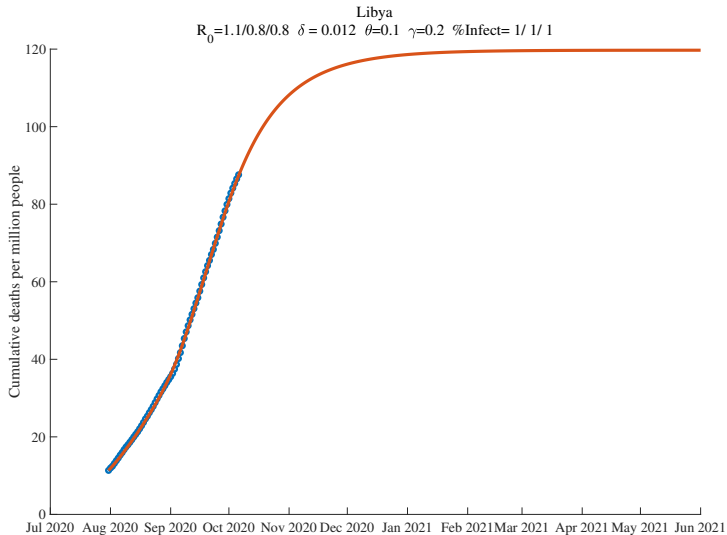
Libya: Daily Deaths per Million People ($\gamma = .2/.15$)

Libya
R_0=1.1/0.8/0.8 δ = 0.010 α=0.05 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

Libya

R_0=1.1/0.8/0.8 $\delta = 0.010$ α=0.05 θ=0.1 %Infect= 1/ 1/ 1

$\gamma \equiv 0.15$

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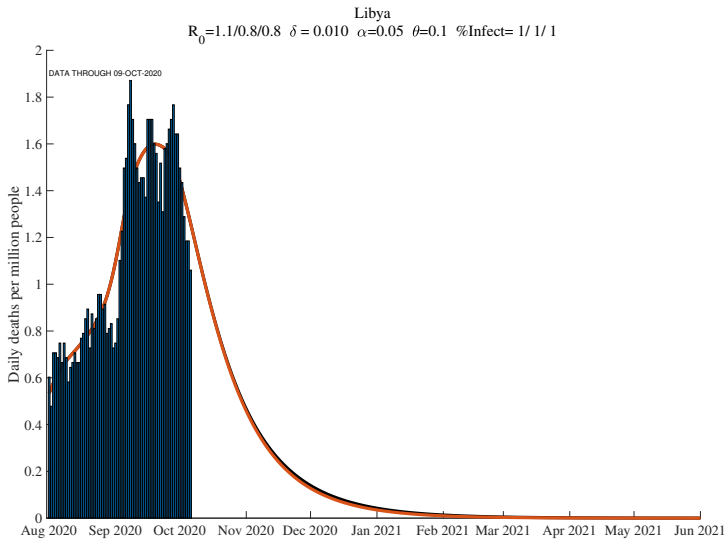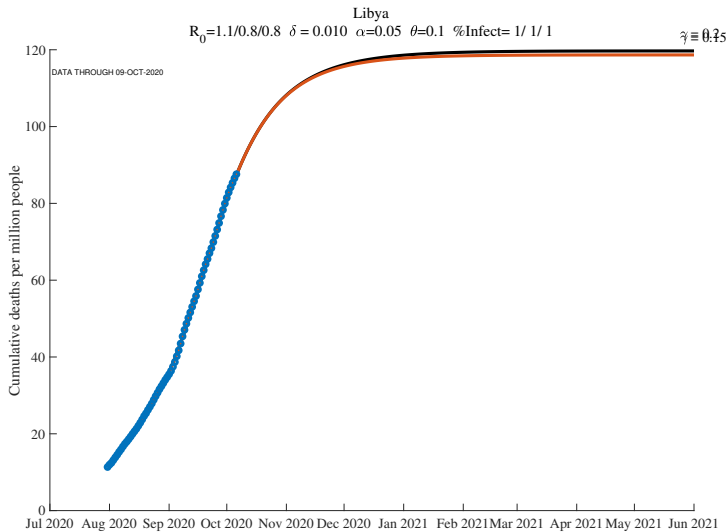
Libya: Daily Deaths per Million People ($\theta = .1/.07/.2$)

Libya
R_0=1.1/0.8/0.8 δ = 0.010 α=0.05 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

Libya
R_0=1.1/0.8/0.8 $\delta = 0.010$ α=0.05 θ=0.1 %Infect= 1/ 1/ 1

DATA THROUGH 09-OCT-2020

$\theta = 0.2$
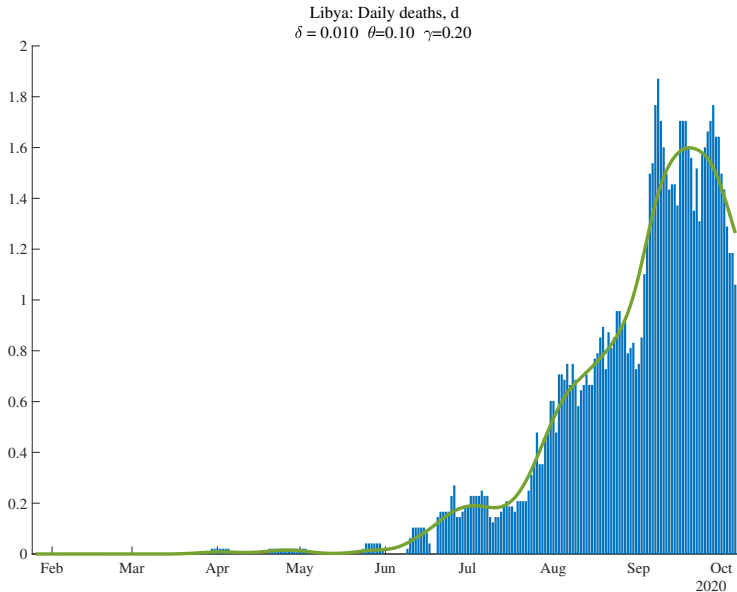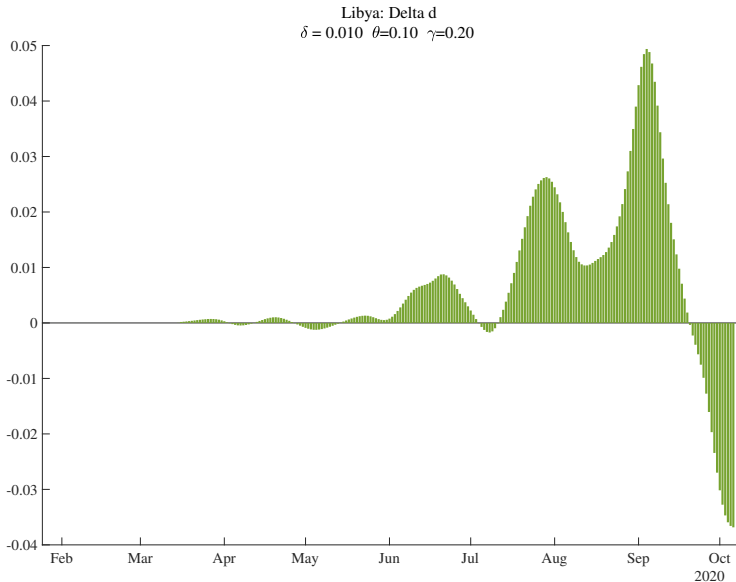
$\theta = 0.1$
$\theta = 0.07$
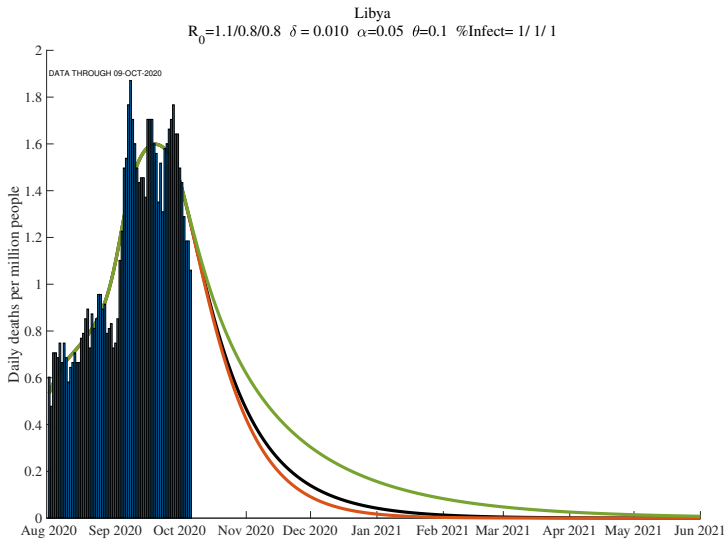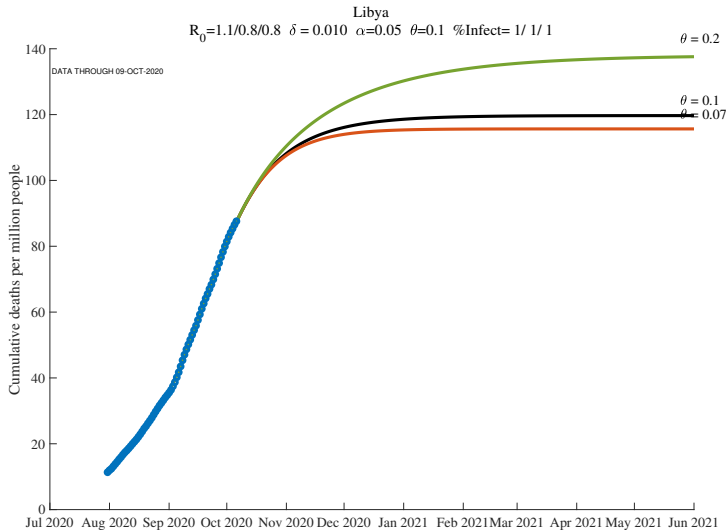
Data Underlying Estimates
of Time-Varying R_0

– Inferred from daily deaths, and

– the change in daily deaths, and

– the change in (the change in daily deaths)

Libya: Daily Deaths, Actual and Smoothed

Libya: Daily deaths, d
$\delta = 0.010$ $\theta = 0.10$ $\gamma = 0.20$

Libya: Change in Smoothed Daily Deaths

Libya: Delta d
$\delta = 0.010$ $\theta = 0.10$ $\gamma = 0.20$

Libya: Change in (Change in Smoothed Daily Deaths)

Libya: Delta (Delta d)
$\delta = 0.010$ $\theta=0.10$ $\gamma=0.20$