QuaranTeam2

Lukas Coffey, Drew Klaubert, David Parks, Arthur Presnetsov

20 April 2020

Import the data.

```
counties <- read.csv("EpiModel_Data.csv", stringsAsFactors = FALSE)
str(counties)
```

```
## 'data.frame':    24 obs. of  6 variables:
##  $ name               : chr  "Allegany" "Anne Arundel" "Baltimore City" "Baltimore County" ...
##  $ county             : int  1 3 510 5 9 11 13 15 17 19 ...
##  $ icu_bed_count      : int  15 80 658 171 8 0 12 9 20 0 ...
##  $ inpatient_bed_count: int  316 748 3953 1317 139 0 143 109 110 47 ...
##  $ pop_density        : num  172 936 6760 1199 260 ...
##  $ county_population  : int  71977 567696 614700 827625 91082 32875 167522 102517 157671 32261 ...
```

Create variables needed for the model.

```
# the infection probability rate
inf_prob_rate <- 0.25

# the infected death rate
death_rate <- 0.0138

# the infected recovery rate
recovery_rate <- 1 / 24.7

# per county activity rate
# using the log base 10 of the per county population density as a proxy for
# transmissive acts per person per time period
activity_rate <- log10(counties$pop_density)

# manually correct baltimore city's activity rate to be equal to the
# maximum of the other counties
activity_rate[3] <- sort(activity_rate, decreasing = TRUE)[2]
```

Compute the SIR model for each county WITHOUT intervention.

```
# number of time steps
n_steps <- 90

# create an empty list to capture the models
sir_models_ni <- list()

# instantiate the models and store them in a list
index <- 1

for (pop in counties$county_population) {
  # assumes no births and no deaths from natural causes
  param <- param.dcm(inf.prob = inf_prob_rate,
                     act.rate = activity_rate[[index]],
                     rec.rate = recovery_rate,
                     a.rate = 0,
```

```
                    ds.rate = 0,
                    di.rate = death_rate,
                    dr.rate = 0)
  # assumes full population is susceptible, 1 infected person
  init <- init.dcm(s.num = pop - 1, i.num = 1, r.num = 0)
  control <- control.dcm(type = "SIR",
                         nsteps = n_steps)
  sir_model <- dcm(param, init, control)
  sir_models_ni[[index]] <- sir_model
  index <- index + 1
}
```

Compute the SIR model for each county WITH intervention starting on day 1, reducing the probability of transmission by 72%.

```
effectiveness <- 0.72
start_day <- 1

# number of time steps
n_steps <- 90

# create an empty list to capture the models
sir_models_i <- list()

# instantiate the models and store them in a list
index <- 1

for (pop in counties$county_population) {
  # assumes no births and no deaths from natural causes
  param <- param.dcm(inf.prob = inf_prob_rate,
                    inter.eff = effectiveness,
                    inter.start = start_day,
                    act.rate = activity_rate[[index]],
                    rec.rate = recovery_rate,
                    a.rate = 0,
                    ds.rate = 0,
                    di.rate = death_rate,
                    dr.rate = 0)
  # assumes full population is susceptible, 1 infected person
  init <- init.dcm(s.num = pop - 1, i.num = 1, r.num = 0)
  control <- control.dcm(type = "SIR",
                         nsteps = n_steps)
  sir_model <- dcm(param, init, control)
  sir_models_i[[index]] <- sir_model
  index <- index + 1
}
```

Determine when the number of hospital beds would be fully occupied if 4% of those infected need hospitalization.

```
# % of infected that need hospitalization
hospitalization_rate <- 0.04

# create empty arrays to capture the results
icu_no_i <- rep(NA, length(counties$name))
```

```r
normal_no_i <- rep(NA, length(counties$name))
max_inf_no_i <- rep(NA, length(counties$name))
icu_i <- rep(NA, length(counties$name))
normal_i <- rep(NA, length(counties$name))
max_inf_i <- rep(NA, length(counties$name))


for (i in 1:length(counties$name)) {
  # NO INTERVENTION ************************************************************
  # number of hospitalized patients per day
  infected <- as.data.frame(sir_models_ni[[i]])$i.num
  hospitalized <- floor(infected * hospitalization_rate)
  total_beds <- counties$icu_bed_count[i] + counties$inpatient_bed_count[i]

  # get the day when the number of infected needing hospitalization
  # exceeds icu capacity
  icu_no_i[i] <- which.max(hospitalized > counties$icu_bed_count[i])

  # get the day when the number of infected needing hospitalization
  # exceeds total bed capacity
  normal_no_i[i] <- which.max(hospitalized > total_beds)

  # get the maximum number of infected
  max_inf_no_i[i] <- round(max(infected))
  # NO INTERVENTION ************************************************************
  # ****************************************************************************
  # INTERVENTION ***************************************************************
  # number of hospitalized patients per day
  infected <- as.data.frame(sir_models_i[[i]])$i.num
  hospitalized <- floor(infected * hospitalization_rate)

  # get the day when the number of infected needing hospitalization
  # exceeds icu capacity
  icu_i[i] <- which.max(hospitalized > counties$icu_bed_count[i])

  # get the day when the number of infected needing hospitalization
  # exceeds total bed capacity
  normal_i[i] <- which.max(hospitalized > total_beds)

  # get the maximum number of infected
  max_inf_i[i] <- round(max(infected))
  # INTERVENTION ***************************************************************
}

# manually correct for counties without hospital beds
icu_no_i[counties$icu_bed_count == 0] <- 0
normal_no_i[counties$inpatient_bed_count == 0] <- 0
icu_i[counties$icu_bed_count == 0] <- 0
normal_i[counties$inpatient_bed_count == 0] <- 0

# create a table of the results
results <- cbind(counties$name,
                 icu_no_i,
```

```
                 normal_no_i,
                 max_inf_no_i,
                 icu_i,
                 normal_i,
                 max_inf_i)
colnames(results) <- c("County",
                       "ICU-No I",
                       "IPB-No I",
                       "MaxInf-No I",
                       "ICU-I",
                       "IPB-I",
                       "Max Inf-I")
print(as.table(results))
```

```
##   County           ICU-No I IPB-No I MaxInf-No I ICU-I IPB-I Max Inf-I
## A Allegany         13       20       49147       60    1     7022
## B Anne Arundel     13       16       420110      51    67    216708
## C Baltimore City   14       17       466468      57    70    270204
## D Baltimore County 13       16       617853      53    67    336626
## E Calvert          11       17       63657       49    74    16778
## F Caroline         0        0        21607       0     0     1805
## G Carroll          11       16       119208      48    68    38207
## H Cecil            12       16       71413       51    73    15587
## I Charles          13       17       109598      58    74    16270
## J Dorchester       0        23       19007       0     1     103
## K Frederick        0        17       176287      0     73    42828
## L Garrett          15       22       17980       80    1     241
## M Harford          12       16       180250      49    67    65708
## N Howard           11       14       234666      44    57    131151
## O Kent             0        24       12052       0     1     276
## P Montgomery       13       16       787623      50    63    457205
## Q Prince George's  12       15       684806      46    59    393775
## R Queen Anne's     0        0        32297       0     0     1635
## S St. Mary's       13       18       75210       62    84    4789
## T Somerset         0        24       15626       0     1     203
## U Talbot           0        21       24017       0     1     1027
## V Washington       13       17       105828      55    76    28797
## W Wicomico         13       18       71221       58    82    16427
## X Worcester        0        19       33039       0     1     876
```

Compute the Root Sum Squared Error for the intervention model on day 45.

```
# create an empty array to capture the results
estimated_cases <- rep(NA, length(counties$name))

# get the number of infected for each county on day 45
for (i in 1:length(counties$name)) {
  estimated_cases[[i]] <- round(as.data.frame(sir_models_i[[i]])$i.num[45])
}

# actual cases in MD on day 45
actual_cases <- c(33,1005,1378,1664,109,33,308,131,347,20,557,4,195,508,16,
                  2404,3160,24,101,10,16,116,138,31)

# create a comparison table
```

```
results <- cbind(counties$name,
                 actual_cases,
                 estimated_cases,
                 actual_cases - estimated_cases)
colnames(results) <- c("County",
                       "Actual Cases",
                       "Model Cases",
                       "Difference")
print(as.table(results))
```

```
##   County           Actual Cases Model Cases Difference
## A Allegany         33           90          -57
## B Anne Arundel     1005         863         142
## C Baltimore City   1378         2347        -969
## D Baltimore County 1664         1203        461
## E Calvert          109          156         -47
## F Caroline         33           44          -11
## G Carroll          308          249         59
## H Cecil            131          143         -12
## I Charles          347          136         211
## J Dorchester       20           10          10
## K Frederick        557          239         318
## L Garrett          4            15          -11
## M Harford          195          344         -149
## N Howard           508          1173        -665
## O Kent             16           16          0
## P Montgomery       2404         2352        52
## Q Prince George's  3160         2027        1133
## R Queen Anne's     24           40          -16
## S St. Mary's       101          69          32
## T Somerset         10           14          -4
## U Talbot           16           32          -16
## V Washington       116          204         -88
## W Wicomico         138          148         -10
## X Worcester        31           29          2
```

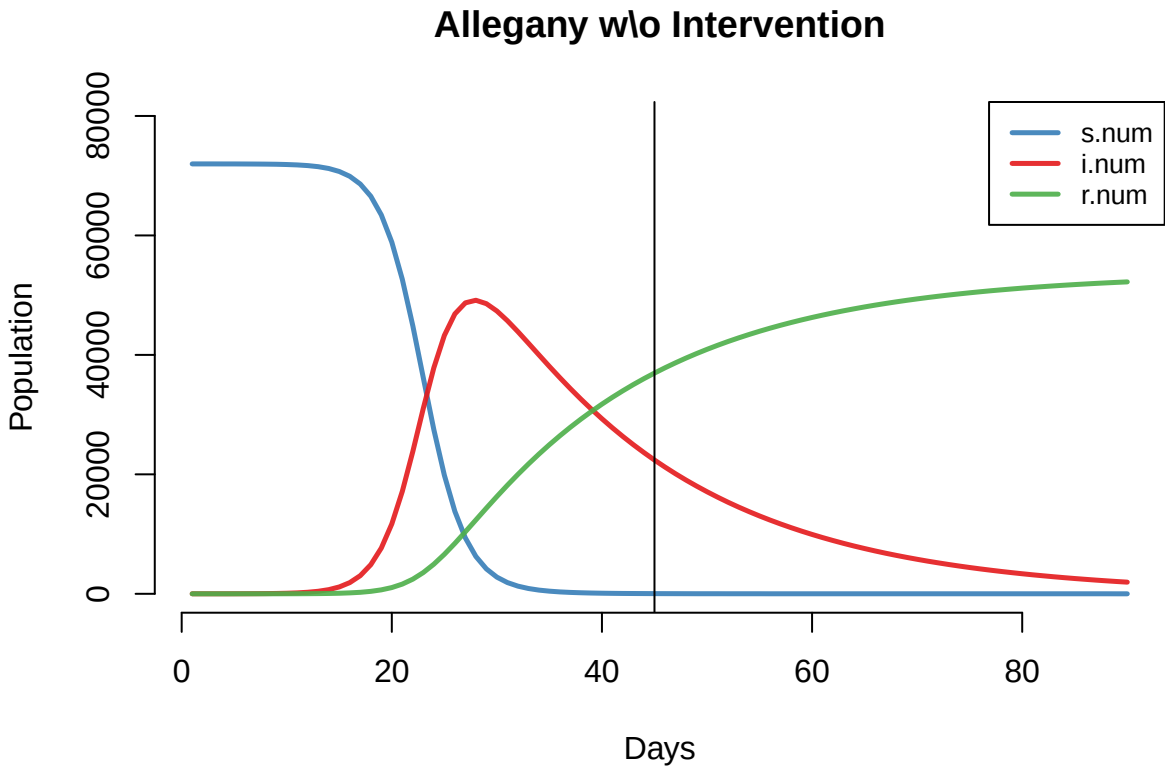
```
# RSSE
sqrt(sum((actual_cases - estimated_cases)^2))
```

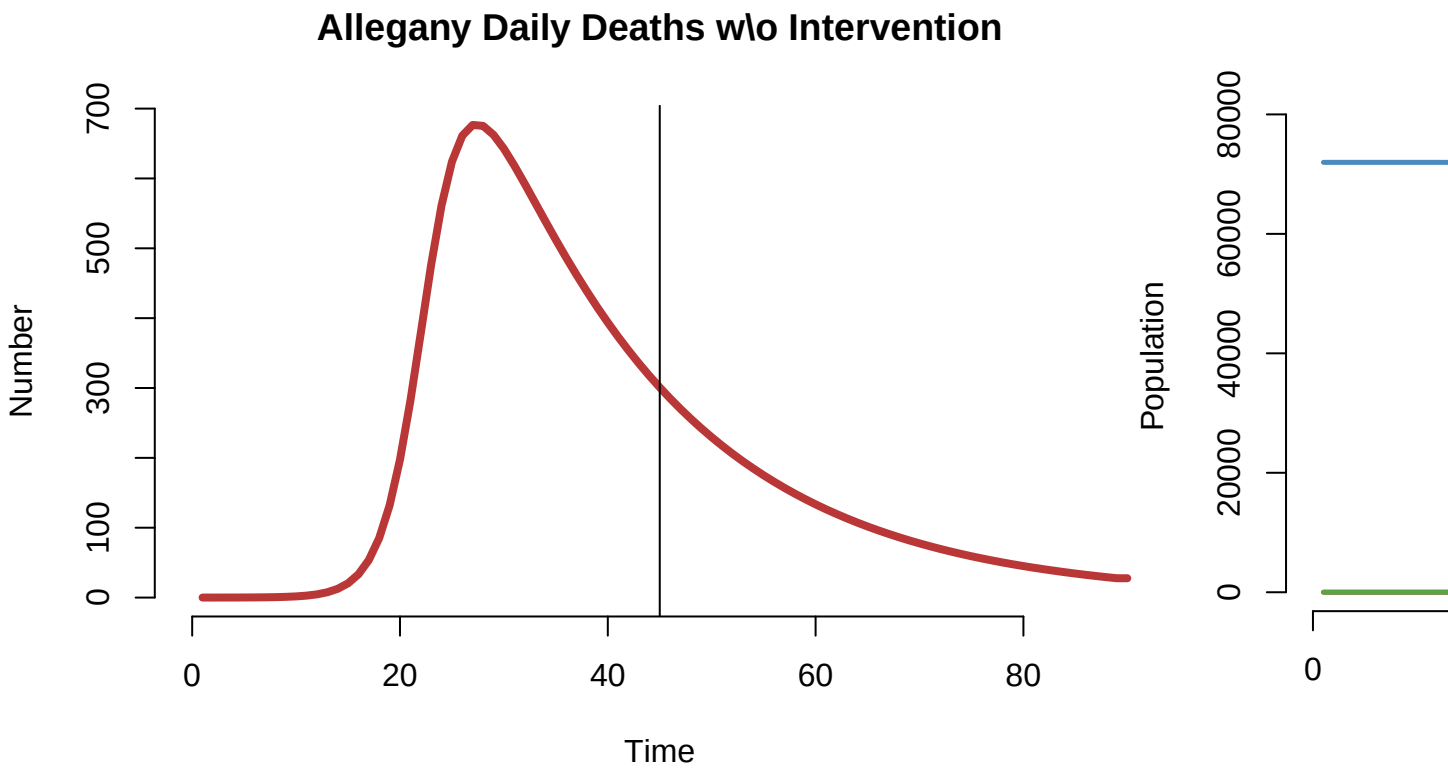
```
## [1] 1756.968
```

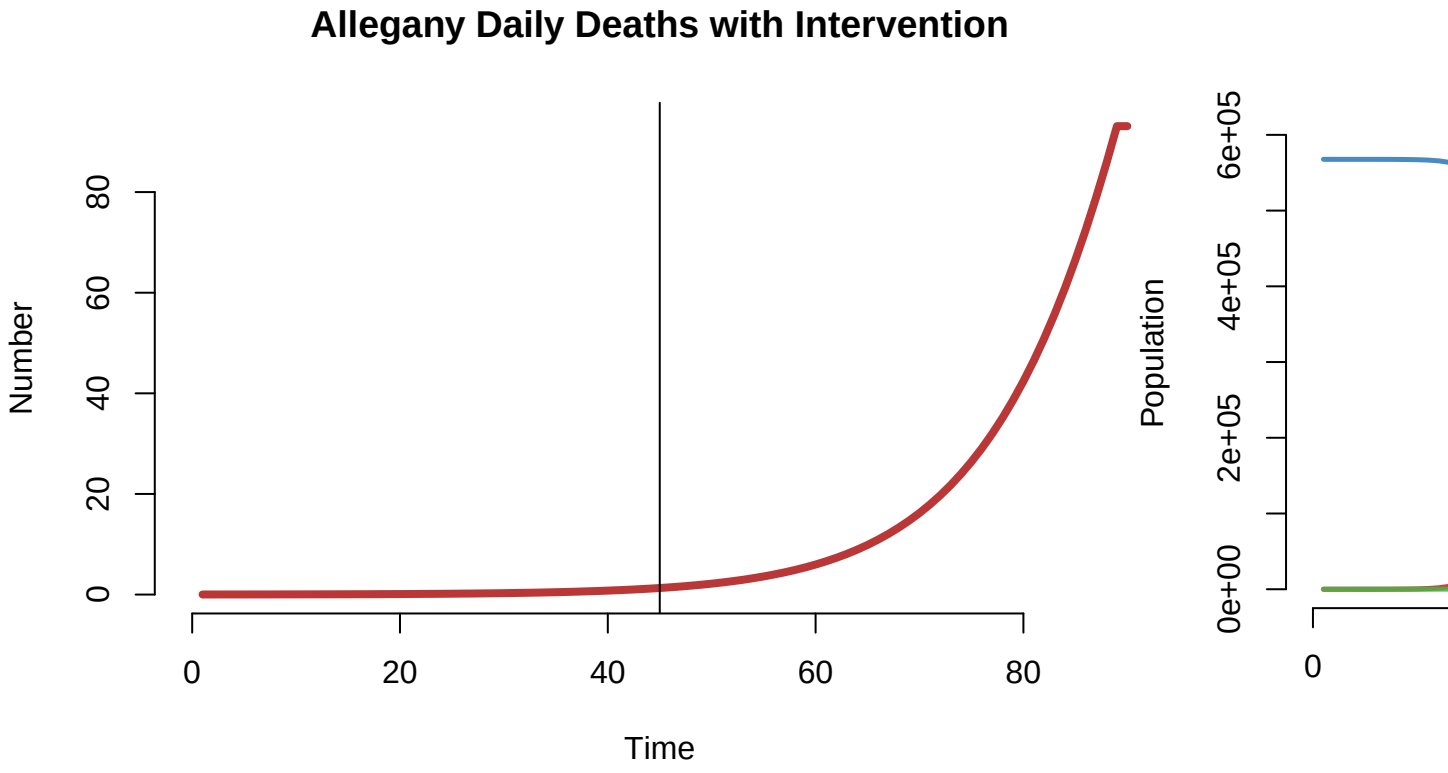
Plot the results

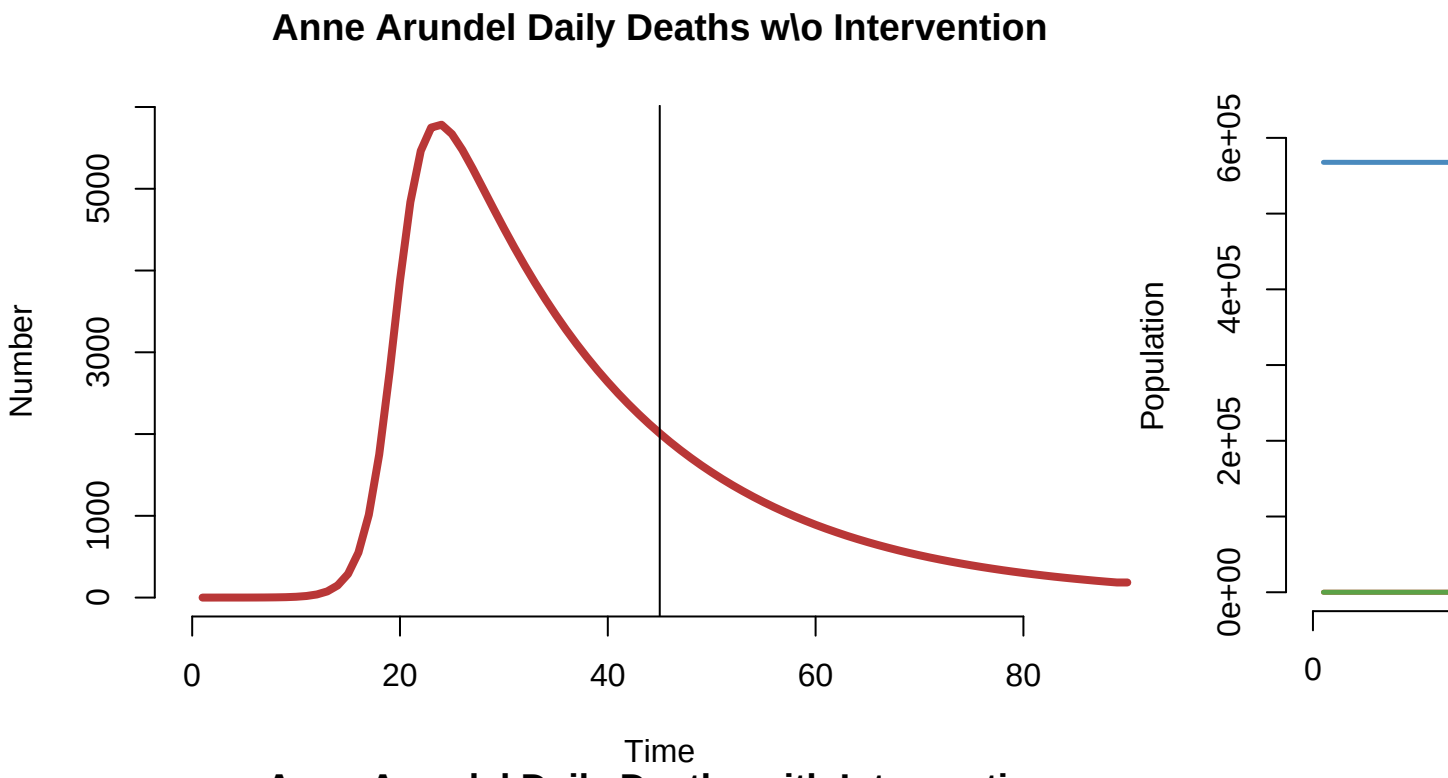
```
for (i in 1:length(counties$name)) {
  # NO INTERVENTION ************************************************************
  # plot the results of the SIR model
  plot(sir_models_ni[[i]],
       main = paste(counties$name[i], "w\\o Intervention"),
       xlab = "Days", ylab = "Population",
       xlim = c(1, n_steps),
       ylim = c(0, counties$county_population[i] * 1.1))
  abline(v=45)


  # plot the number of daily deaths
```

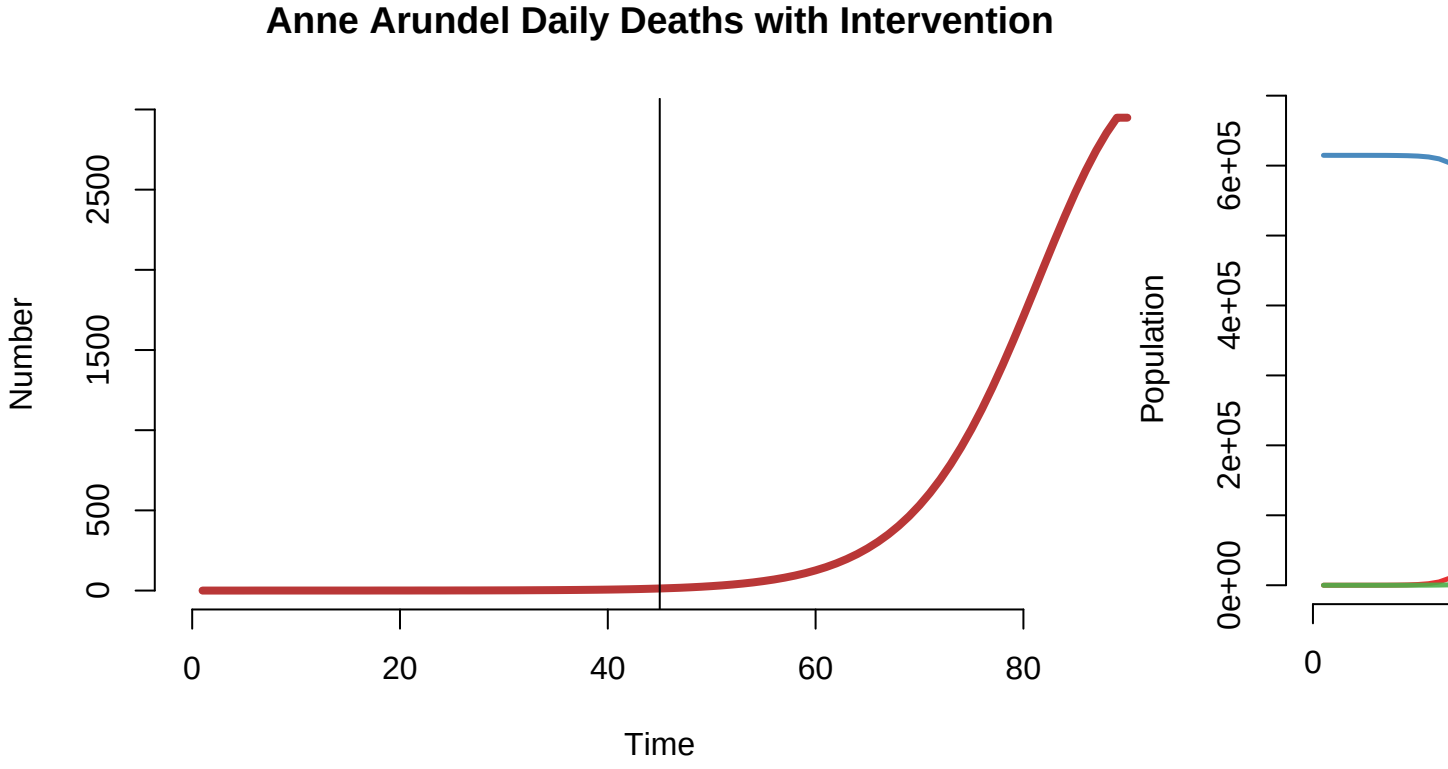
```r
  plot(sir_models_ni[[i]], y = "di.flow", lwd = 4, col = "firebrick",
       main = paste(counties$name[i], "Daily Deaths w\\o Intervention"))
  abline(v=45)
  # NO INTERVENTION ************************************************************
  # ****************************************************************************
  # INTERVENTION ***************************************************************
  # plot the results of the SIR model
  plot(sir_models_i[[i]],
       main = paste(counties$name[i], "with Intervention"),
       xlab = "Days", ylab = "Population",
       xlim = c(1, n_steps),
       ylim = c(0, counties$county_population[i] * 1.1))
  abline(v=45)

  # plot the number of daily deaths
  plot(sir_models_i[[i]], y = "di.flow", lwd = 4, col = "firebrick",
       main = paste(counties$name[i], "Daily Deaths with Intervention"))
  abline(v=45)
  # INTERVENTION ***************************************************************
}
```

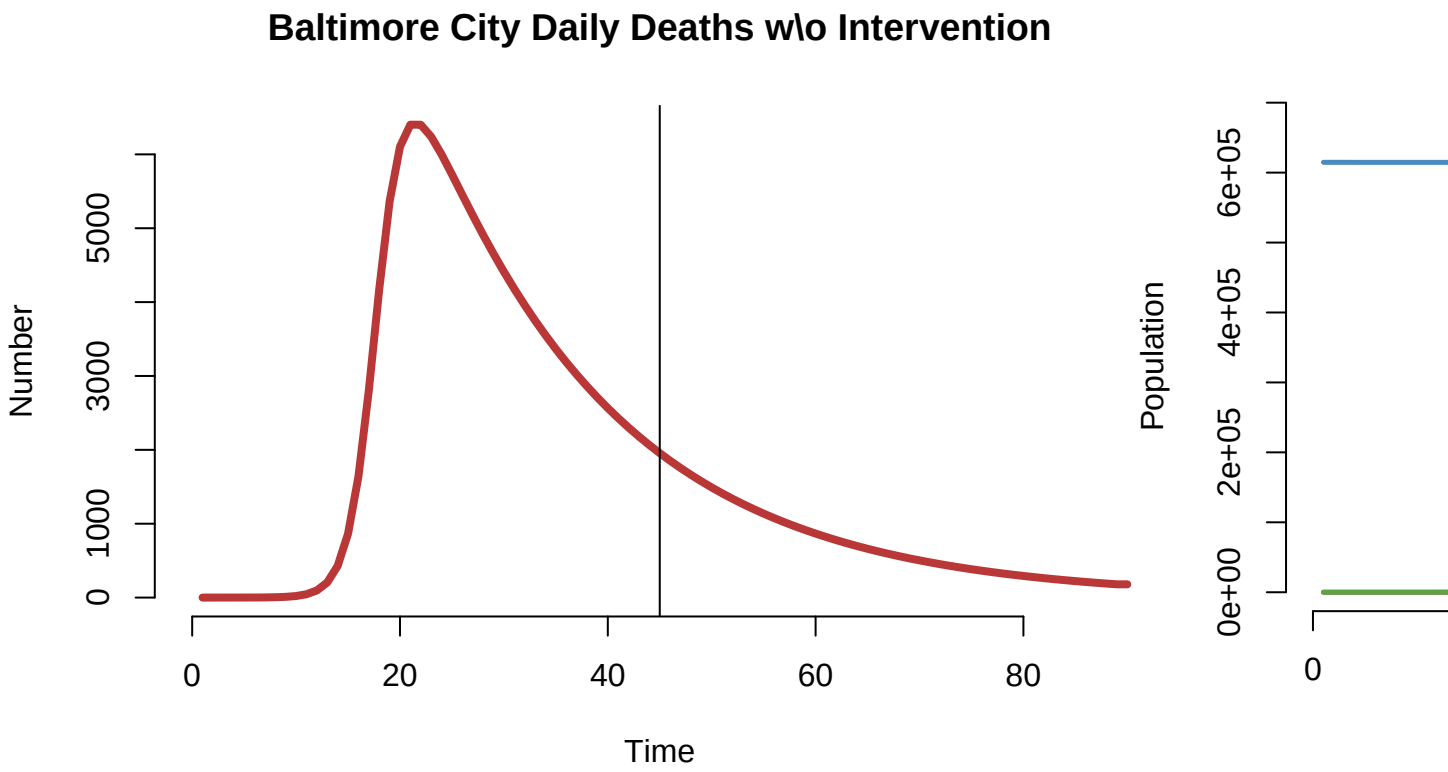


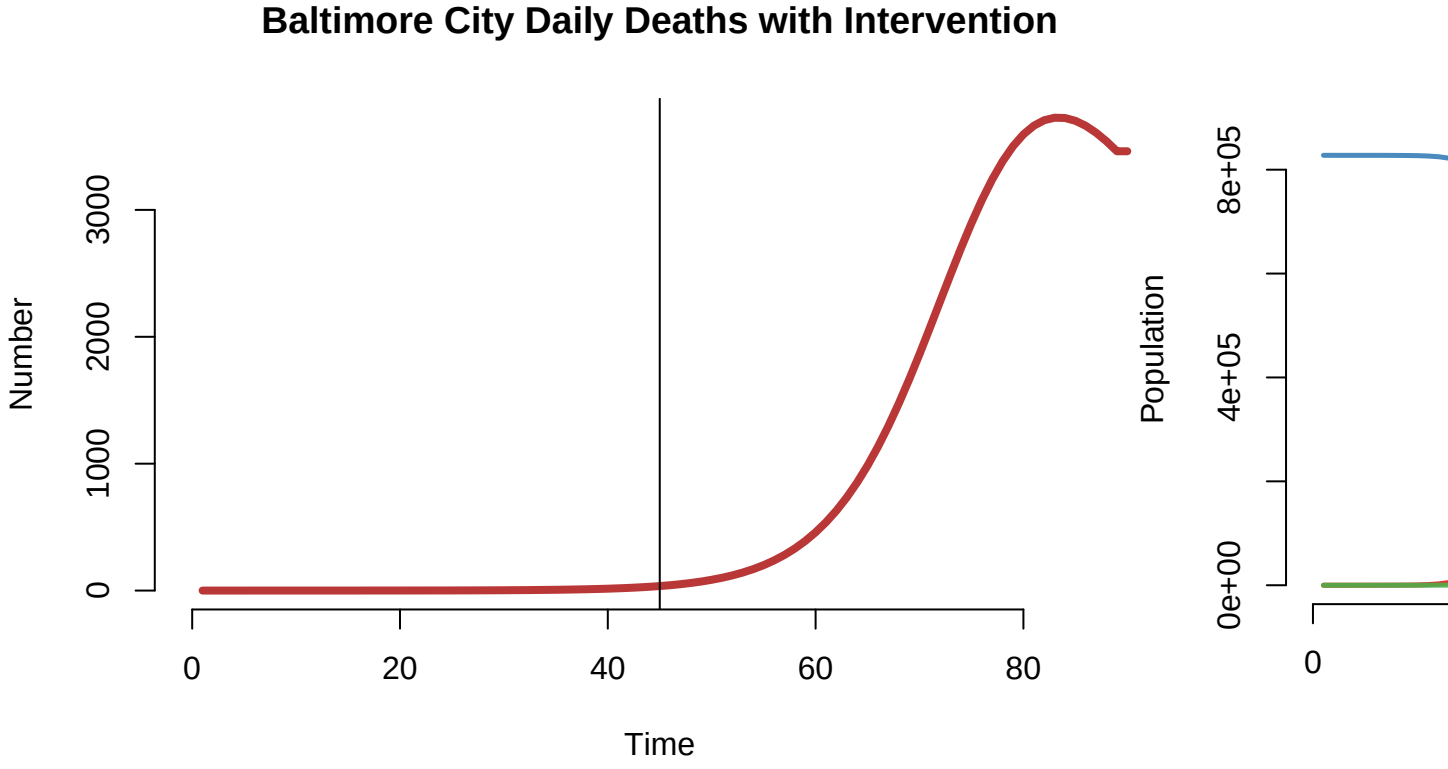

Allegany Daily Deaths w\o Intervention
Number
0
100
300
500
700
0
20
40
60
80
Time
Population
0
20000
40000
60000
80000
0

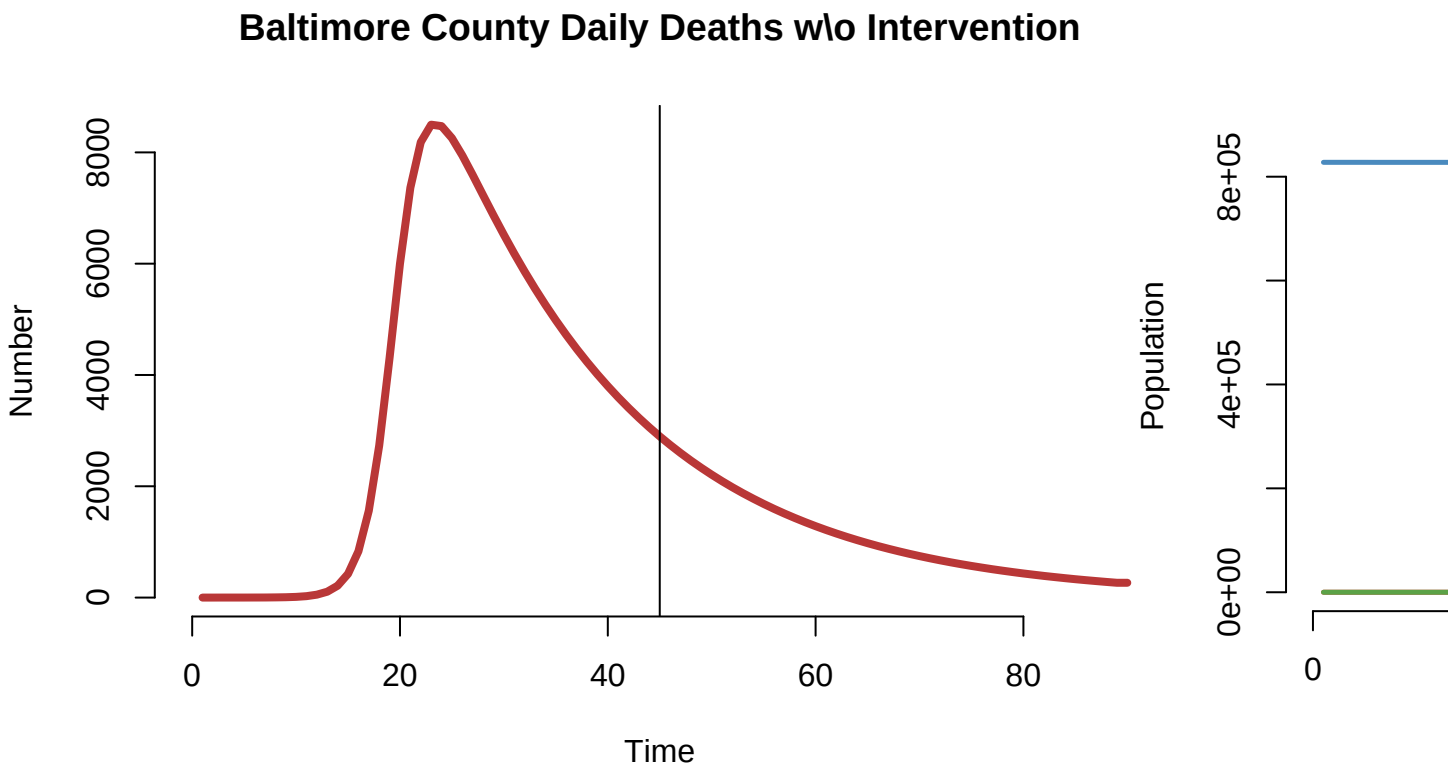

Allegany Daily Deaths with Intervention
Number
0
20
40
60
80
0
20
40
60
80
Time
Population
0e+00
2e+05
4e+05
6e+05
0

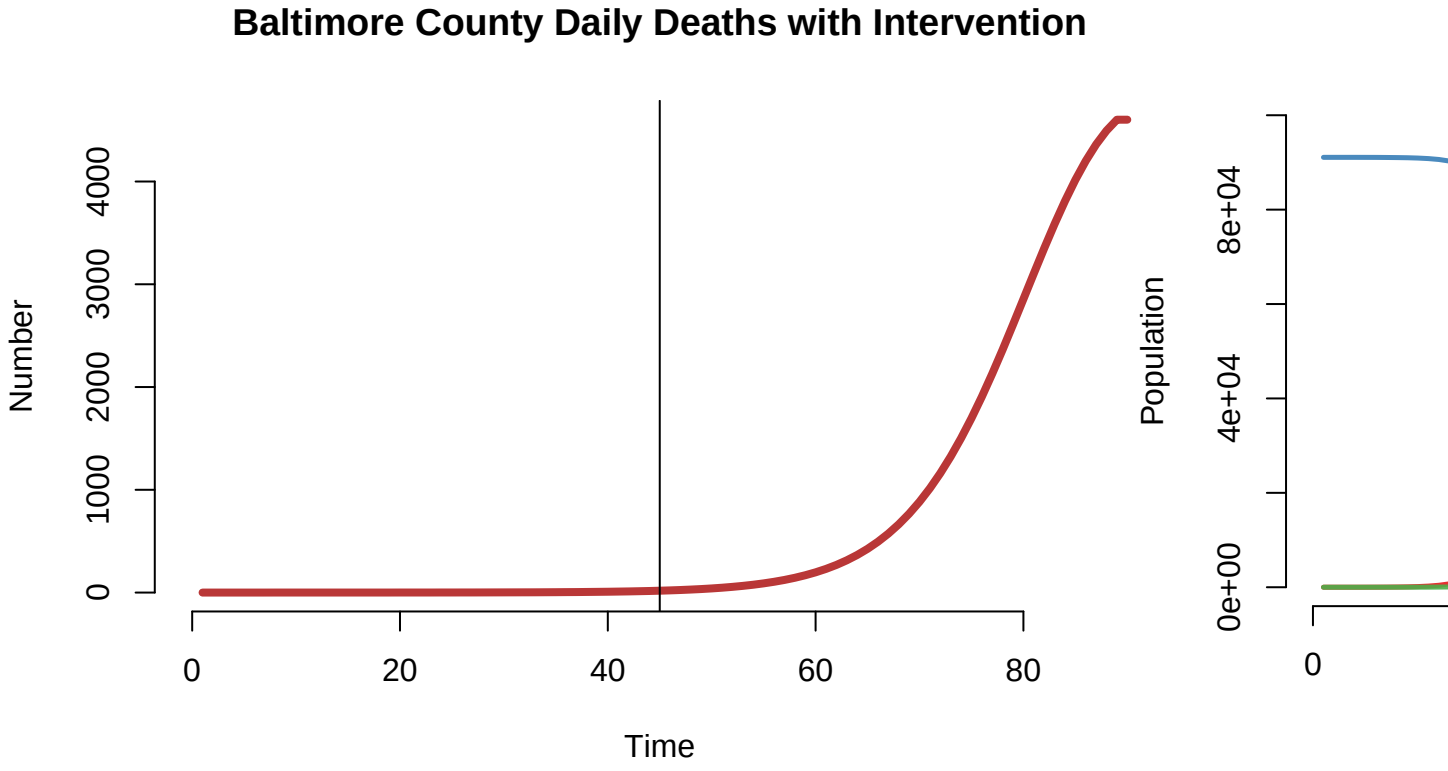

Anne Arundel Daily Deaths w\o Intervention
Number
0
1000
3000
5000
0
20
40
60
80
Time
Population
0e+00
2e+05
4e+05
6e+05
0

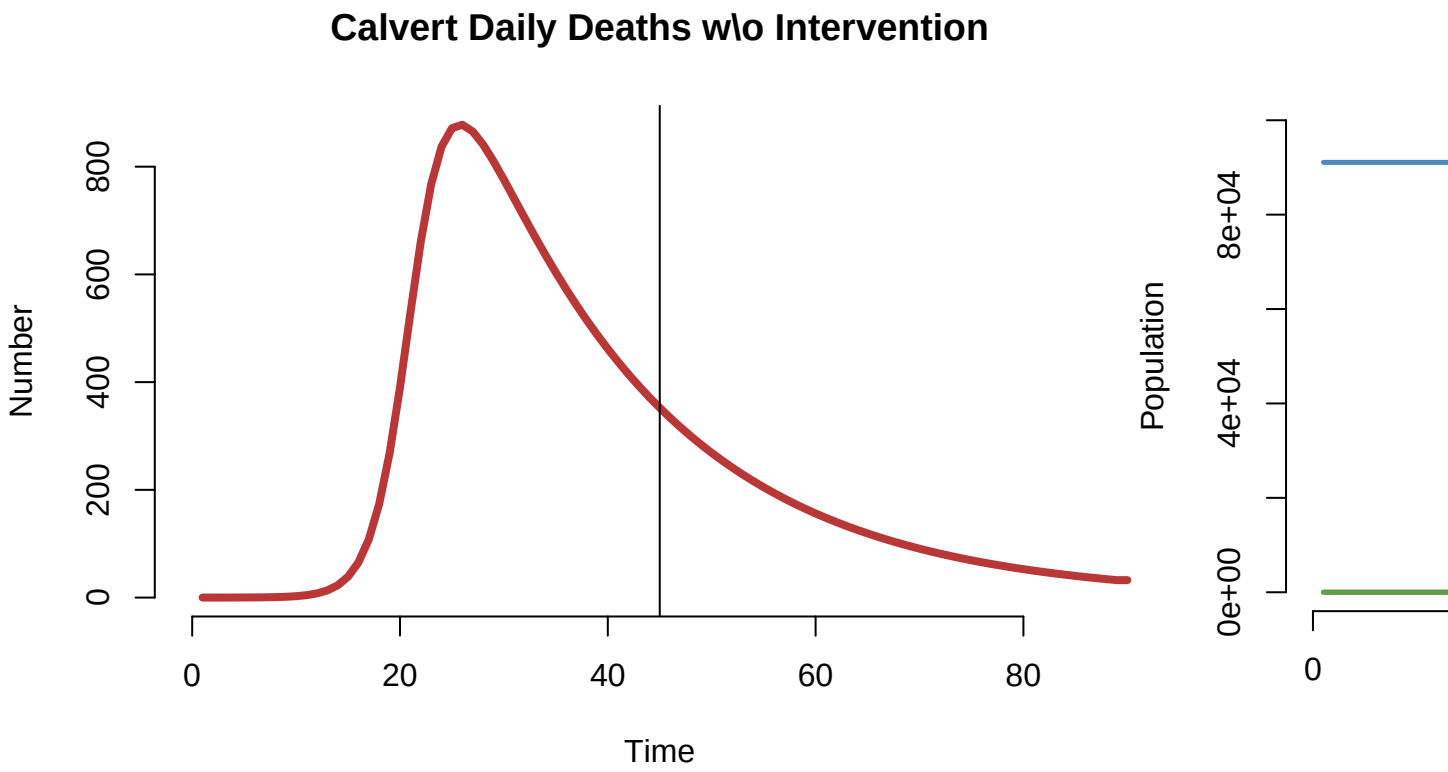

Anne Arundel Daily Deaths with Intervention
Number
0
500
1500
2500
0
20
40
60
80
Time
Population
0e+00
2e+05
4e+05
6e+05
0

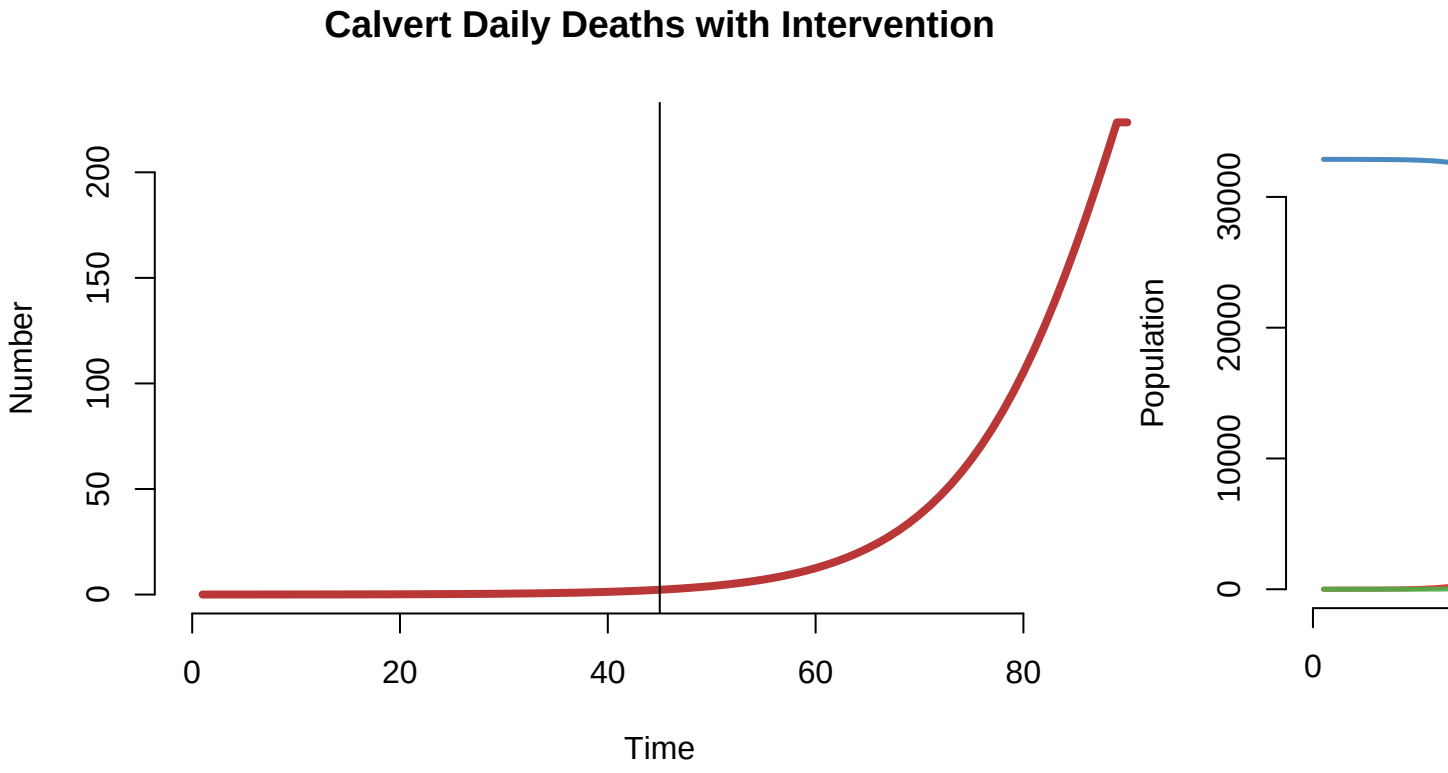

Baltimore City Daily Deaths w\o Intervention
Number
0
1000
3000
5000
0
20
40
60
80
Time
Population
0e+00
2e+05
4e+05
6e+05
0

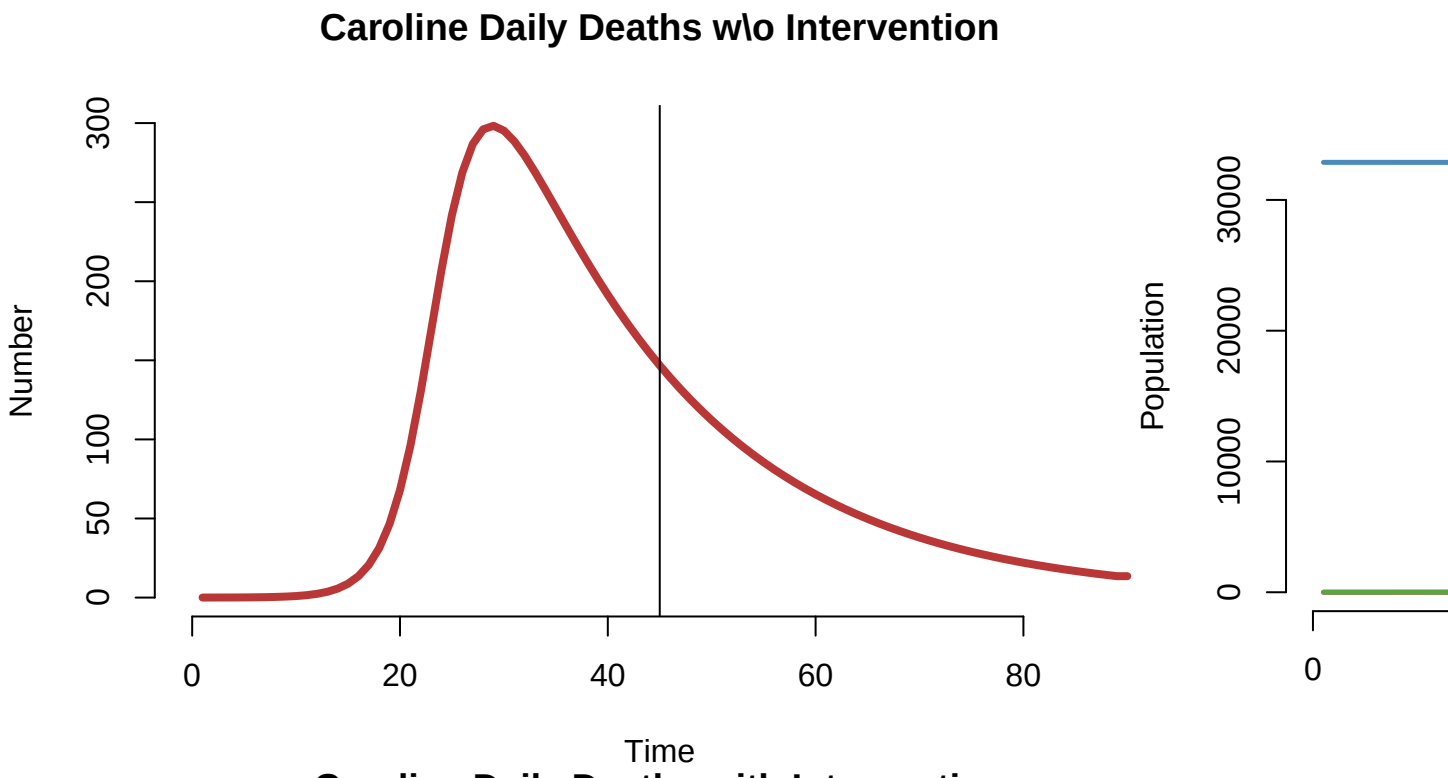

Baltimore City Daily Deaths with Intervention
Number
0
1000
2000
3000
0
20
40
60
80
Time
Population
0e+00
4e+05
8e+05
0

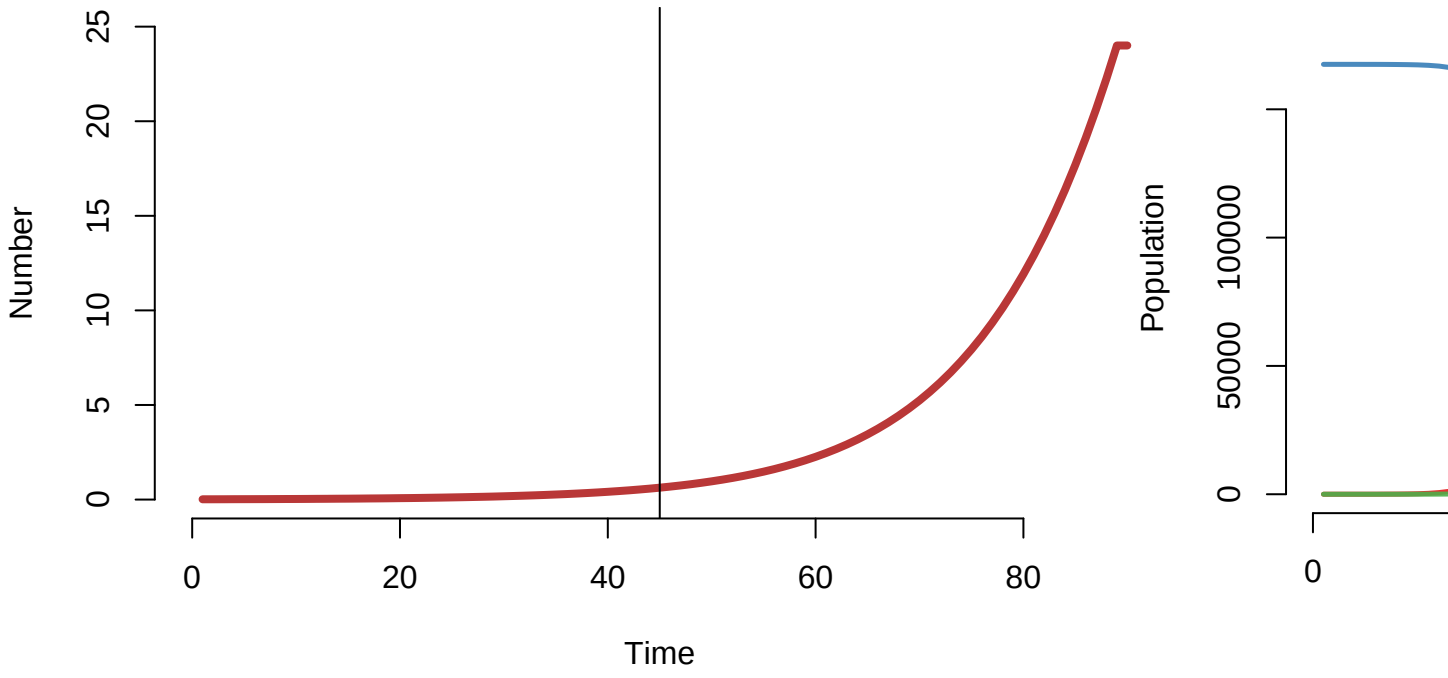

Baltimore County Daily Deaths w\o Intervention
Number
0
2000
4000
6000
8000
0
20
40
60
80
Time
Population
0e+00
4e+05
8e+05
0

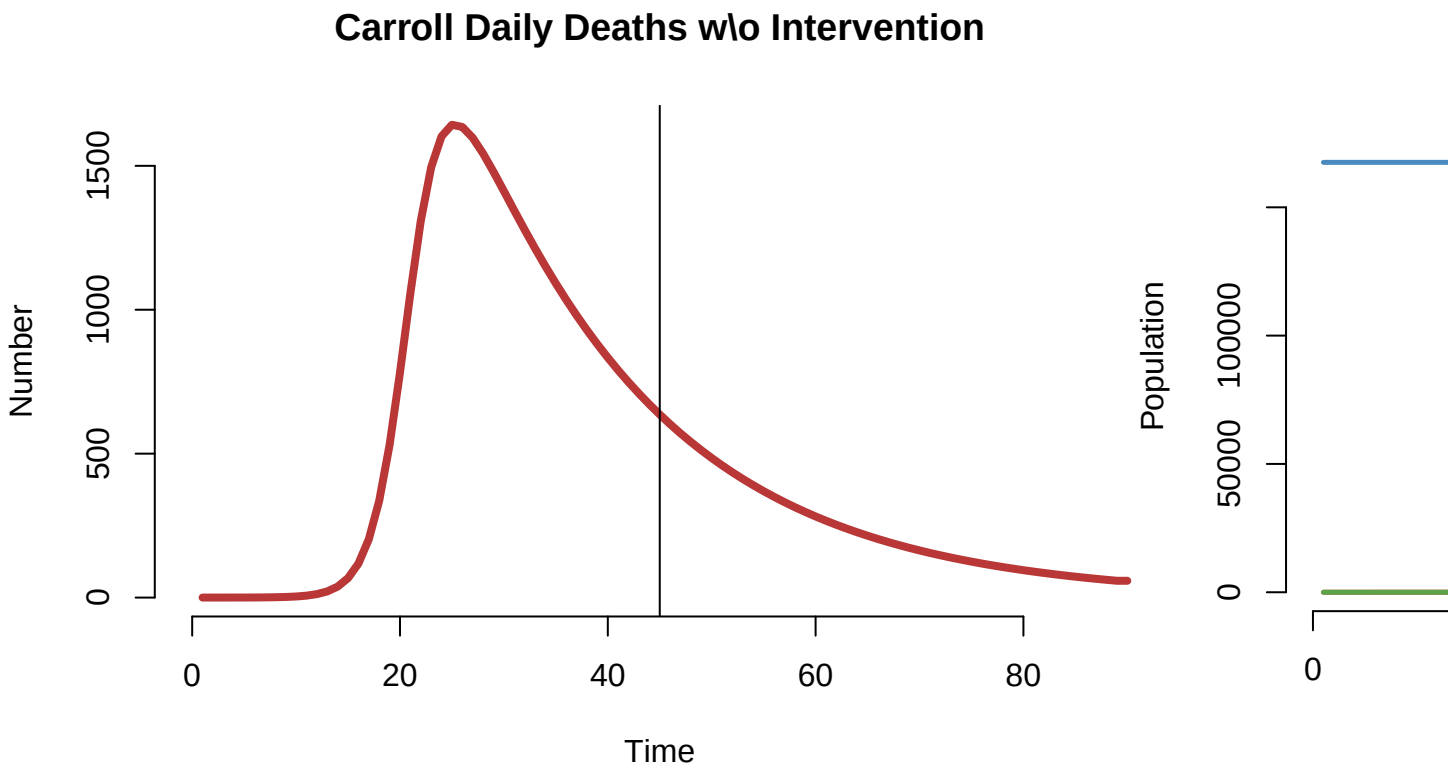

Baltimore County Daily Deaths with Intervention
Number
0
1000
2000
3000
4000
0
20
40
60
80
Time
Population
0e+00
4e+04
8e+04
0

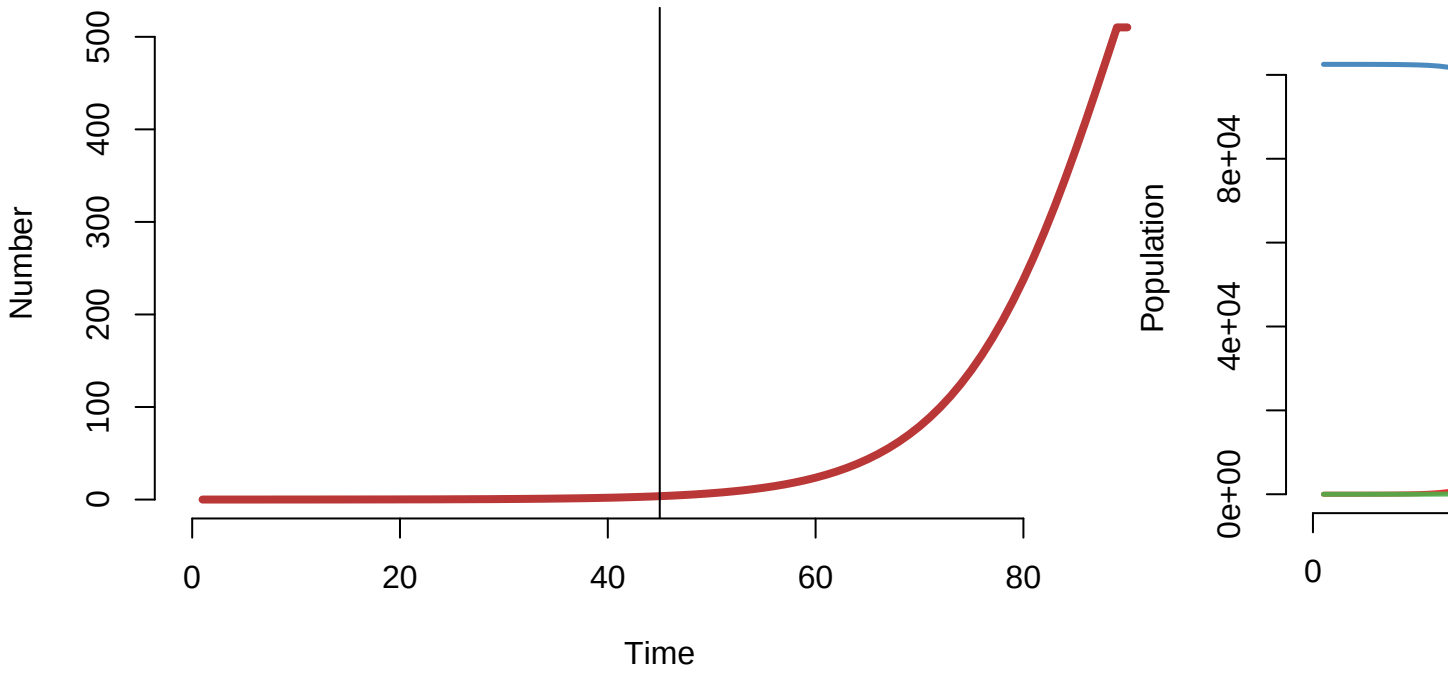

Calvert Daily Deaths w\o Intervention
Number
0
200
400
600
800
0
20
40
60
80
Time
Population
0e+00
4e+04
8e+04
0

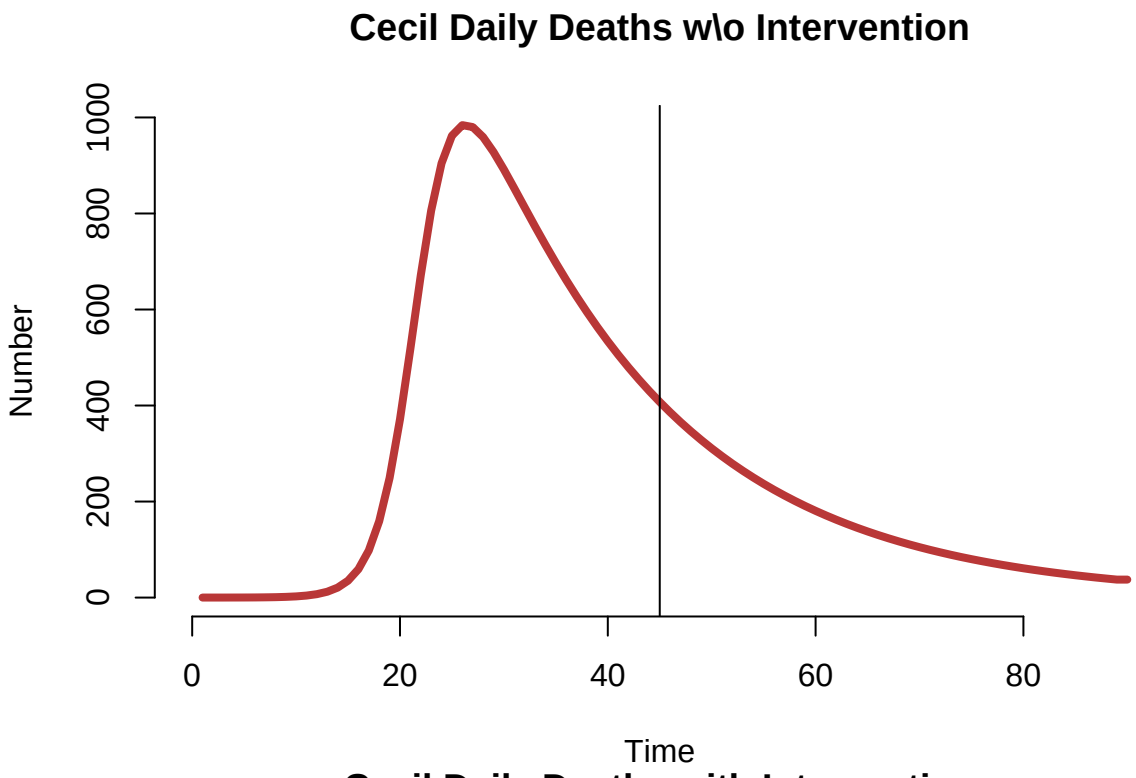

Calvert Daily Deaths with Intervention
Number
0
50
100
150
200
0
20
40
60
80
Time
Population
0
10000
20000
30000
0

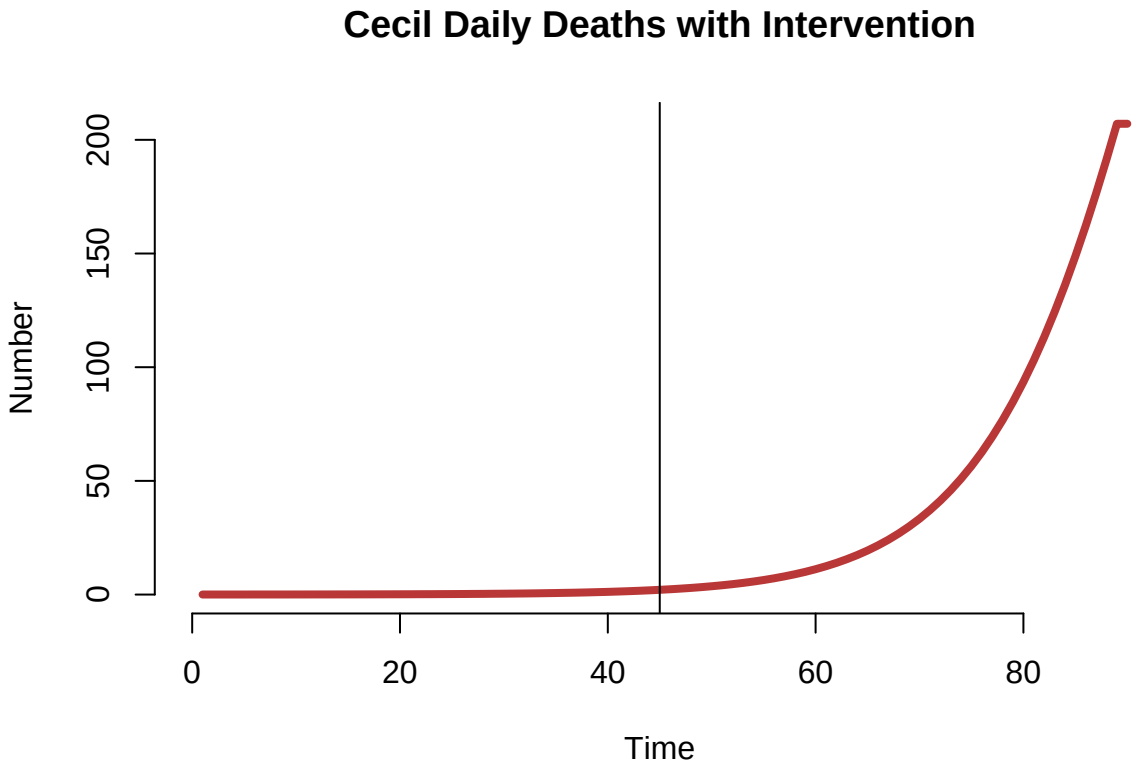

Caroline Daily Deaths w\o Intervention
Number
0
50
100
200
300
0
20
40
60
80
Time
Population
0
10000
20000
30000
0

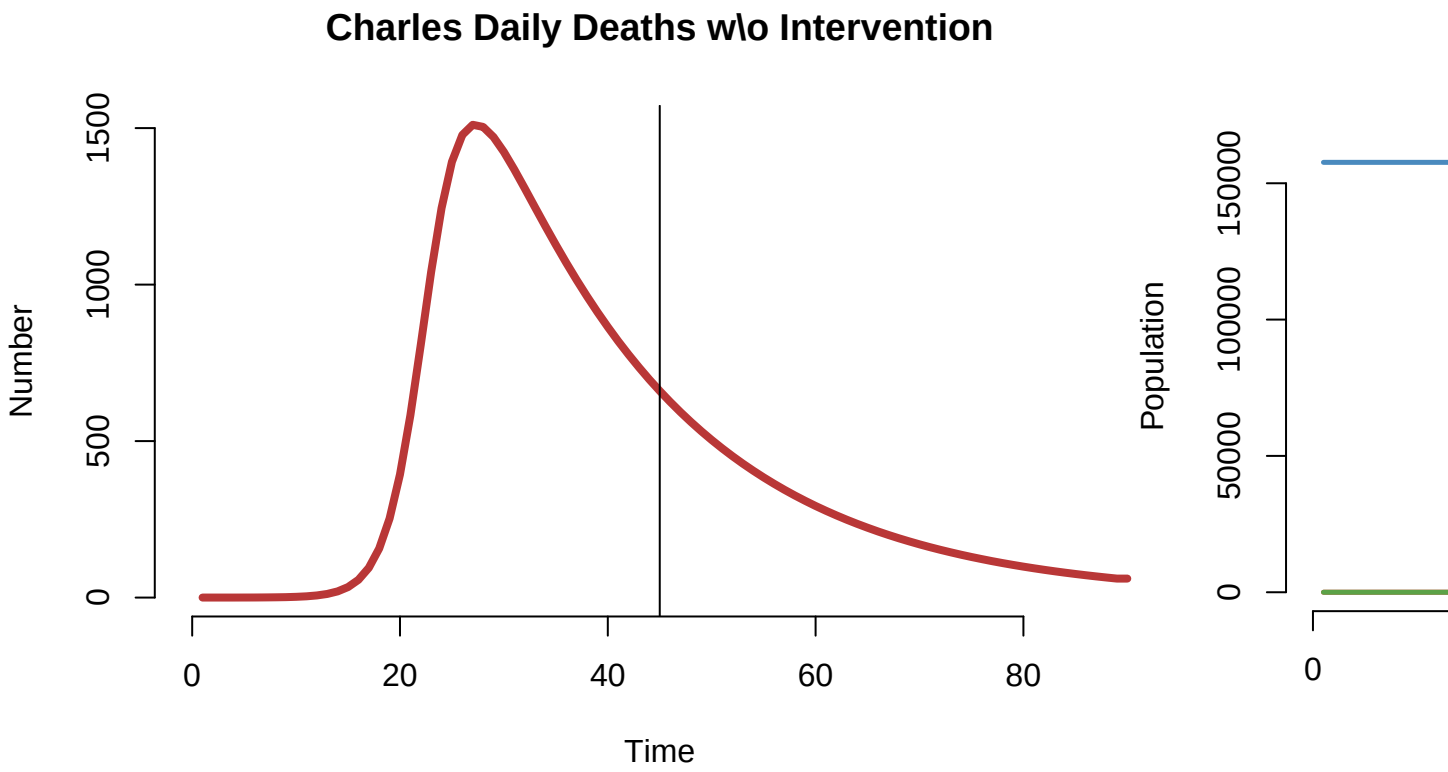

Caroline Daily Deaths with Intervention
Number
0
5
10
15
20
25
0
20
40
60
80
Time
Population
0
50000
100000
0

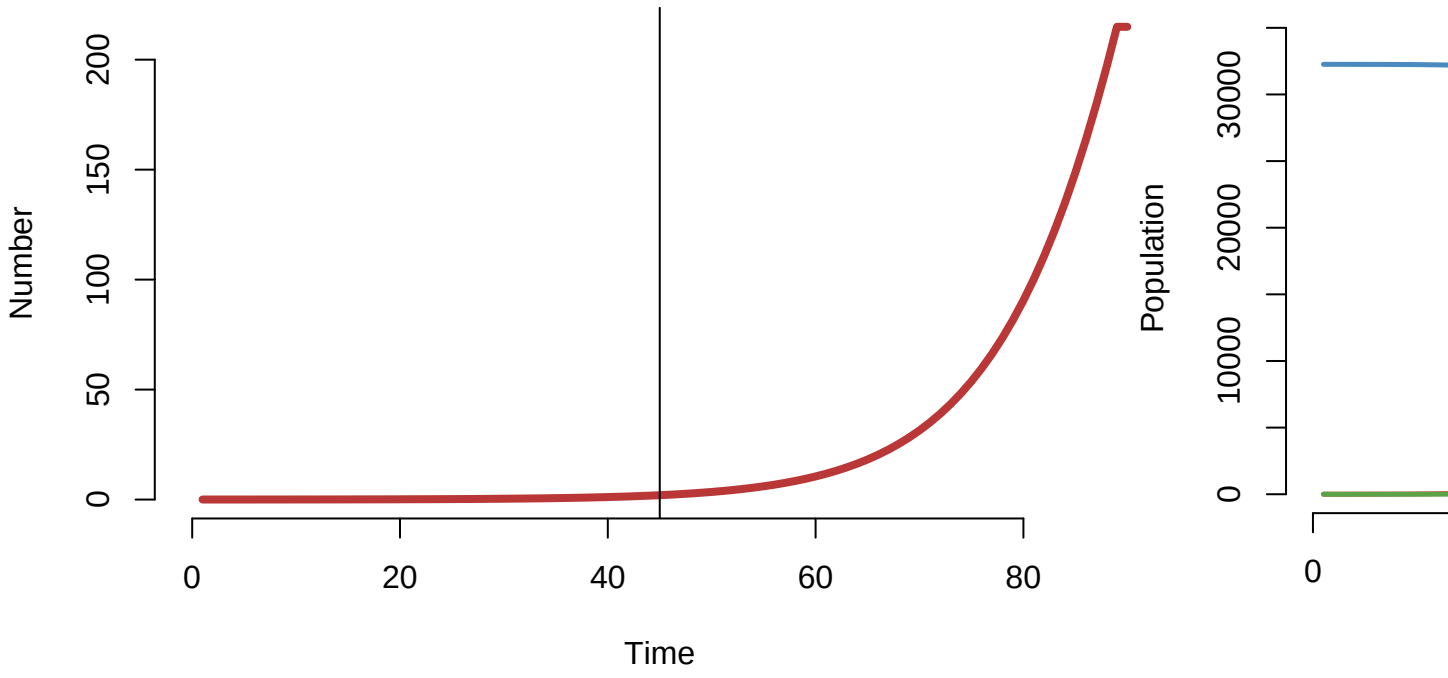

Carroll Daily Deaths w\o Intervention
Number
0
500
1000
1500
0
20
40
60
80
Time
Population
0
50000
100000
0

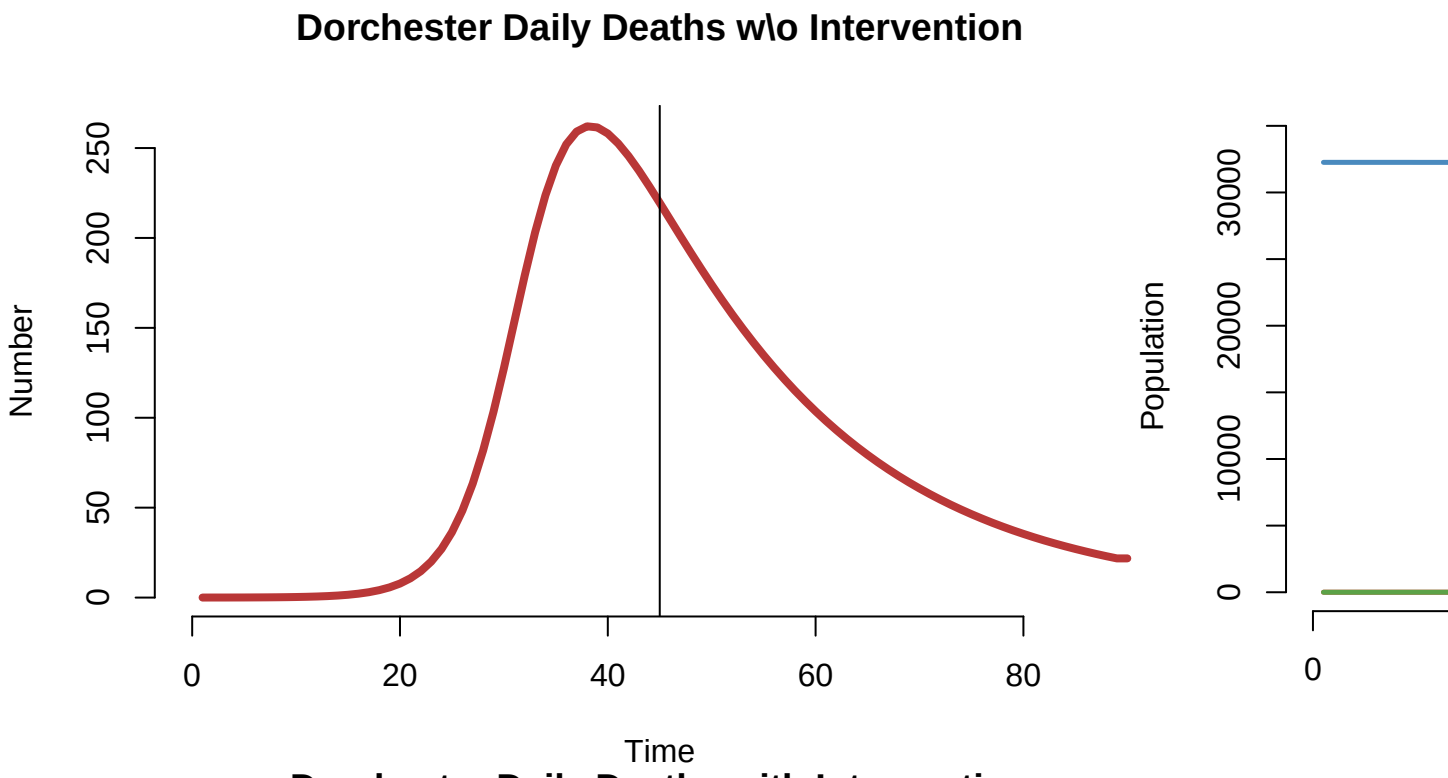

Carroll Daily Deaths with Intervention
Number
0
100
200
300
400
500
0
20
40
60
80
Time
Population
0e+00
4e+04
8e+04
0

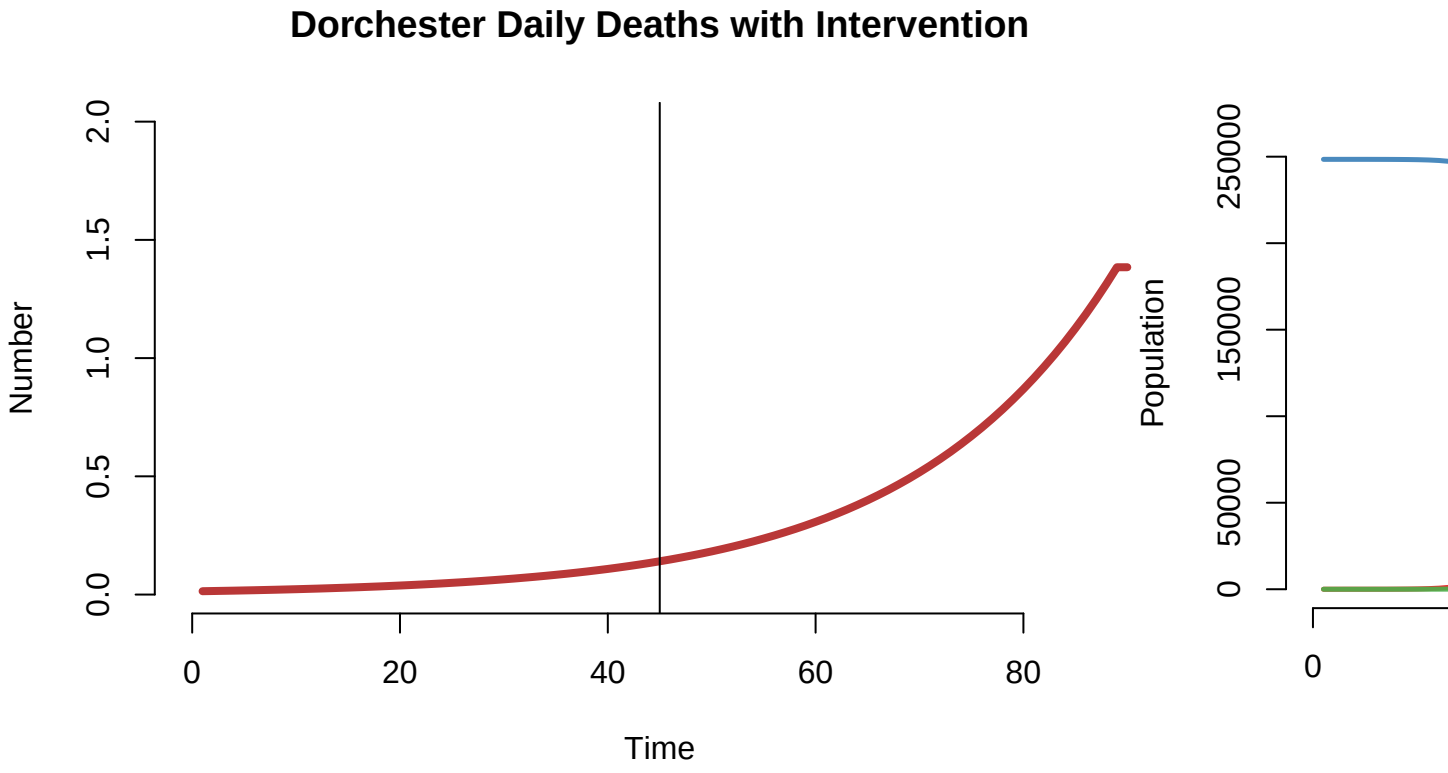

Cecil Daily Deaths w\o Intervention
Number
0
200
400
600
800
1000
0
20
40
60
80
Time
Population
0e+00
4e+04
8e+04
0

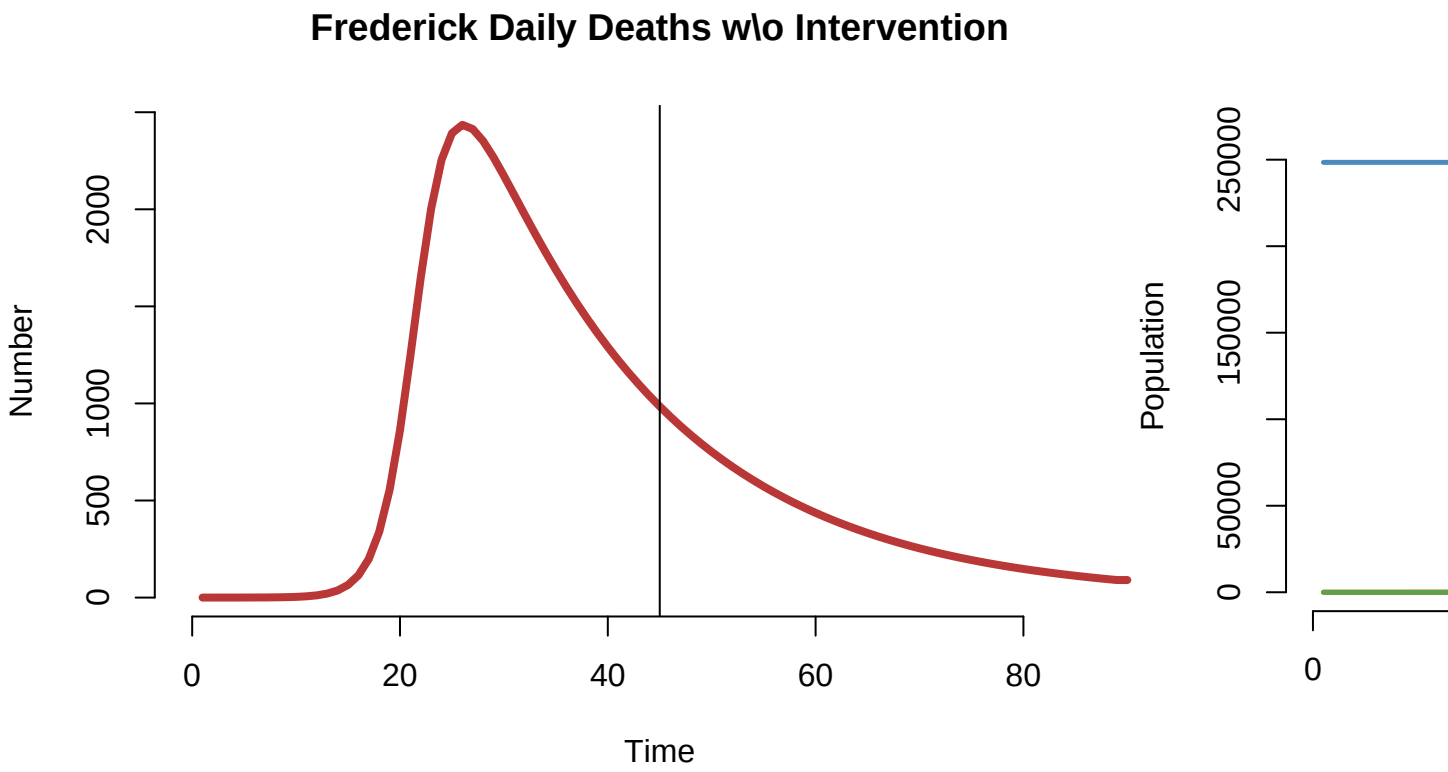

Cecil Daily Deaths with Intervention
Number
0
50
100
150
200
0
20
40
60
80
Time
Population
0
50000
100000
150000
0

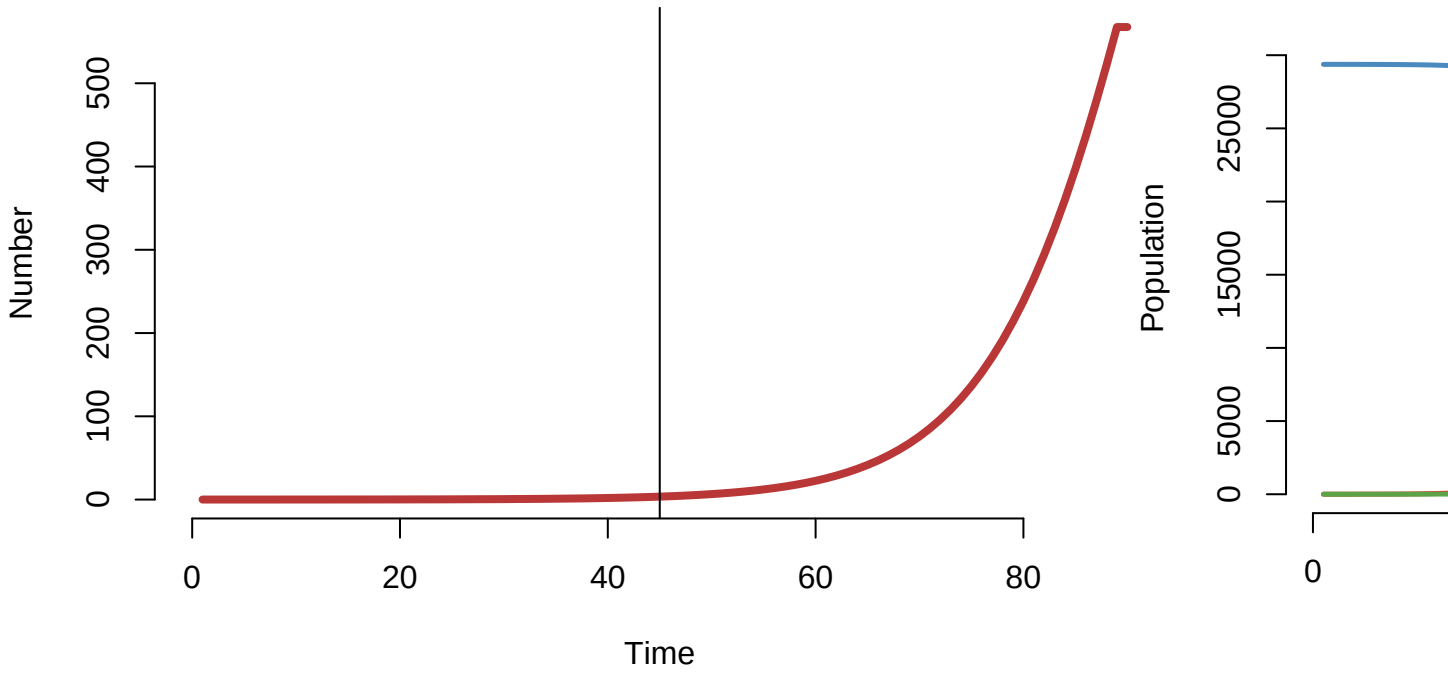

Charles Daily Deaths w\o Intervention
Number
0
500
1000
1500
0
20
40
60
80
Time
Population
0
50000
100000
150000
0

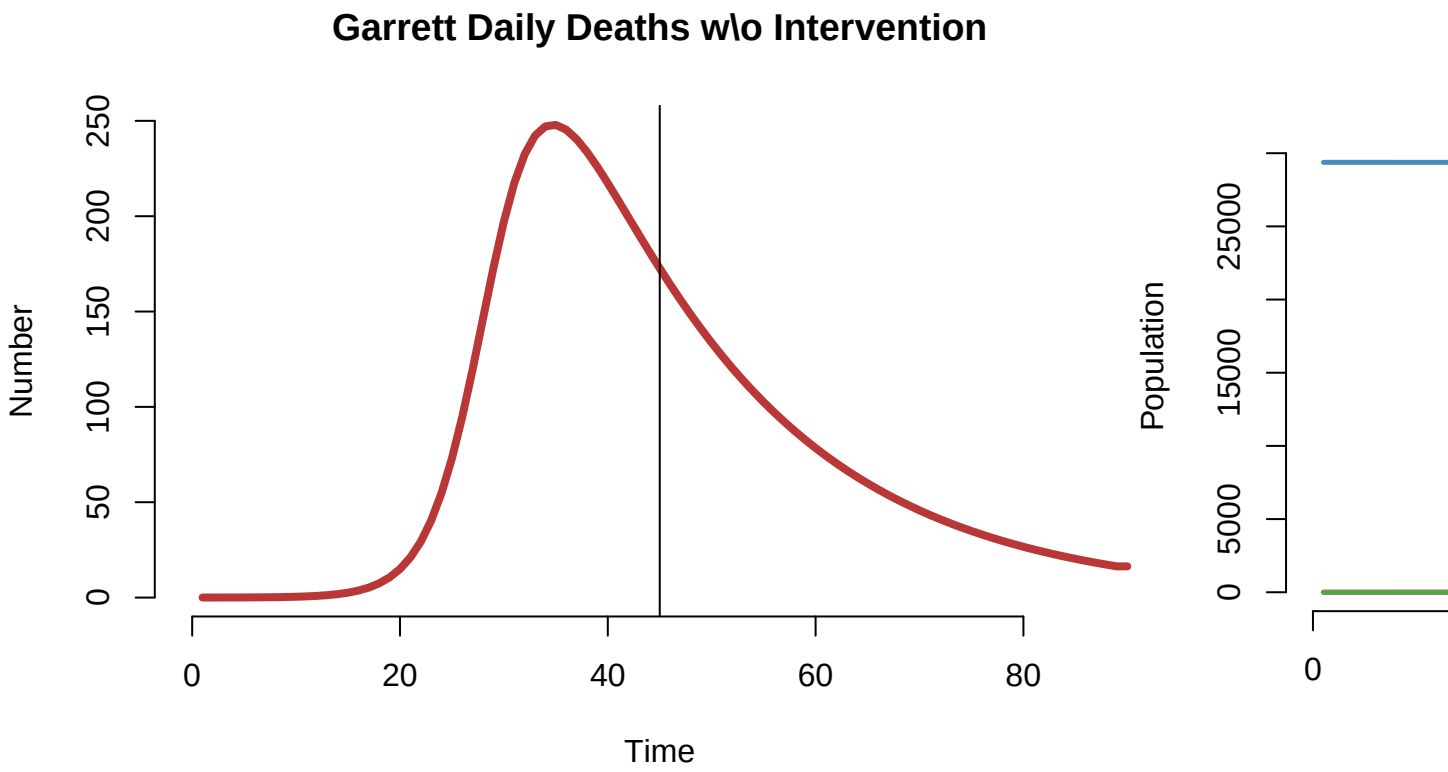

Charles Daily Deaths with Intervention
Number
0
50
100
150
200
0
20
40
60
80
Time
Population
0
10000
20000
30000
0

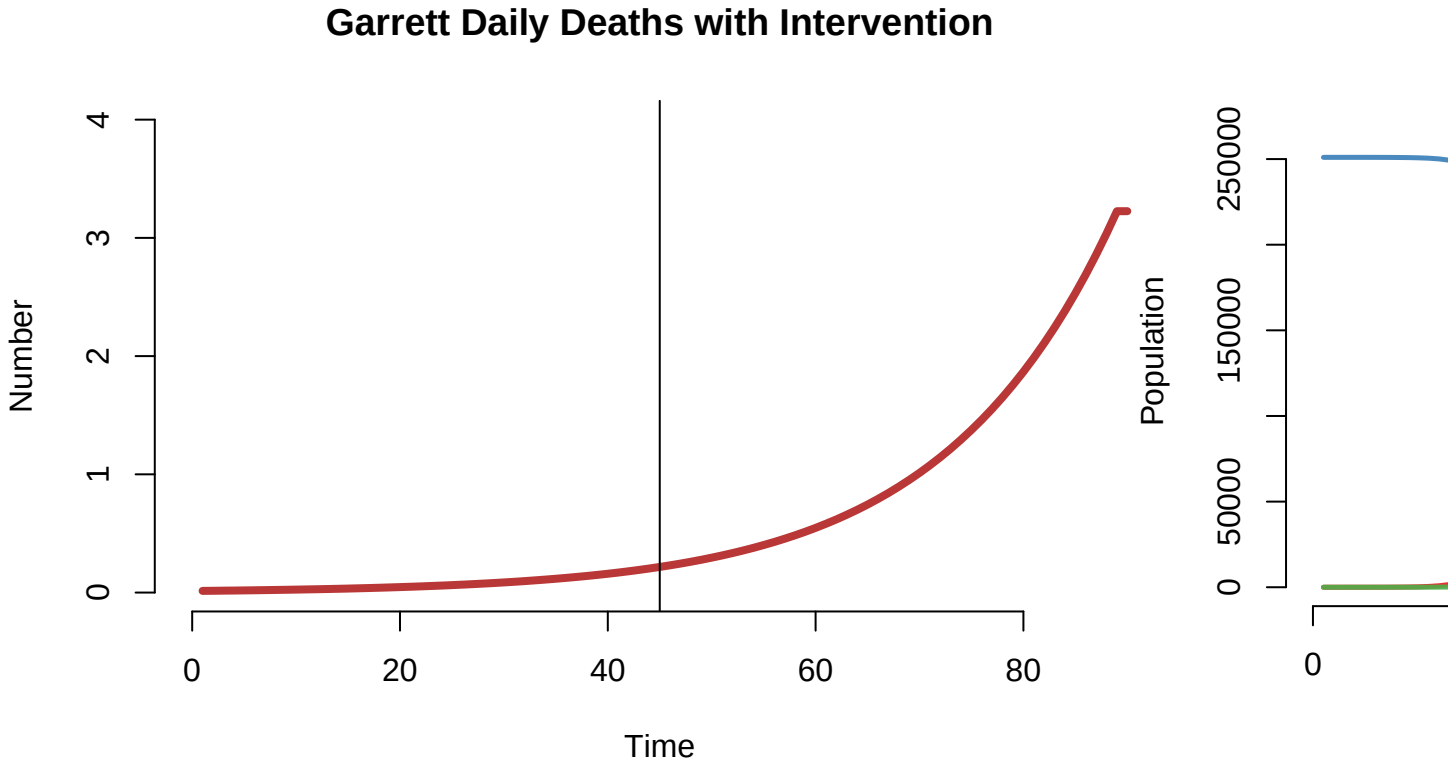

Dorchester Daily Deaths w\o Intervention
Number
0
50
100
150
200
250
0
20
40
60
80
Time
Population
0
10000
20000
30000
0

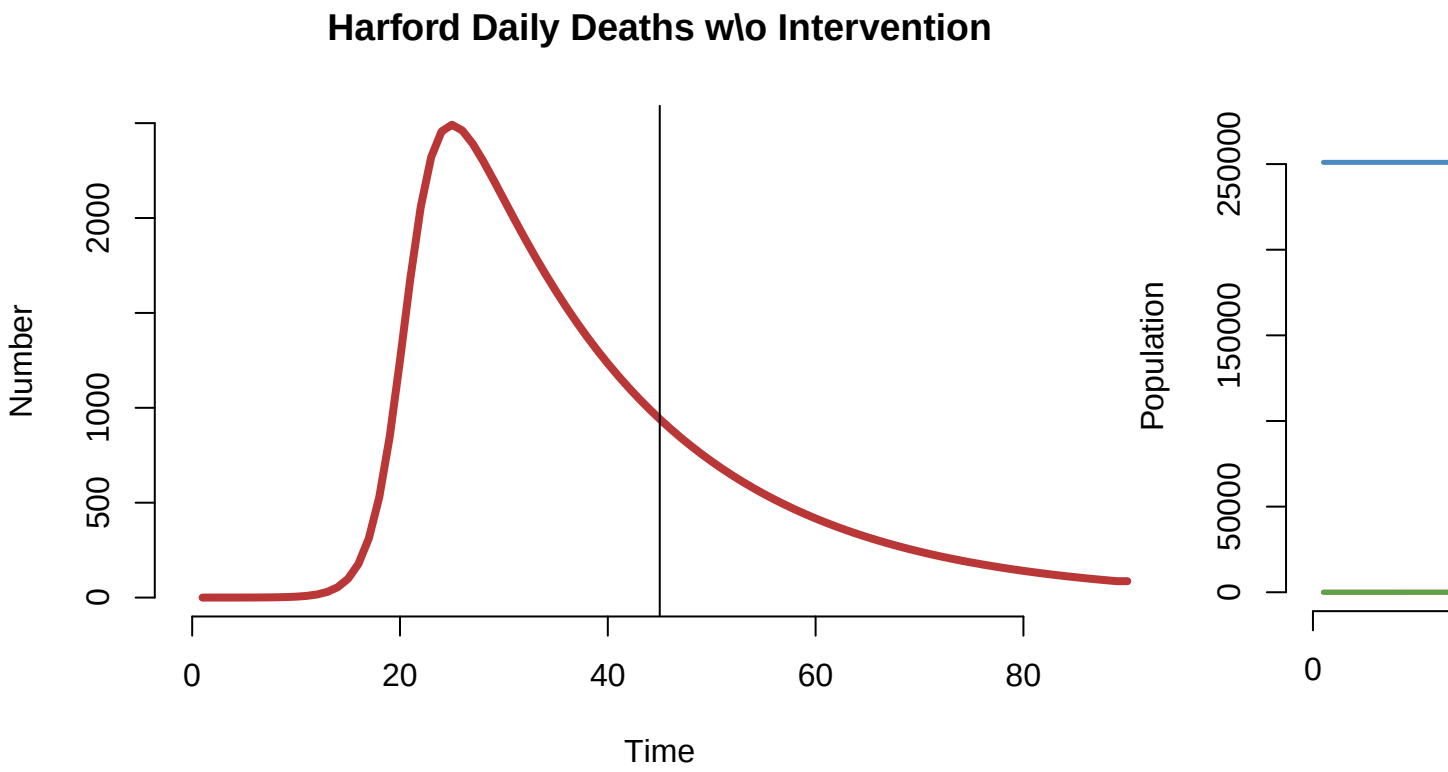

Dorchester Daily Deaths with Intervention
Number
0.0
0.5
1.0
1.5
2.0
0
20
40
60
80
Time
Population
0
50000
150000
250000
0

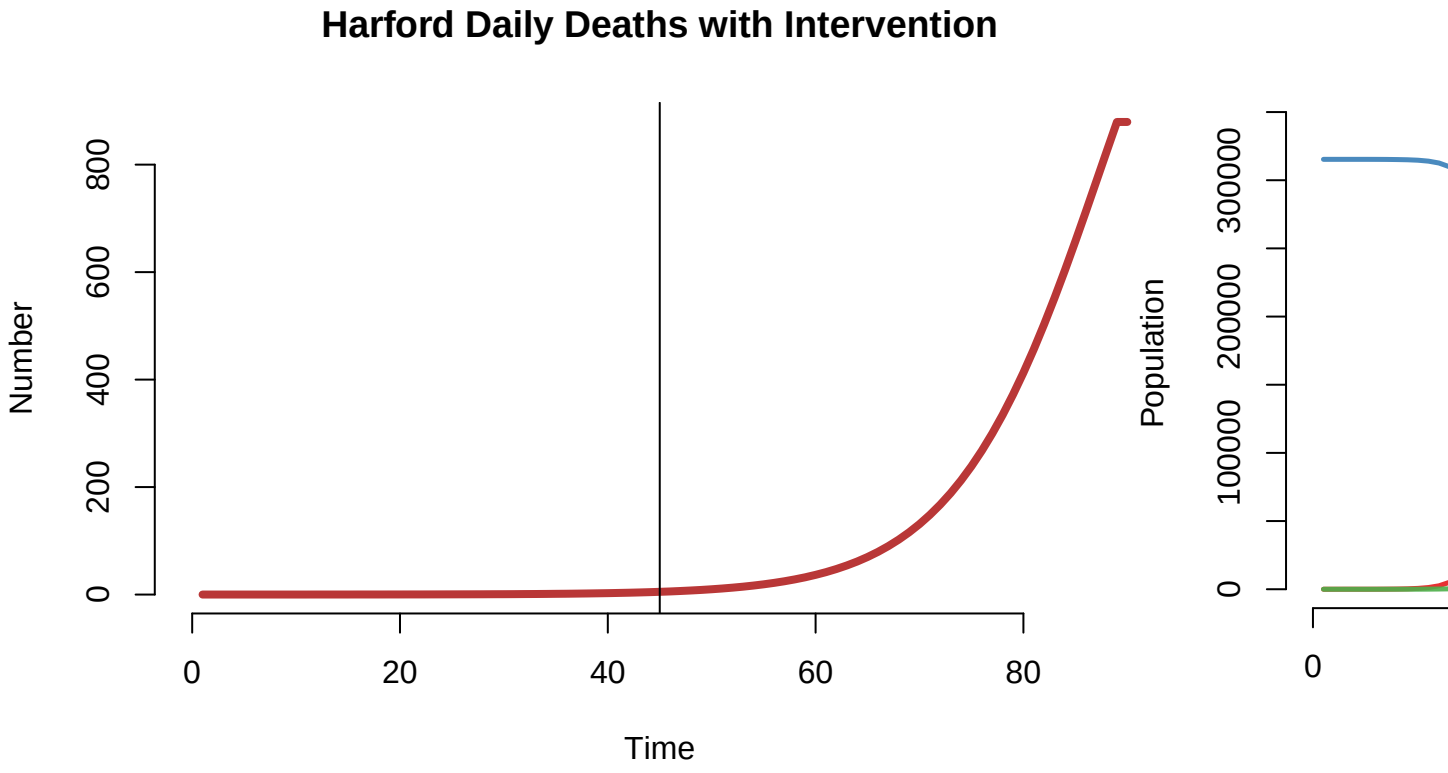

Frederick Daily Deaths w\o Intervention
Number
0
500
1000
2000
0
20
40
60
80
Time
Population
0
50000
150000
250000
0

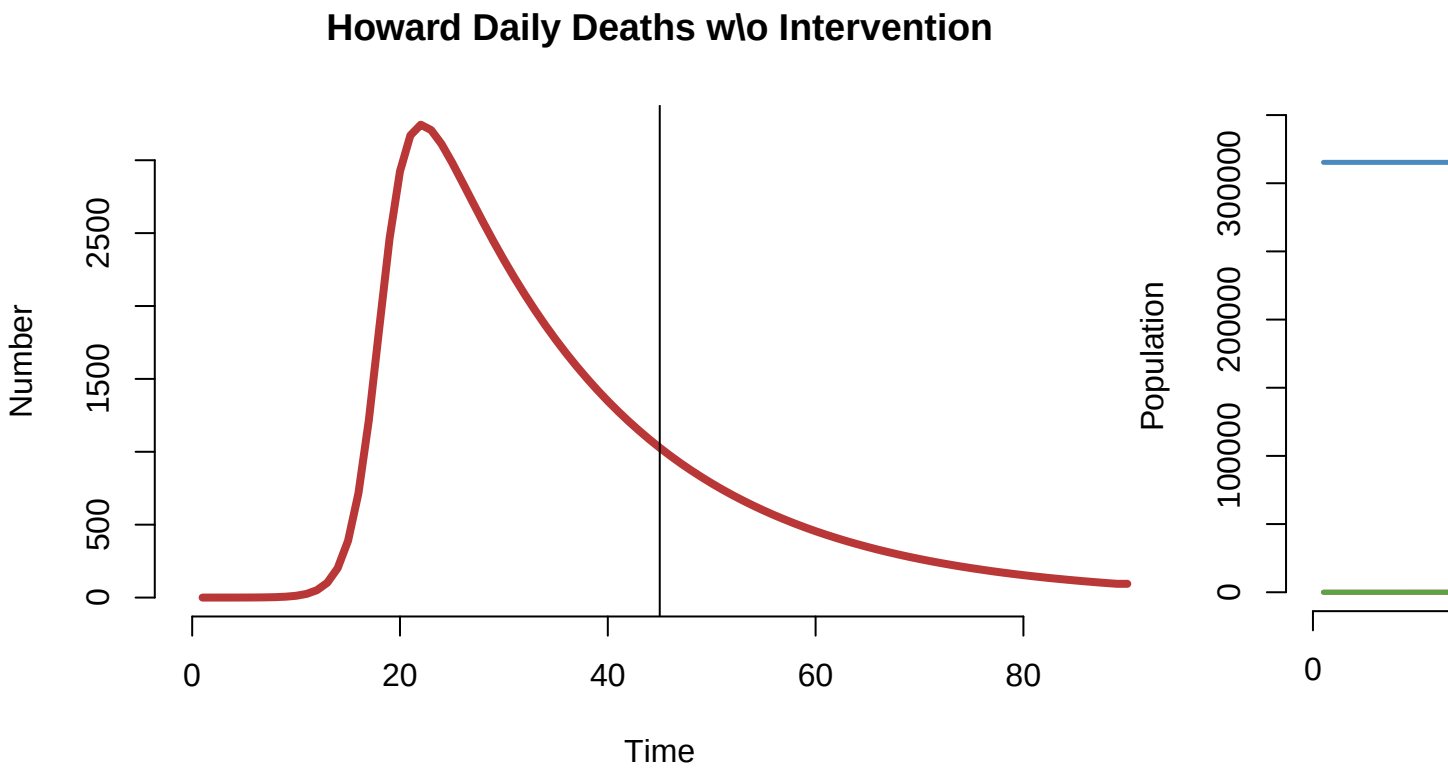

Frederick Daily Deaths with Intervention
Number
0
100
200
300
400
500
0
20
40
60
80
Time
Population
0
5000
15000
25000
0

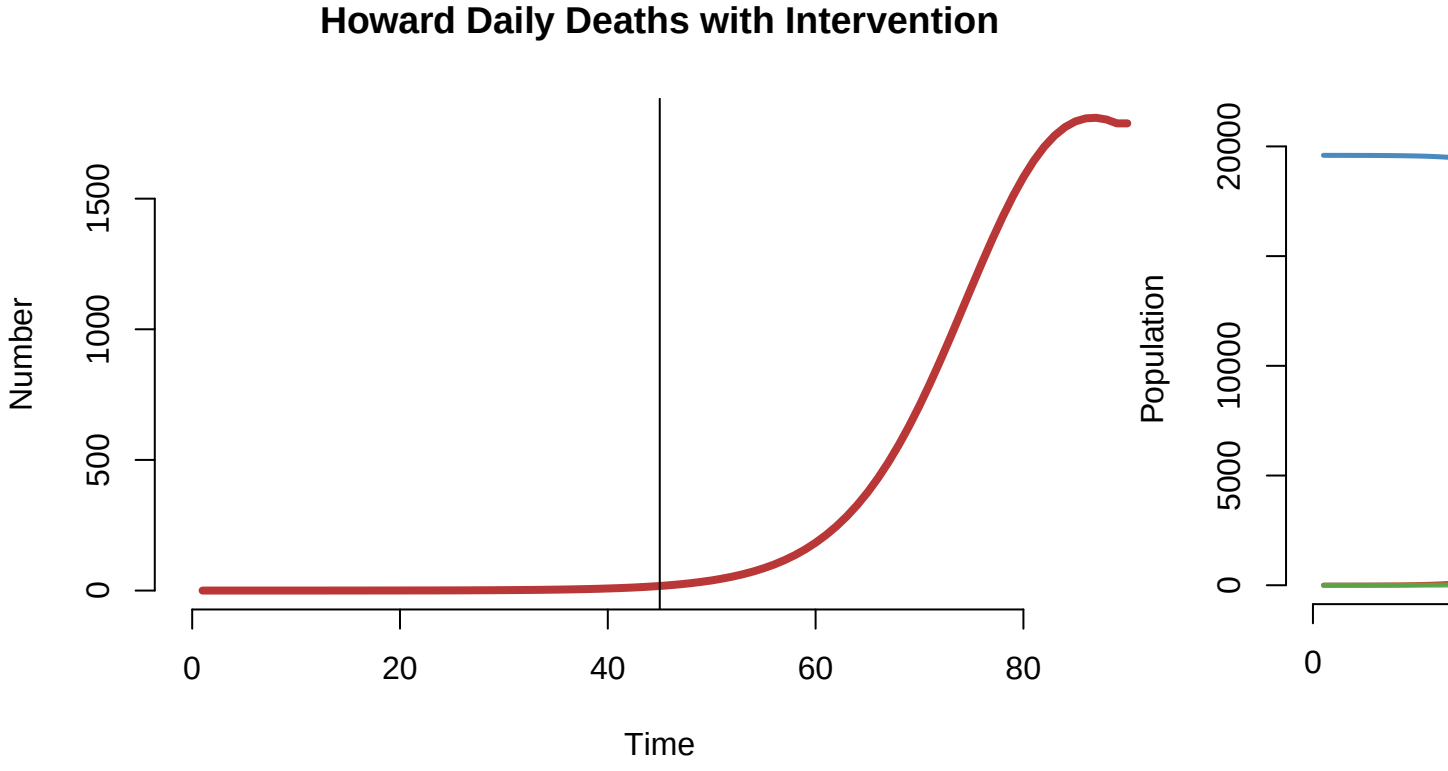

Garrett Daily Deaths w\o Intervention
Number
0
50
100
150
200
250
0
20
40
60
80
Time
Population
0
5000
15000
25000
0

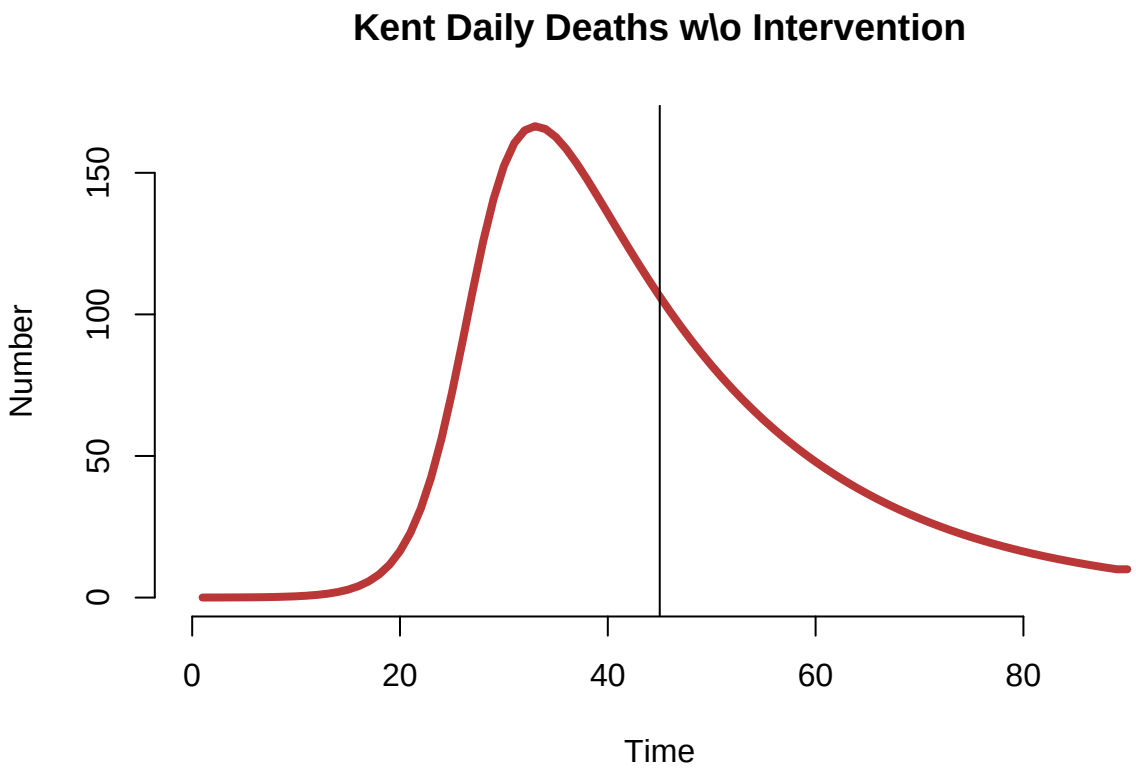

Garrett Daily Deaths with Intervention
Number
0
1
2
3
4
0
20
40
60
80
Time
Population
0
50000
150000
250000
0

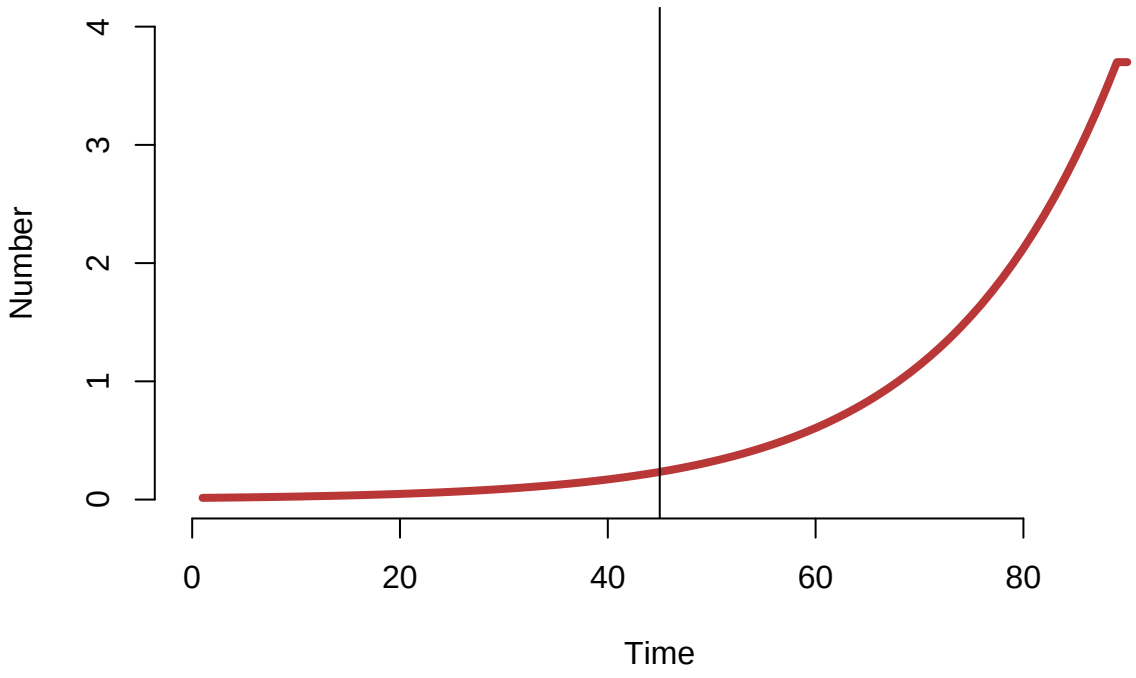

Harford Daily Deaths w\o Intervention
Number
0
500
1000
2000
0
20
40
60
80
Time
Population
0
50000
150000
250000
0

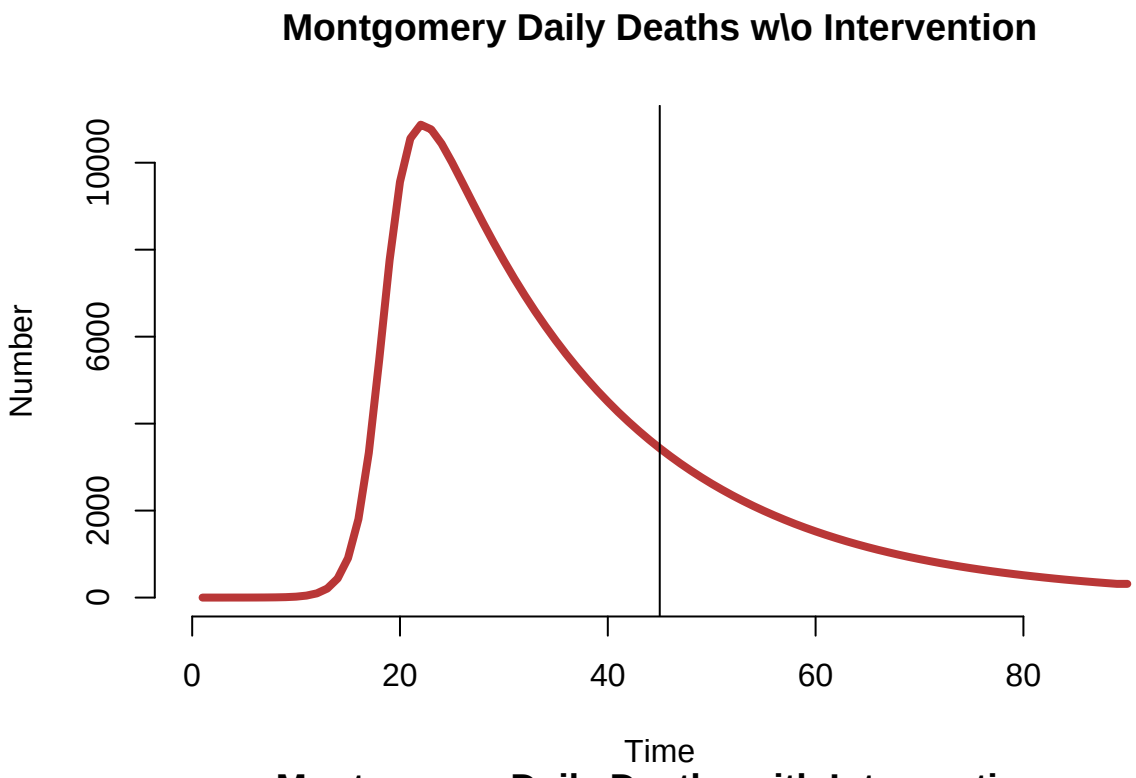

Harford Daily Deaths with Intervention
Number
0
200
400
600
800
0
20
40
60
80
Time
Population
0
100000
200000
300000
0

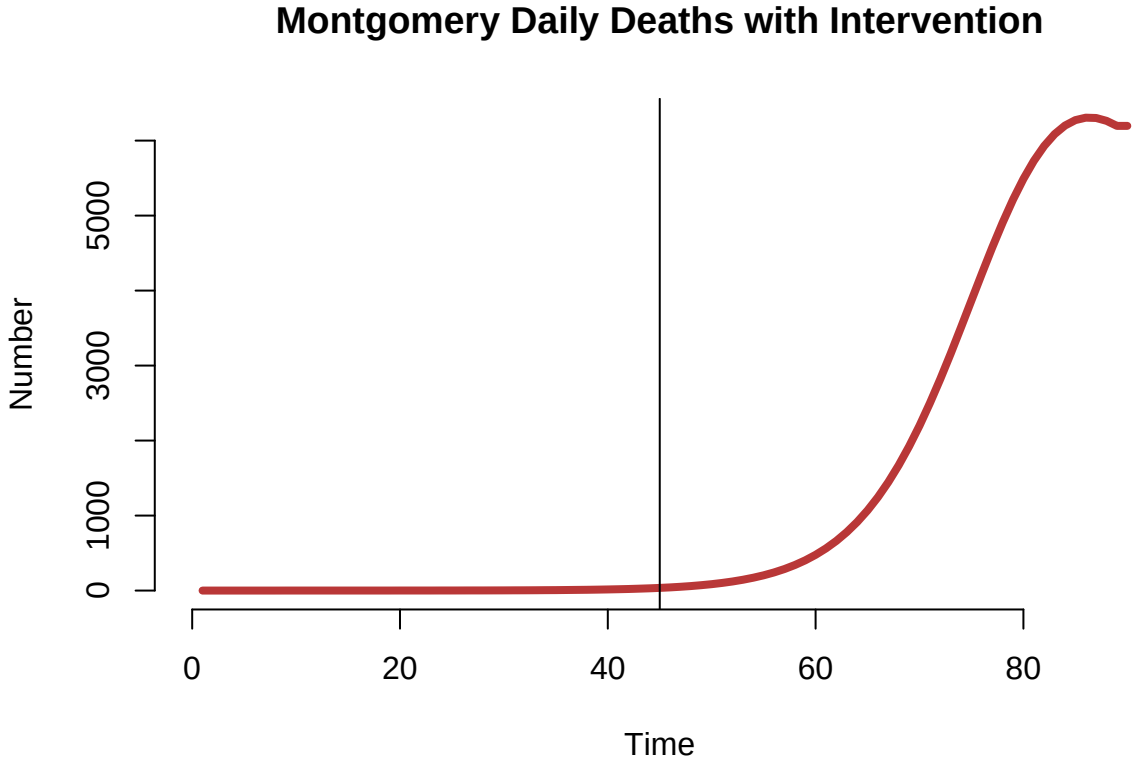

Howard Daily Deaths w\o Intervention
Number
0
500
1500
2500
0
20
40
60
80
Time
Population
0
100000
200000
300000
0

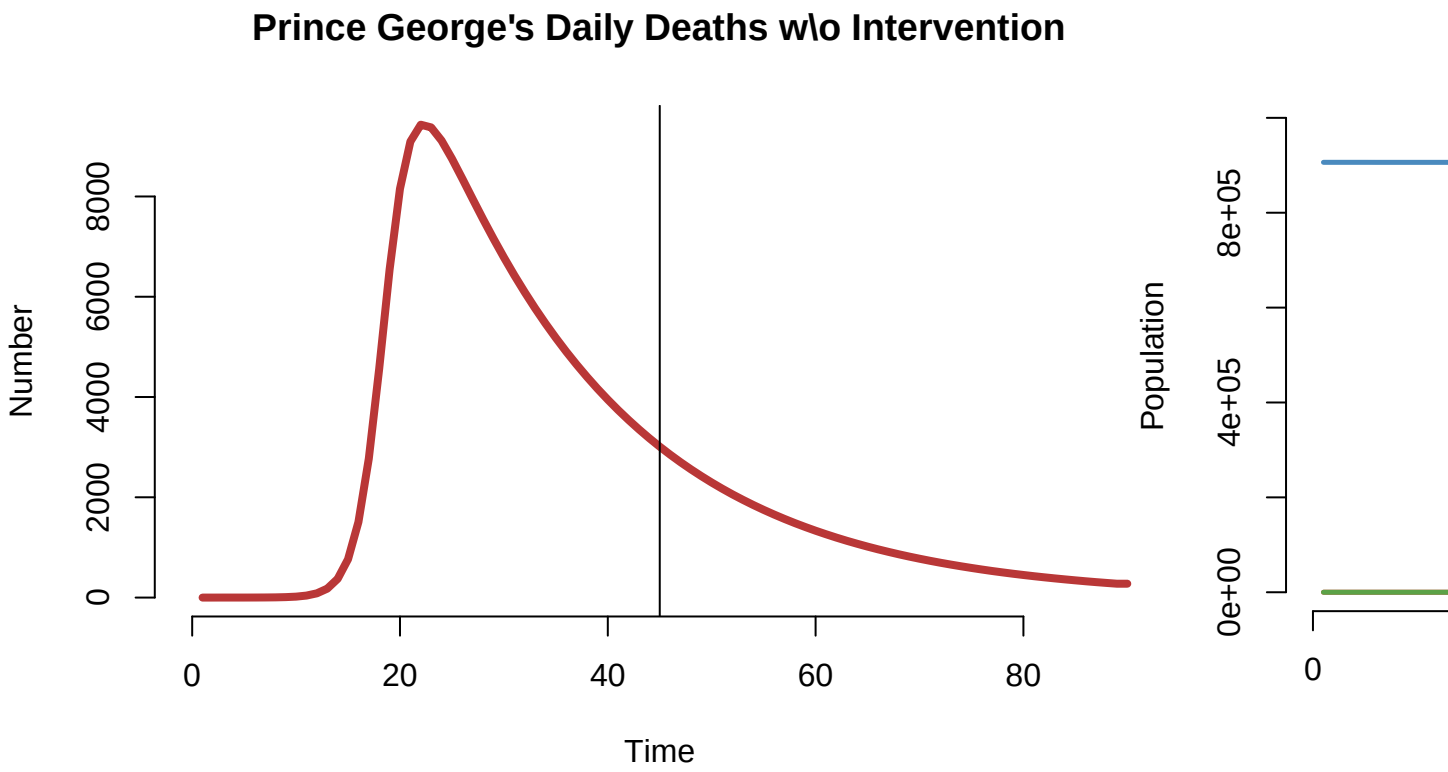

Howard Daily Deaths with Intervention
Number
0
500
1000
1500
0
20
40
60
80
Time
Population
0
5000
10000
20000
0

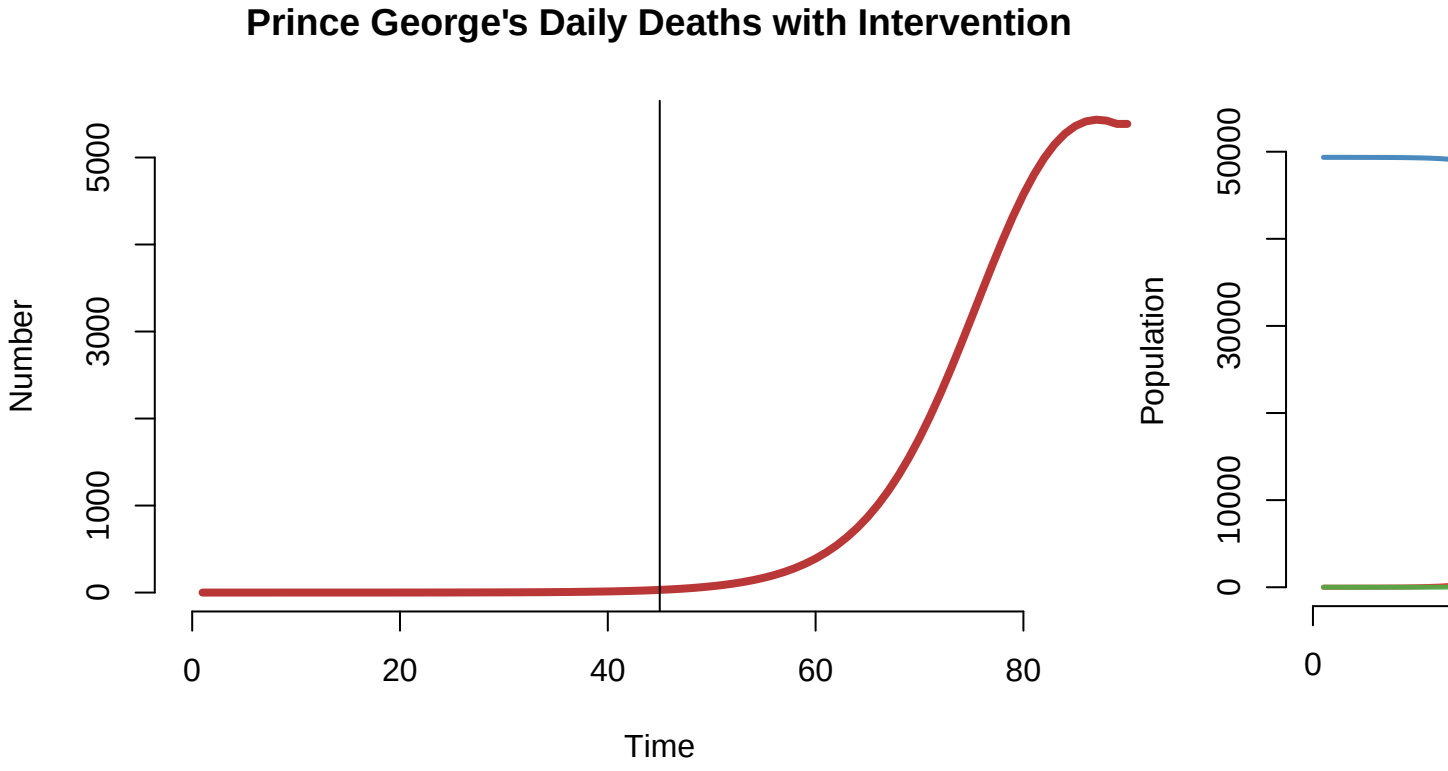

Kent Daily Deaths w\o Intervention
Number
0
50
100
150
0
20
40
60
80
Time
Population
0
5000
10000
20000
0

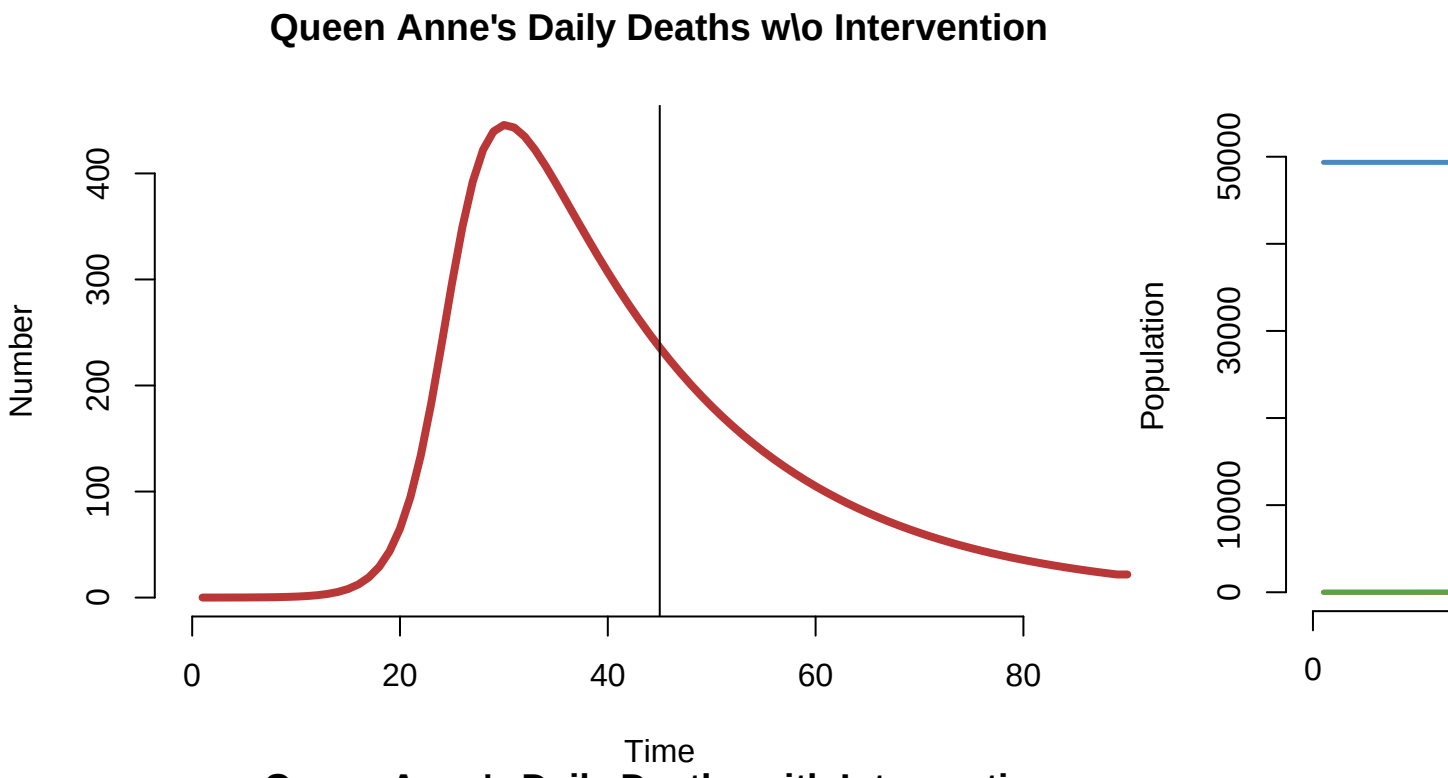

Kent Daily Deaths with Intervention
Number
0
1
2
3
4
0
20
40
60
80
Time
Population
0e+00
4e+05
8e+05
0

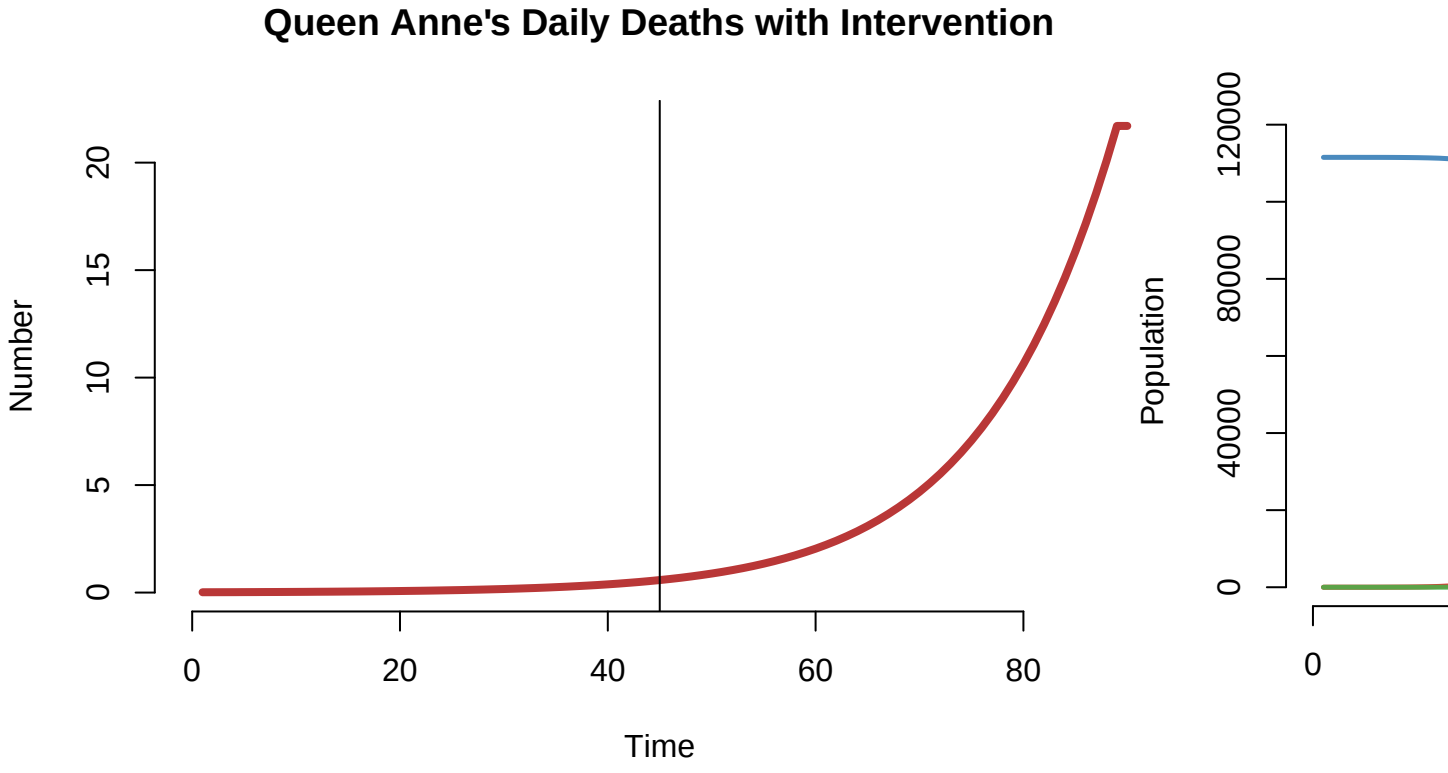

Montgomery Daily Deaths w\o Intervention
Number
0
2000
6000
10000
0
20
40
60
80
Time
Population
0e+00
4e+05
8e+05
0

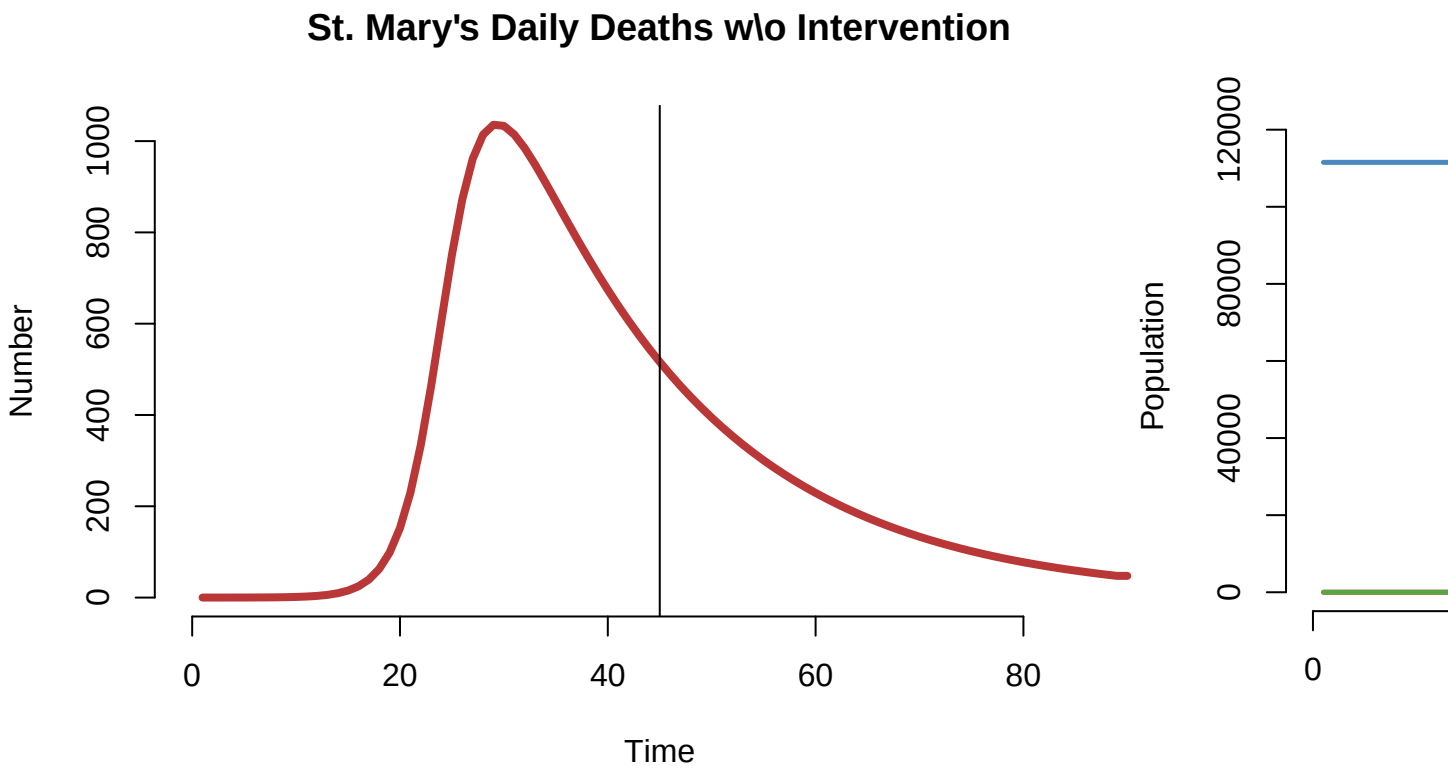

Montgomery Daily Deaths with Intervention
Number
0
1000
3000
5000
0
20
40
60
80
Time
Population
0e+00
4e+05
8e+05
0

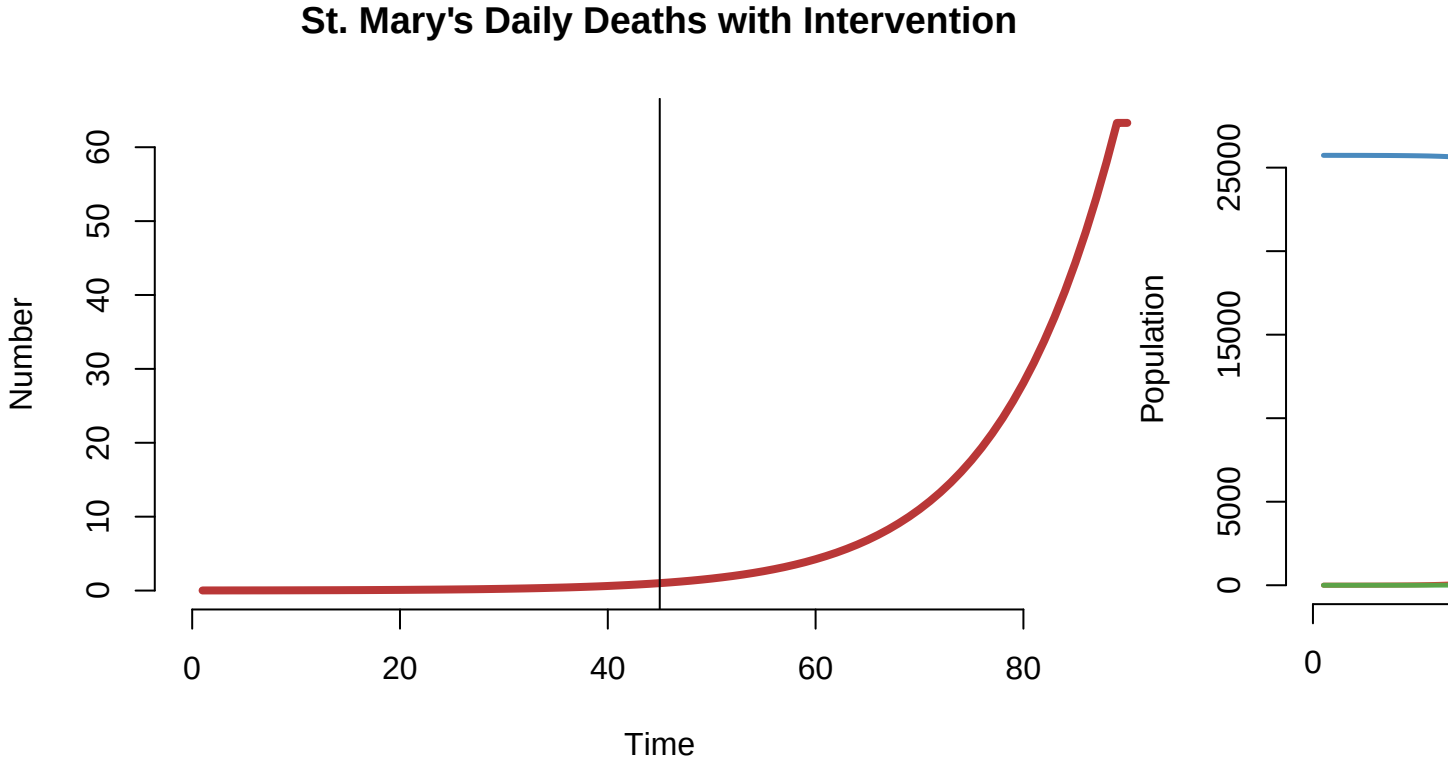

Prince George's Daily Deaths w\o Intervention
Number
0
2000
4000
6000
8000
0
20
40
60
80
Time
Population
0e+00
4e+05
8e+05
0

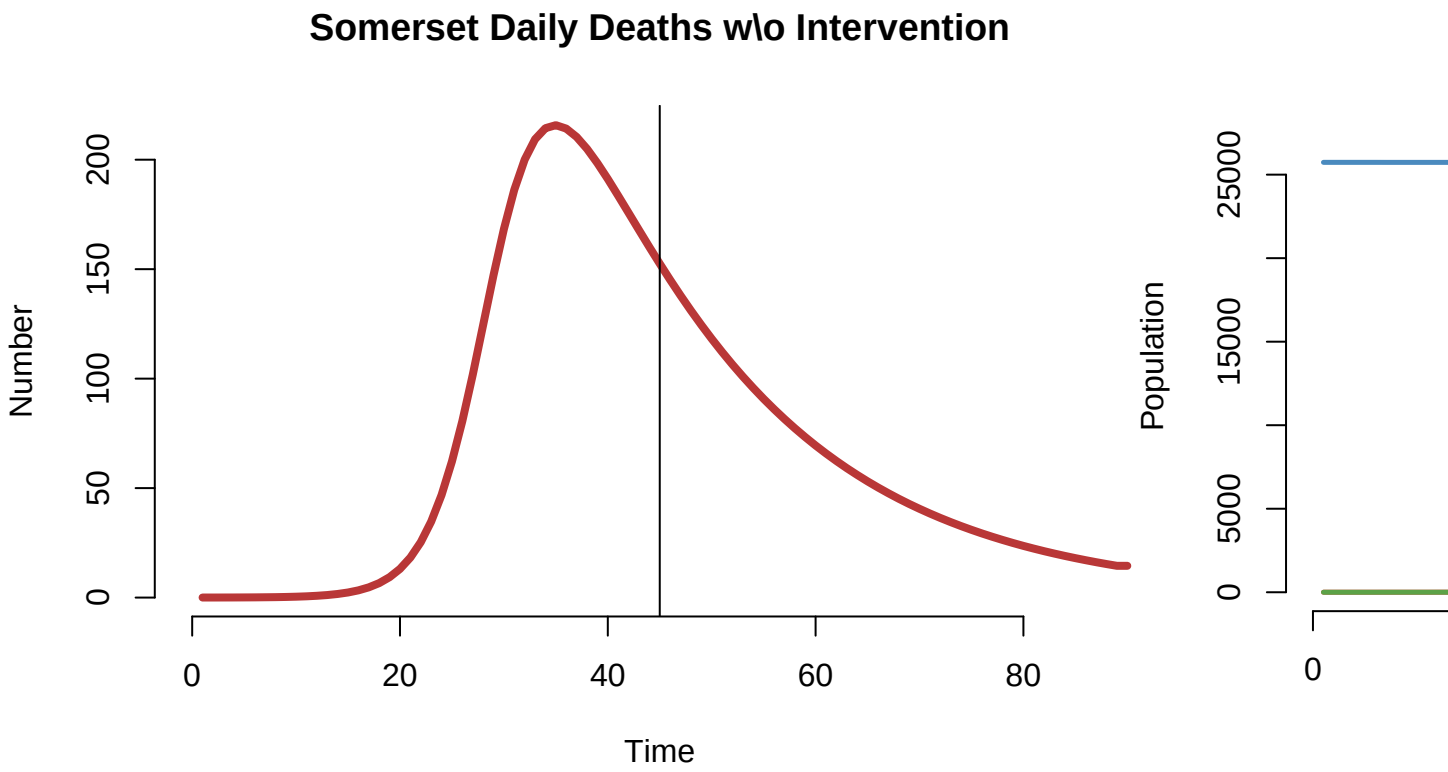

Prince George's Daily Deaths with Intervention
Number
0
1000
3000
5000
0
20
40
60
80
Time
Population
0
10000
30000
50000
0

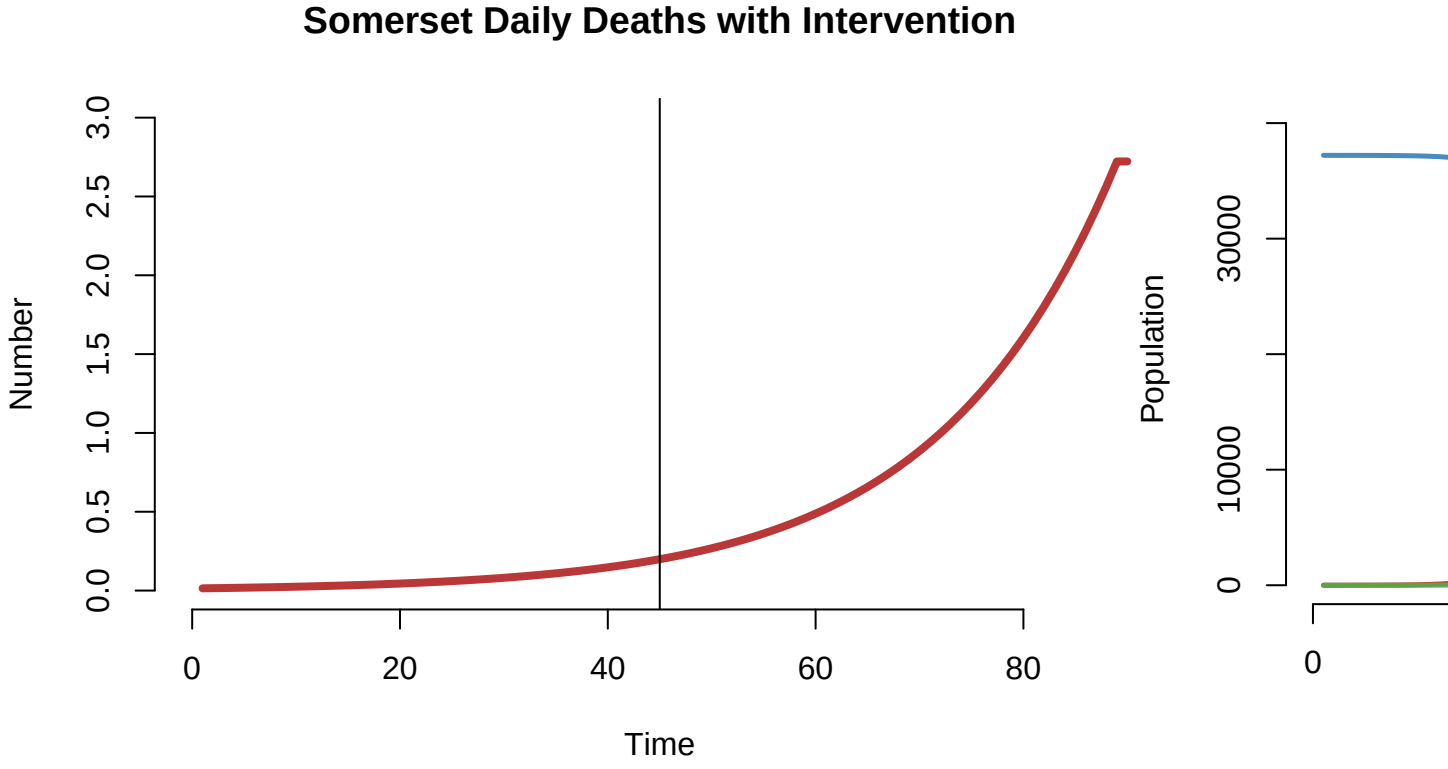

Queen Anne's Daily Deaths w\o Intervention
Number
0
100
200
300
400
0
20
40
60
80
Time
Population
0
10000
30000
50000
0

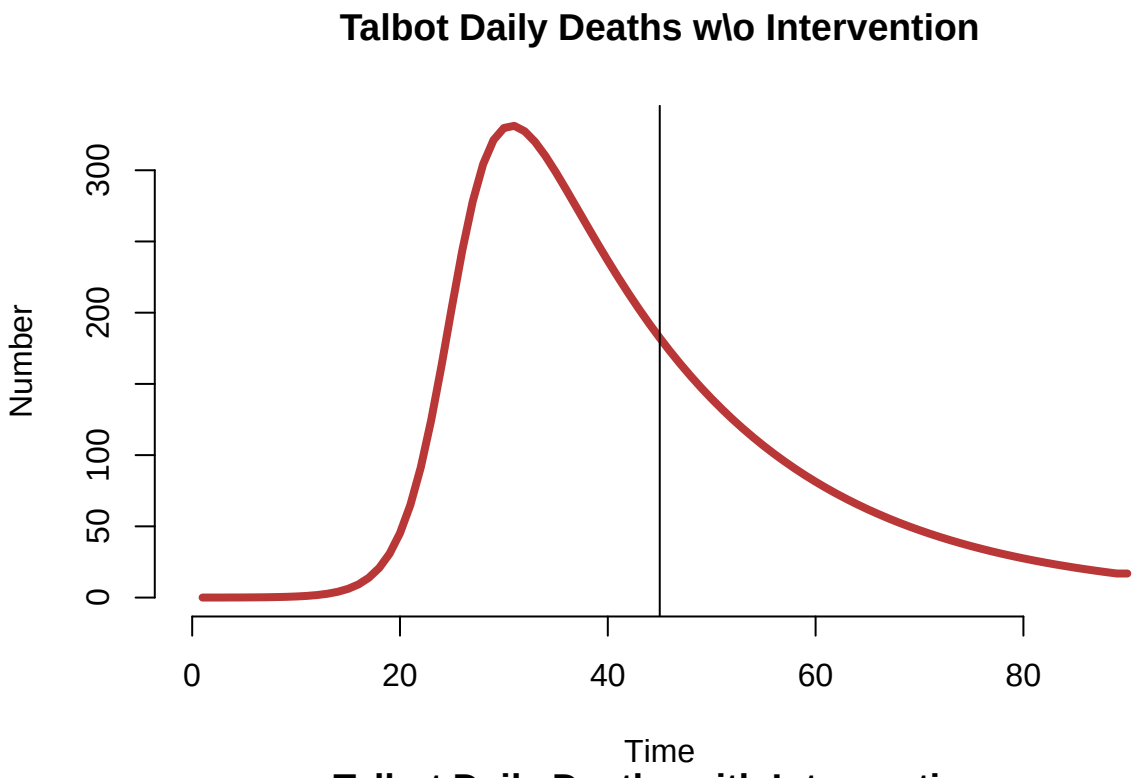

Queen Anne's Daily Deaths with Intervention
Number
0
5
10
15
20
0
20
40
60
80
Time
Population
0
40000
80000
120000
0

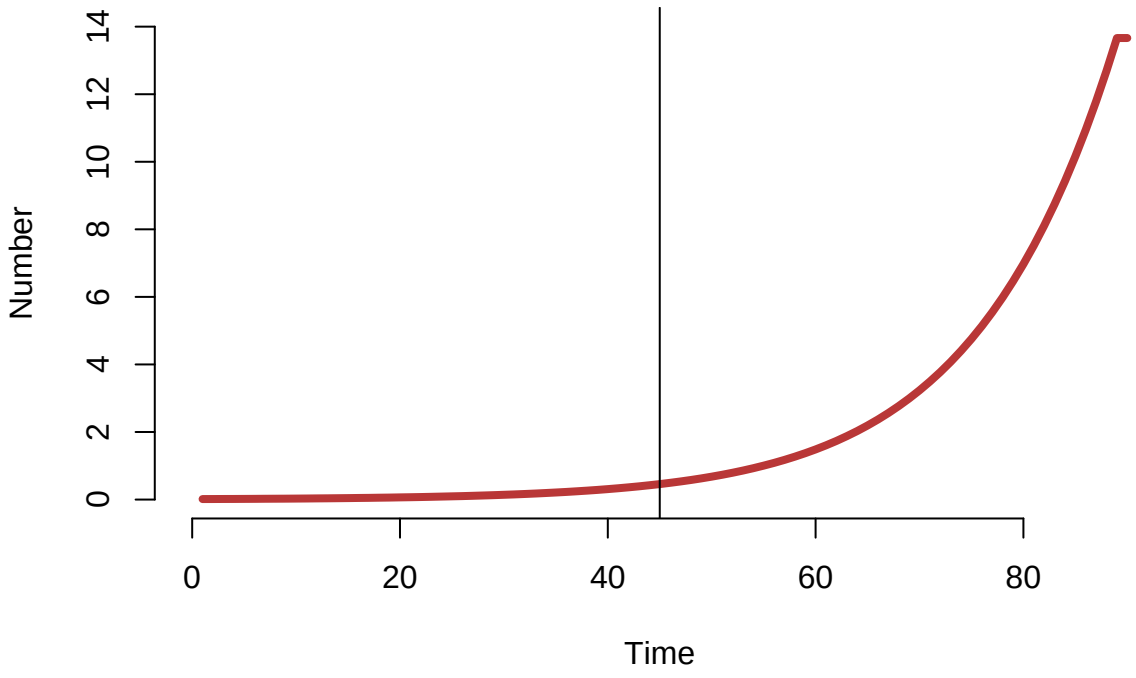

St. Mary's Daily Deaths w\o Intervention
Number
0
200
400
600
800
1000
0
20
40
60
80
Time
Population
0
40000
80000
120000
0

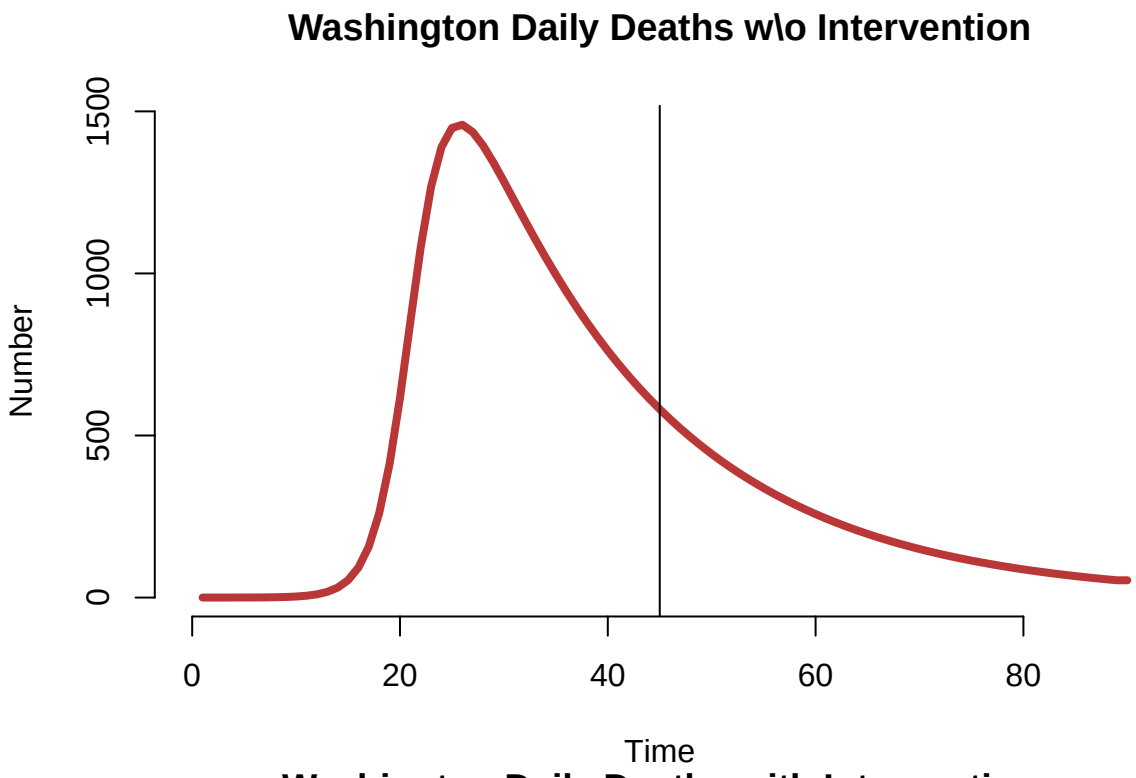

St. Mary's Daily Deaths with Intervention
Number
0
10
20
30
40
50
60
0
20
40
60
80
Time
Population
0
5000
15000
25000
0

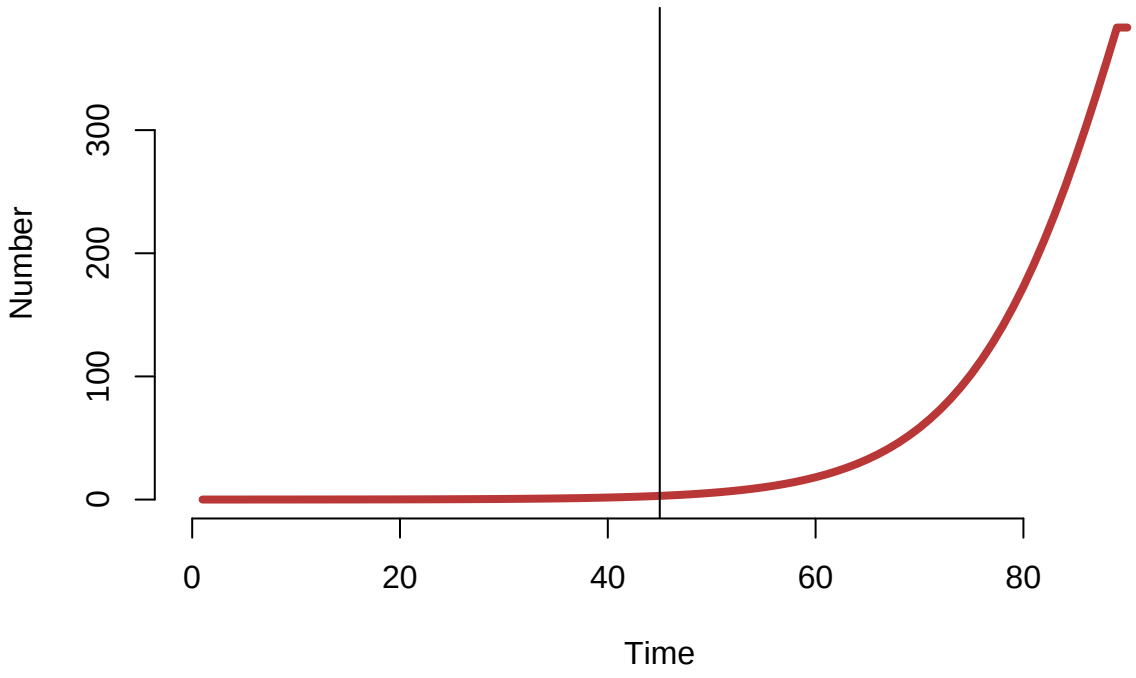

Somerset Daily Deaths w\o Intervention
Number
0
50
100
150
200
0
20
40
60
80
Time
Population
0
5000
15000
25000
0

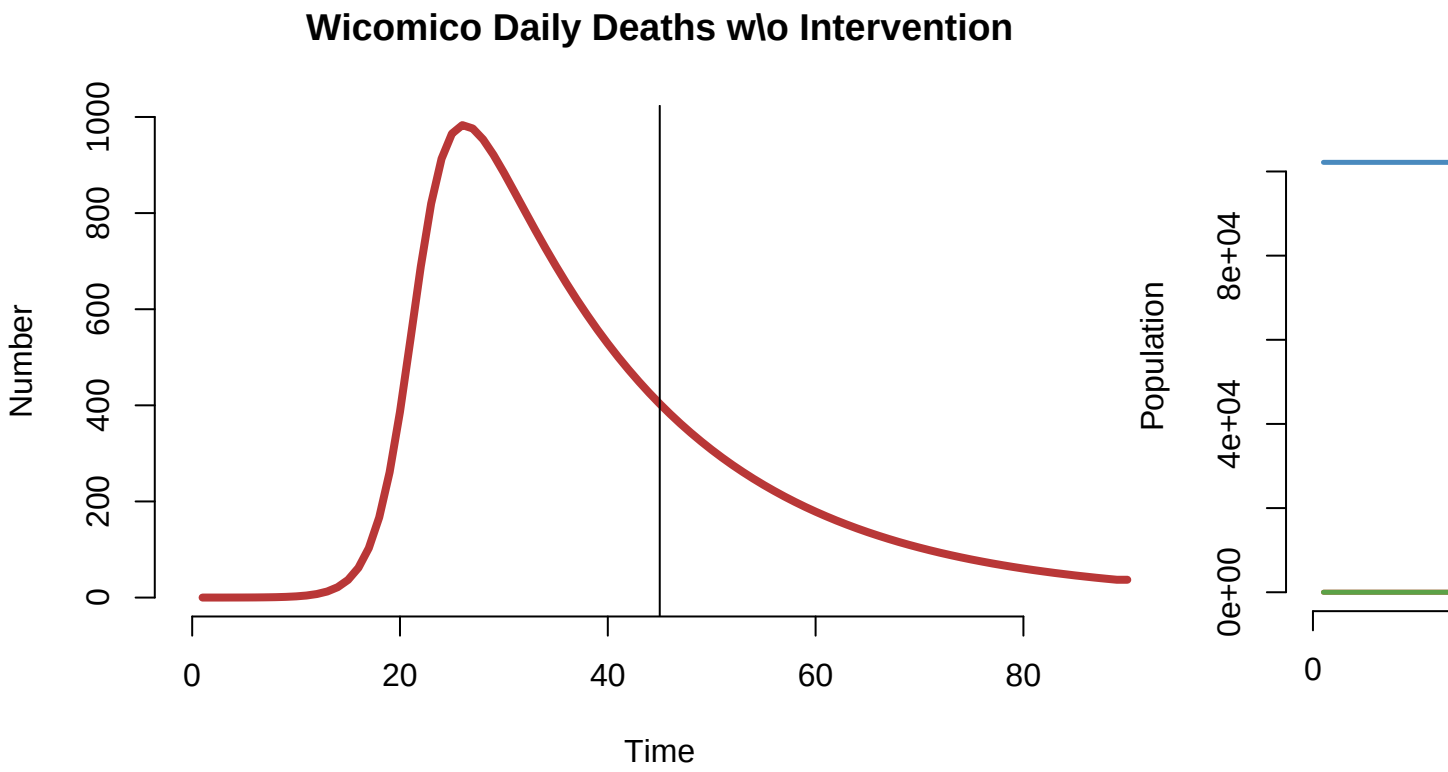

Somerset Daily Deaths with Intervention
Number
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
20
40
60
80
Time
Population
0
10000
30000
0

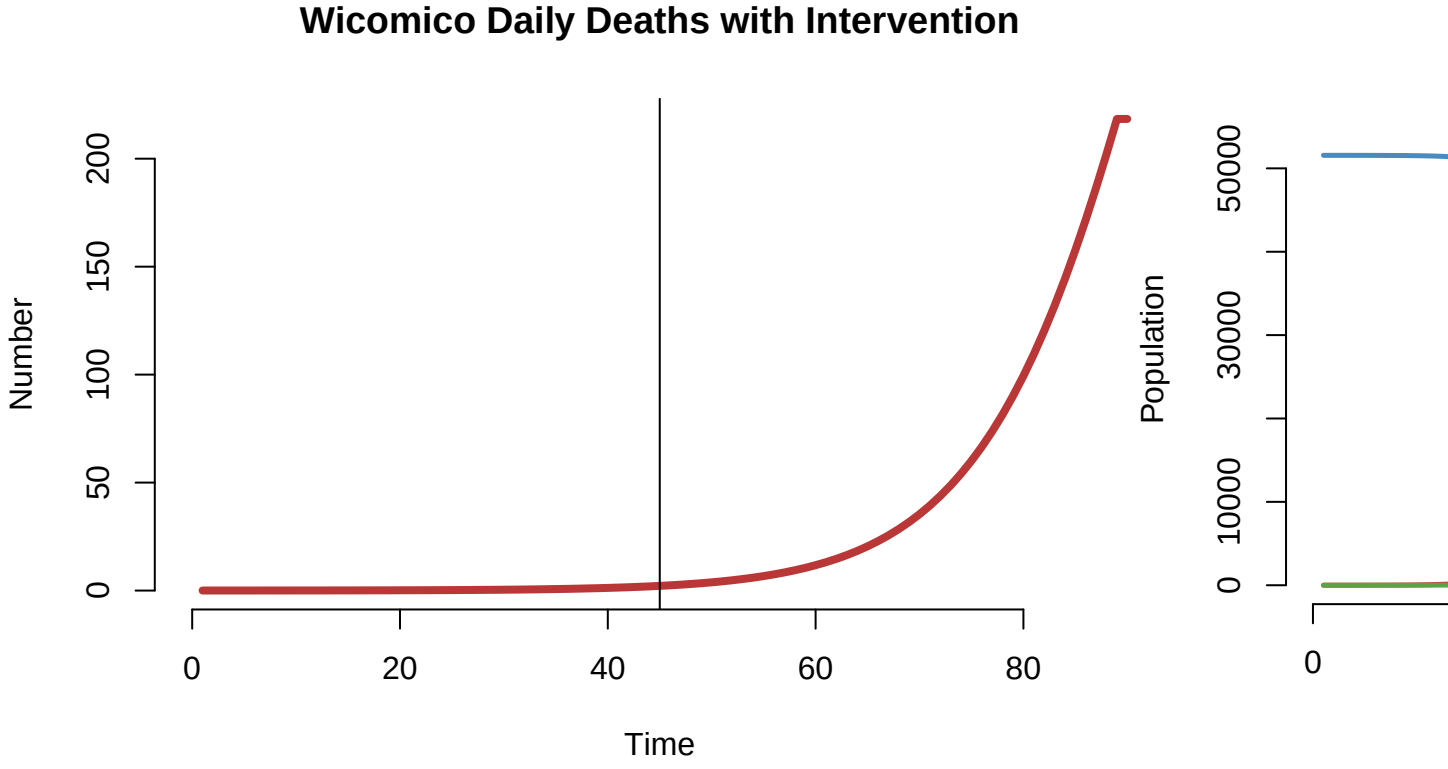

Talbot Daily Deaths w\o Intervention
Number
0
50
100
200
300
0
20
40
60
80
Time
Population
0
10000
30000
0

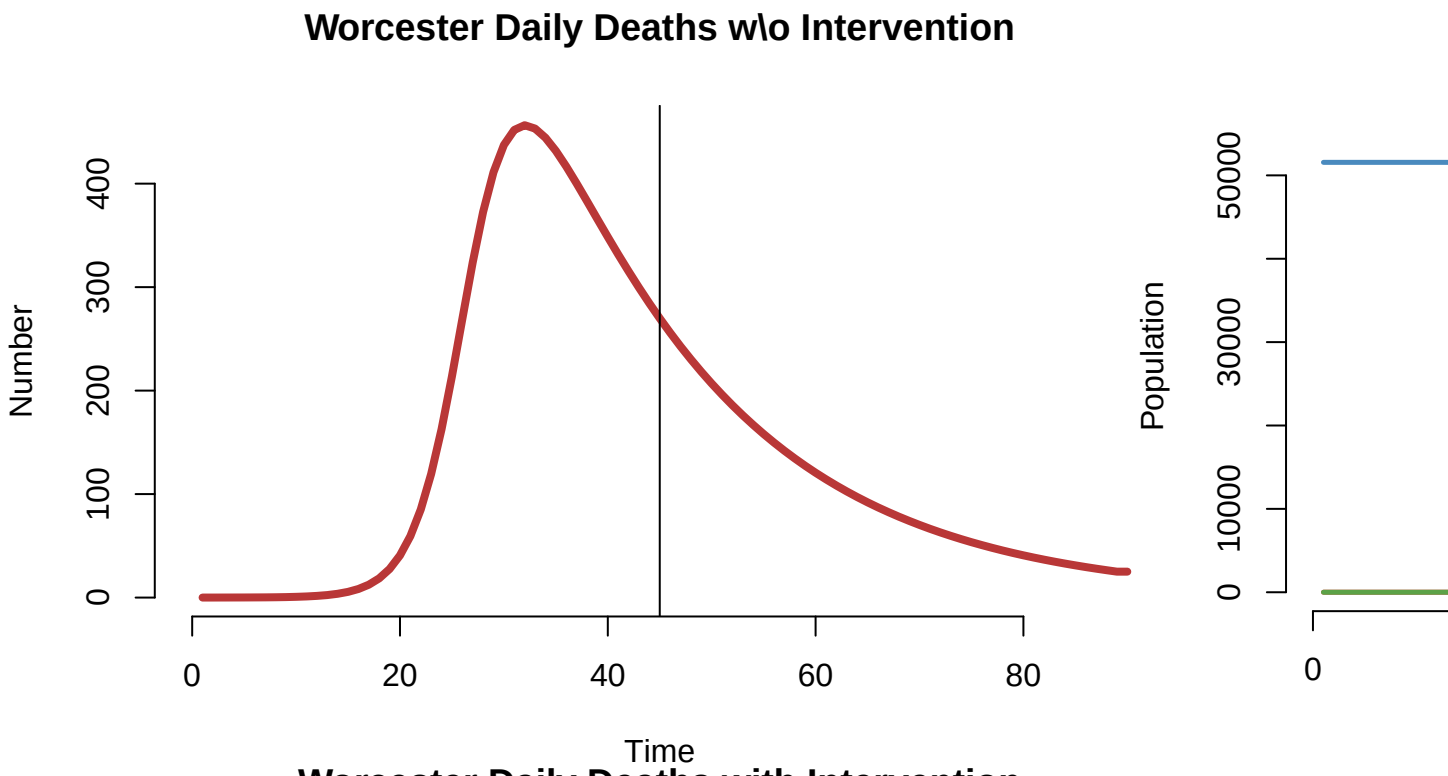

Talbot Daily Deaths with Intervention
Number
0
2
4
6
8
10
12
14
0
20
40
60
80
Time
Population
0
50000
100000
150000
0

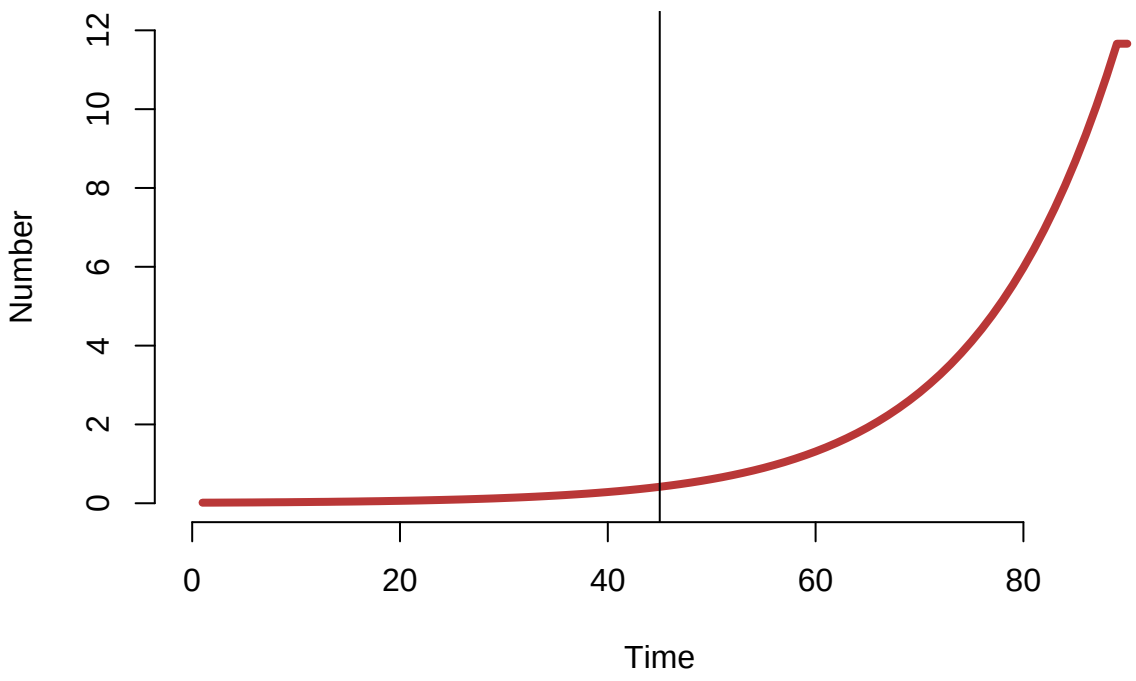

Washington Daily Deaths w\o Intervention
Number
0
500
1000
1500
0
20
40
60
80
Time
Population
0
50000
100000
150000
0


Washington Daily Deaths with Intervention
Number
0
100
200
300
0
20
40
60
80
Time
Population
0e+00
4e+04
8e+04
0


Wicomico Daily Deaths w\o Intervention
Number
0
200
400
600
800
1000
0
20
40
60
80
Time
Population
0e+00
4e+04
8e+04
0


Wicomico Daily Deaths with Intervention
Number
0
50
100
150
200
0
20
40
60
80
Time
Population
0
10000
30000
50000
0


Worcester Daily Deaths w\o Intervention
Number
0
100
200
300
400
0
20
40
60
80
Time
Population
0
10000
30000
50000
0


Worcester Daily Deaths with Intervention
Number
0
2
4
6
8
10
12
0
20
40
60
80
Time