Epidemiologic Study of the Manhattan, NY COVID-19 Data During the Period March 7, 2020 to June 4, 2020

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Venue: MATH 420 Mid-Semester Project Presentation

Problem Description

- Datasets:
  - Manhattan Covid Data
  - District of Columbia Covid Data

- Goals:
  - By fitting the model to the data, we achieve estimate for the parameters of the model which can be interpreted to real life characteristics of the virus
  - By fitting the model to only the beginning of the data we see if the model is capable of making predictions about things such as the maximum number of concurrent cases and the total number of deaths

Models Used

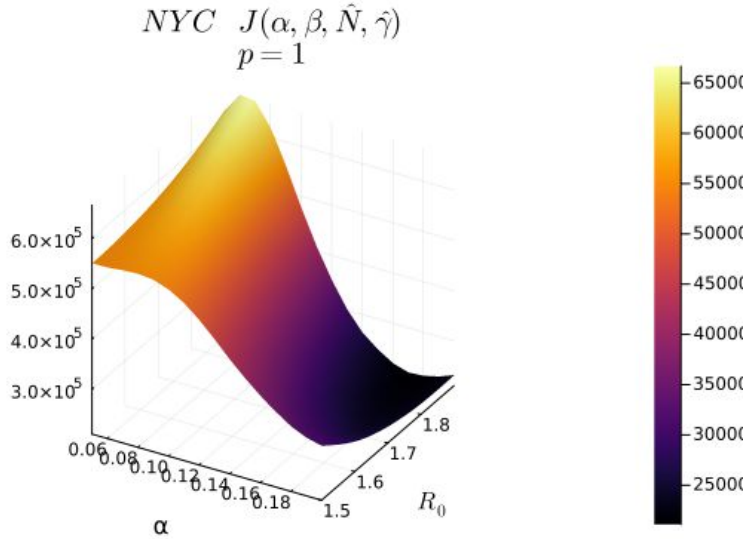
SIR

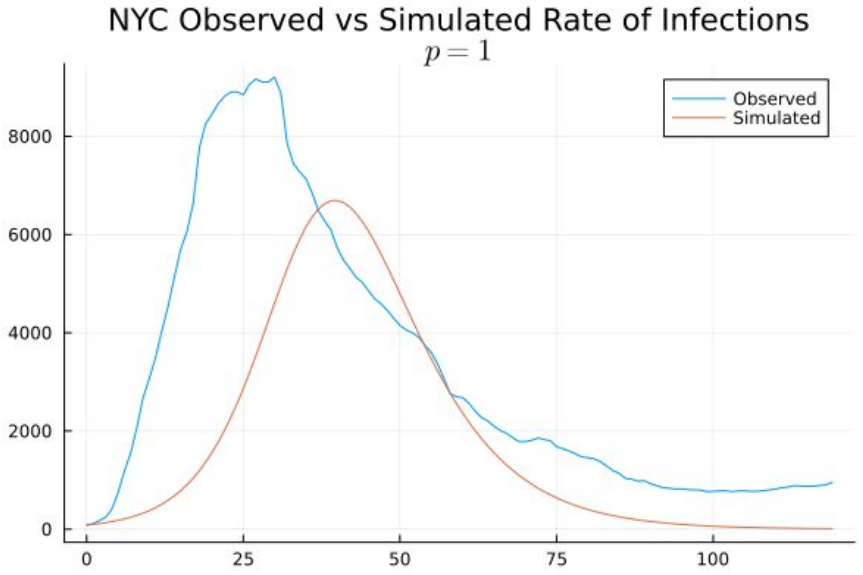
$$\begin{cases} \frac{dS}{dt} = -\beta S \frac{I}{N} \ , \quad S(0) \\ \frac{dI}{dt} = \beta S \frac{I}{N} - \alpha I \ , \quad I(0) \\ \frac{dR}{dt} = \alpha I \ , \quad R(0) \end{cases}$$

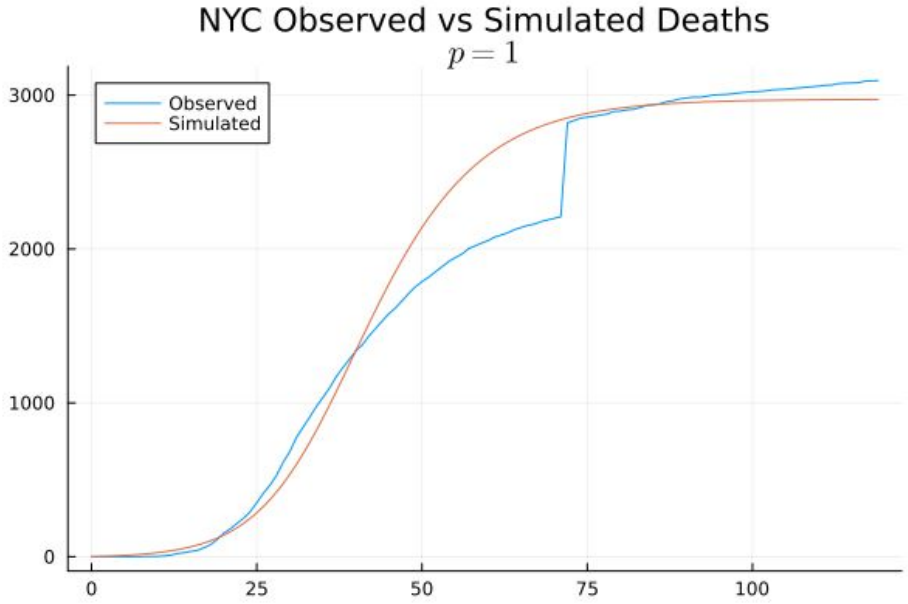
SEIR

$$\begin{cases} \frac{dS}{dt} = -\beta \frac{SI}{N} \ , \quad S(0) \\ \frac{dE}{dt} = \beta \frac{SI}{N} - \delta E \ , \quad E(0) \\ \frac{dI}{dt} = \delta E - \alpha I \ , \quad I(0) \\ \frac{dR}{dt} = \alpha I \ , \quad R(0) \end{cases}$$

SIR - NYC p = 1







α = 0.17

β = 0.323

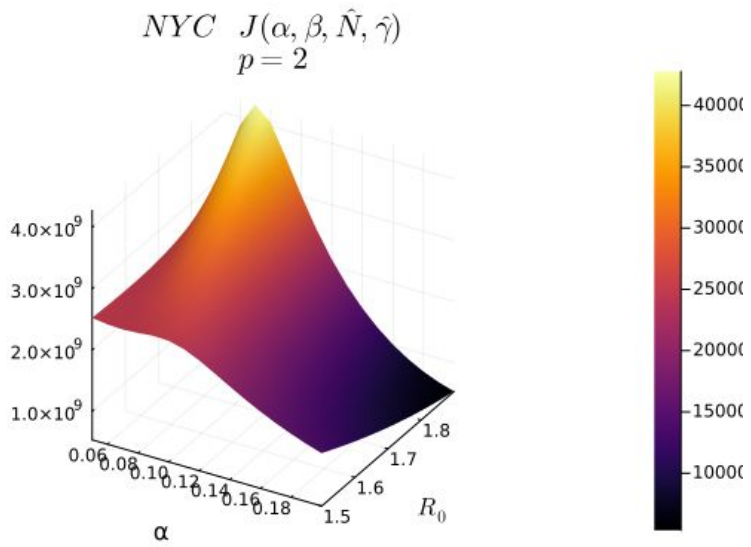
R0 = 1.9

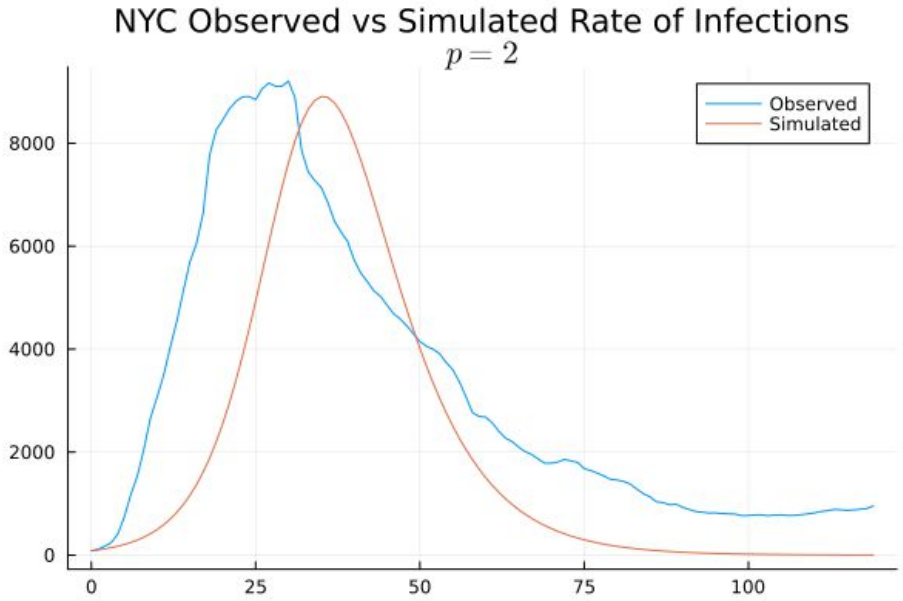
N = 48861 or 3%

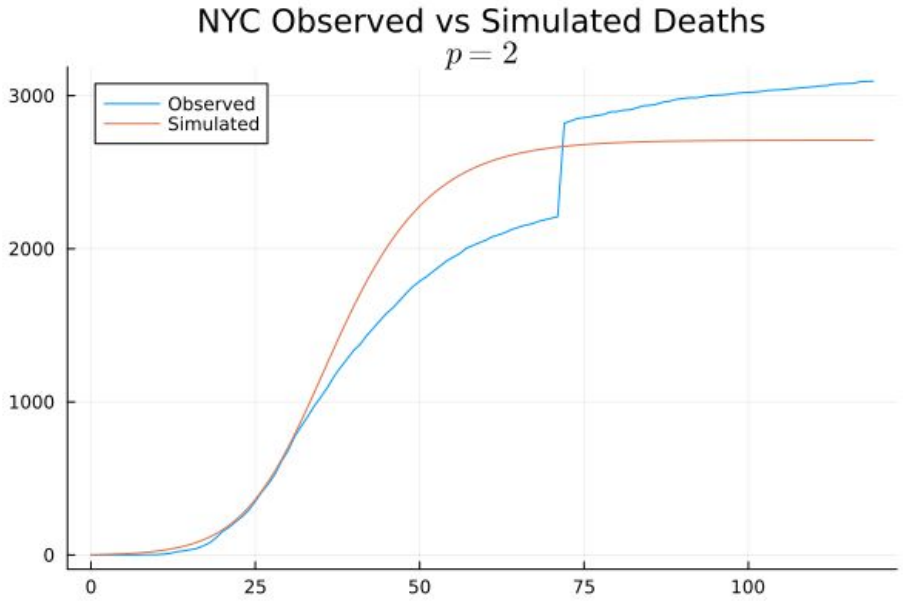
γ = 0.08*

*CDC estimates death rate for this period to be 8.5%

SIR - NYC p = 2







α = 0.2

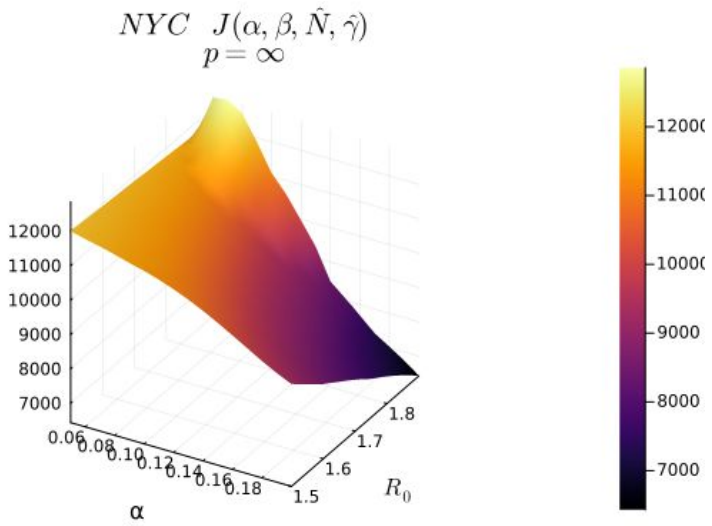
β = 0.38

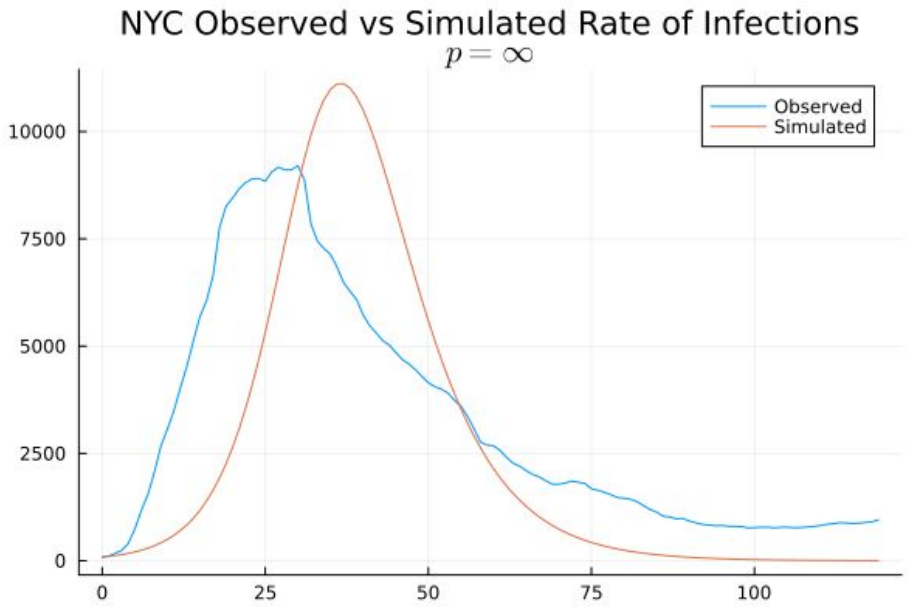
R0 = 1.9

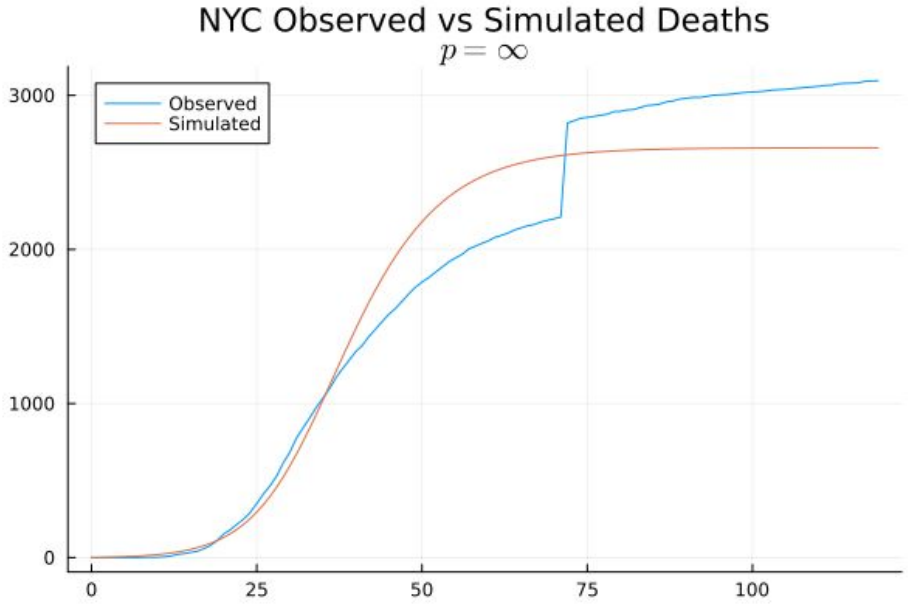
N = 65148 or 4%

γ = 0.054

SIR - NYC p = ∞







α = 0.2

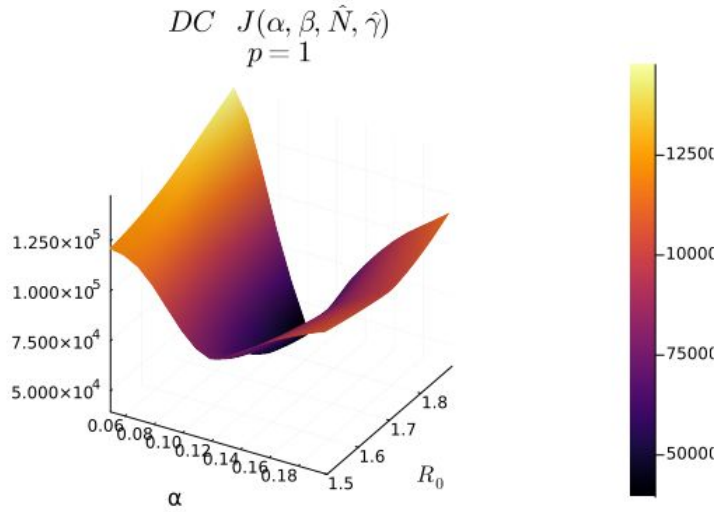
β = 0.38

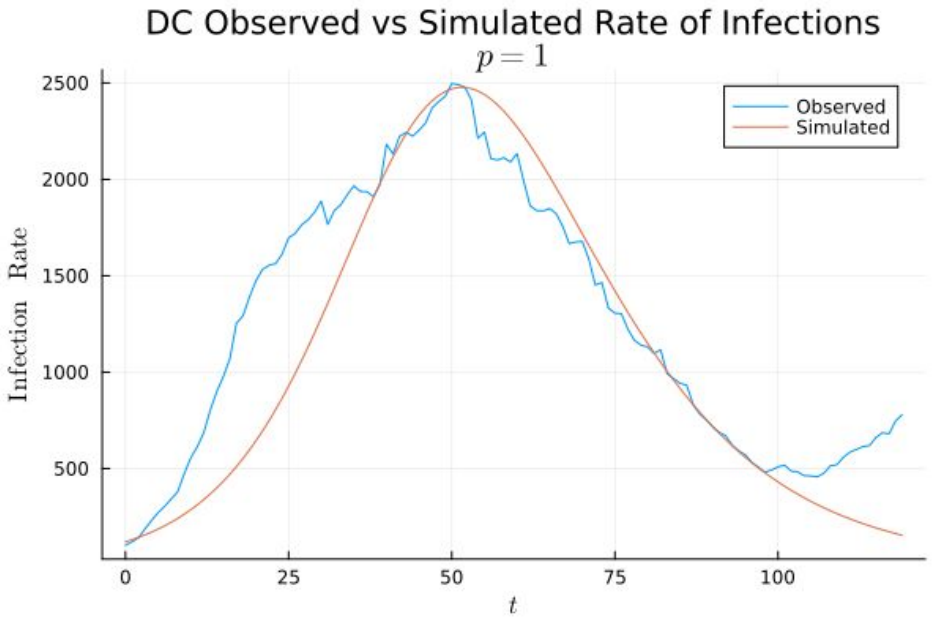
R0 = 1.9

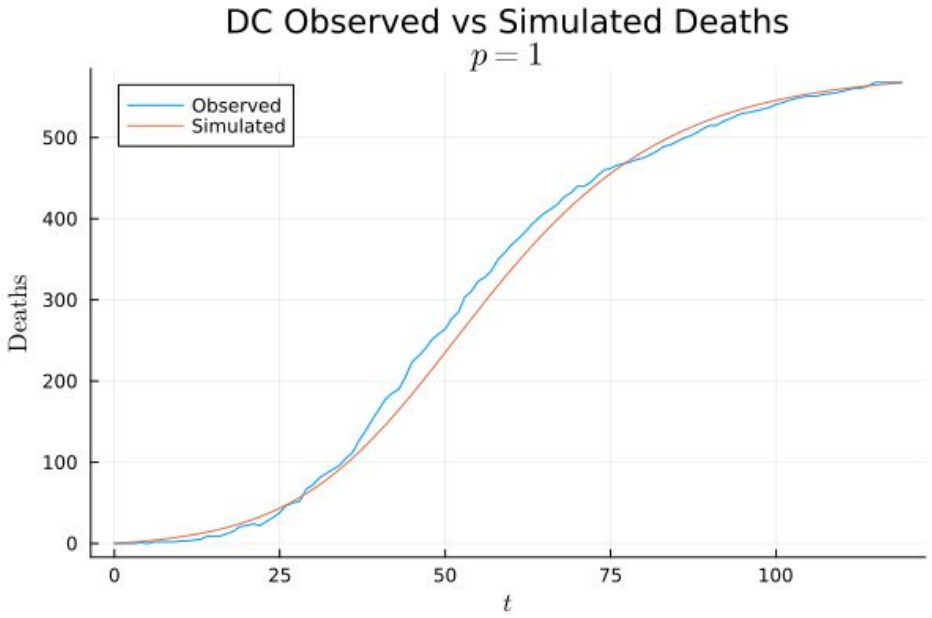
N = 81435 or 5%

γ = 0.042

SIR - DC p = 1







α = 0.1

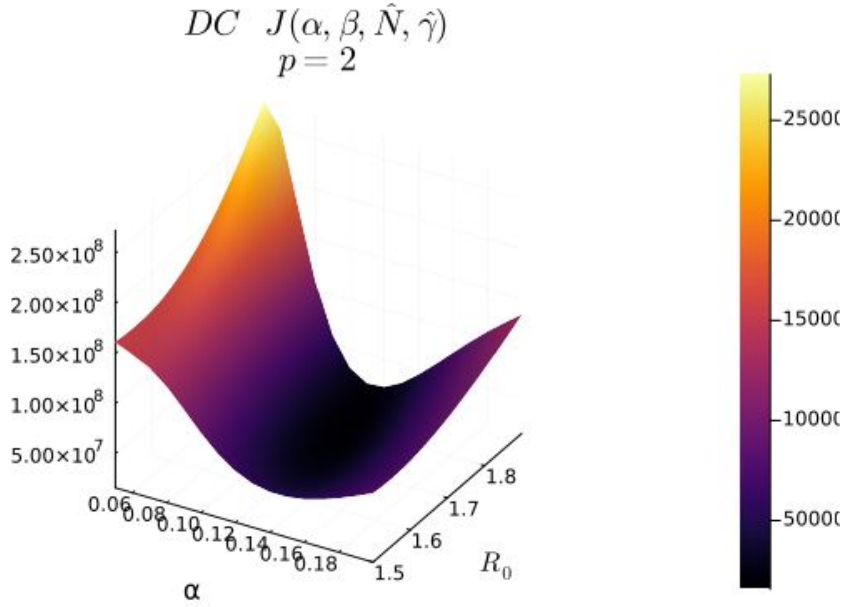
β = 0.19

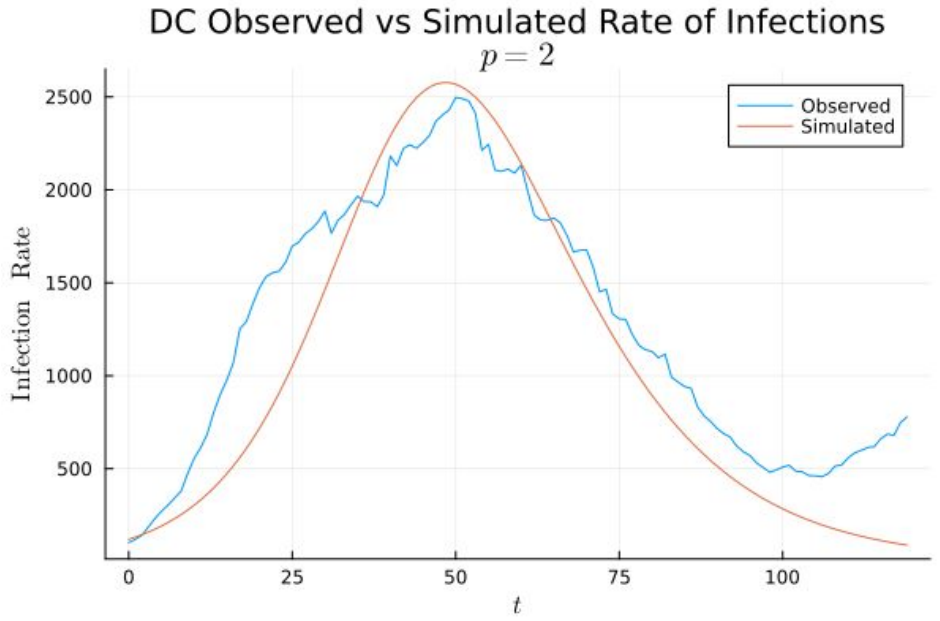
R0 = 1.9

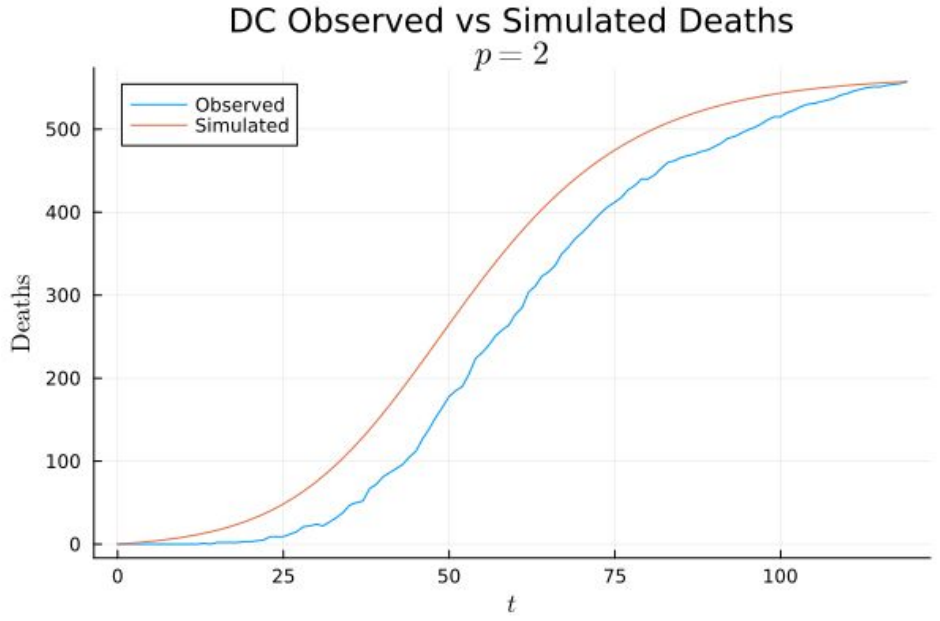
N = 17643 or 2.5%

γ = 0.01

SIR - DC p = 2







α = 0.12

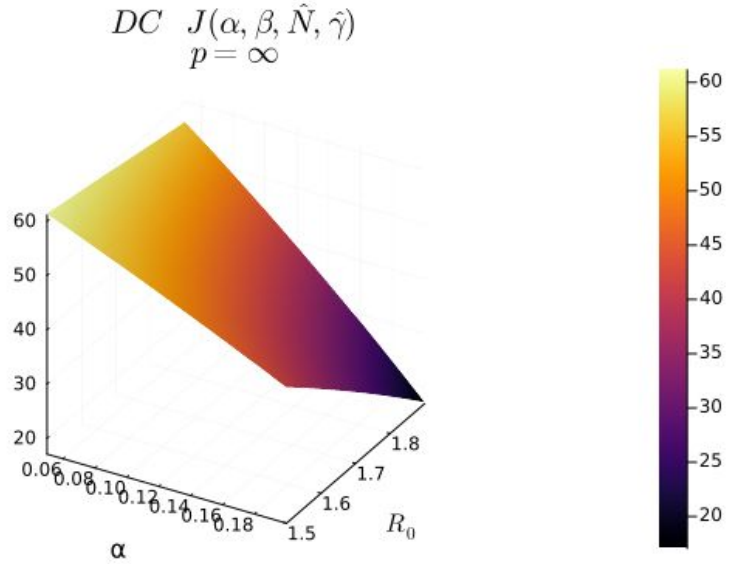
β = 0.216

R0 = 1.8

N = 21172 or 3%

γ = 0.01

SIR - DC p = ∞



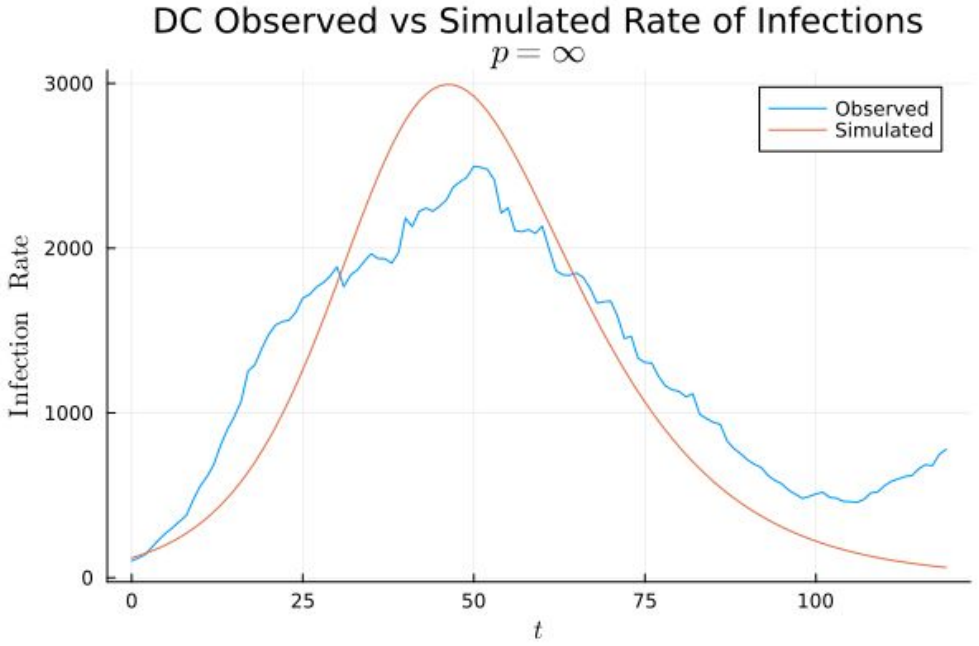
α = 0.13

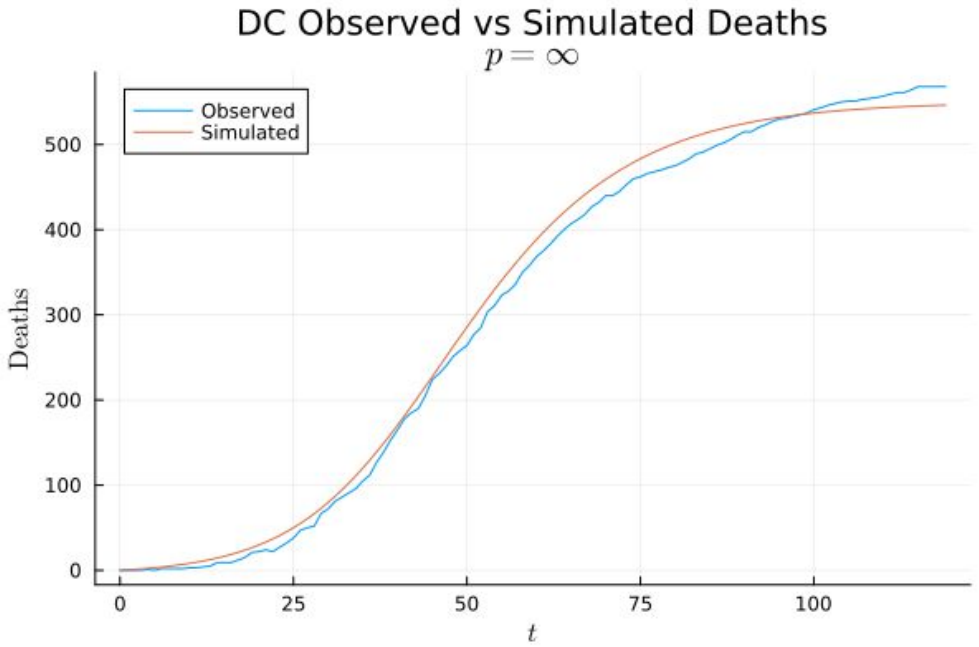
β = 0.234

R0 = 1.8

N = 24701 or 3.5%

γ = 0.01

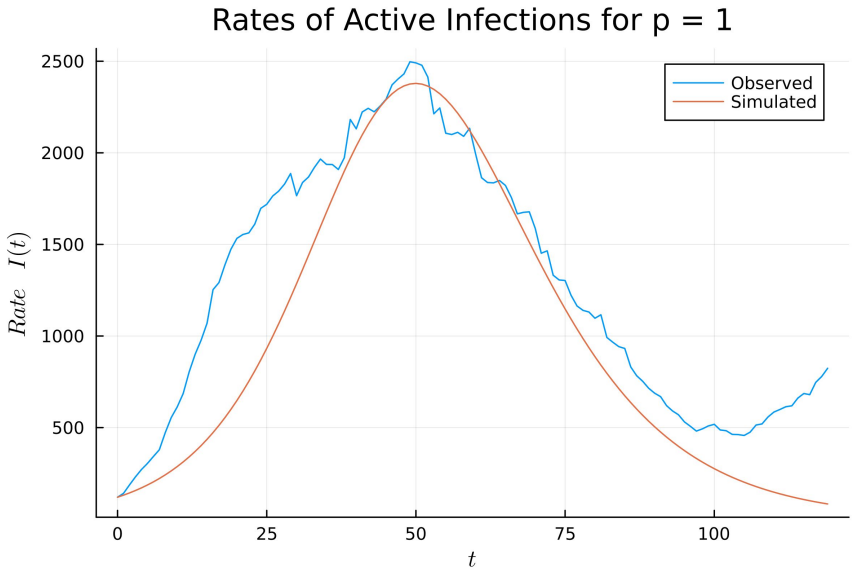


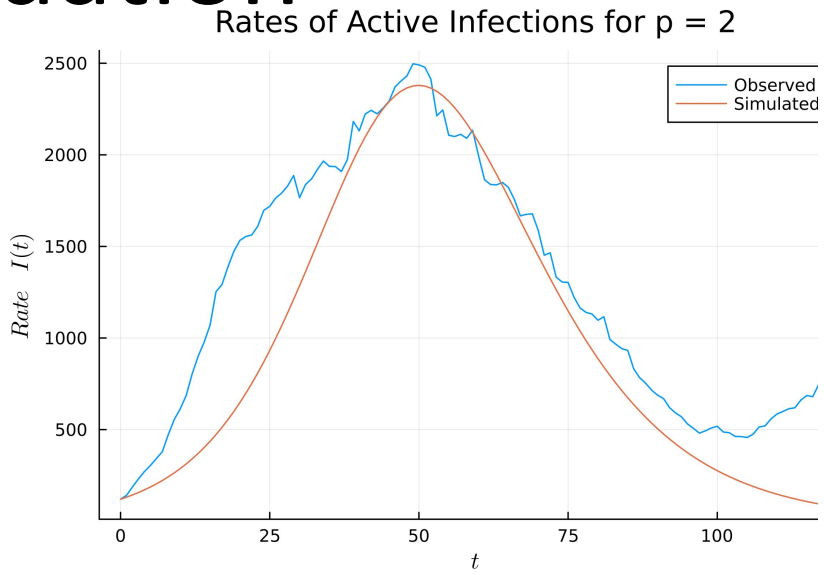


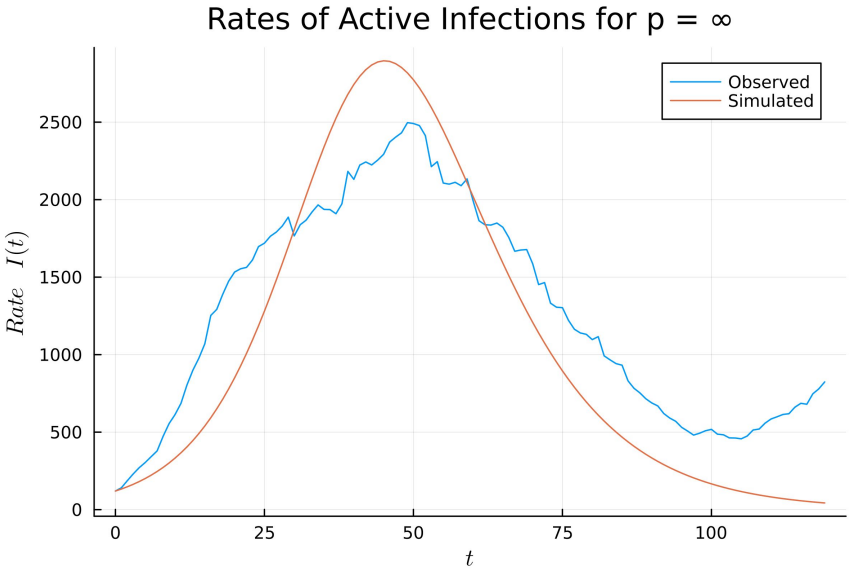
SIR Model Parameters

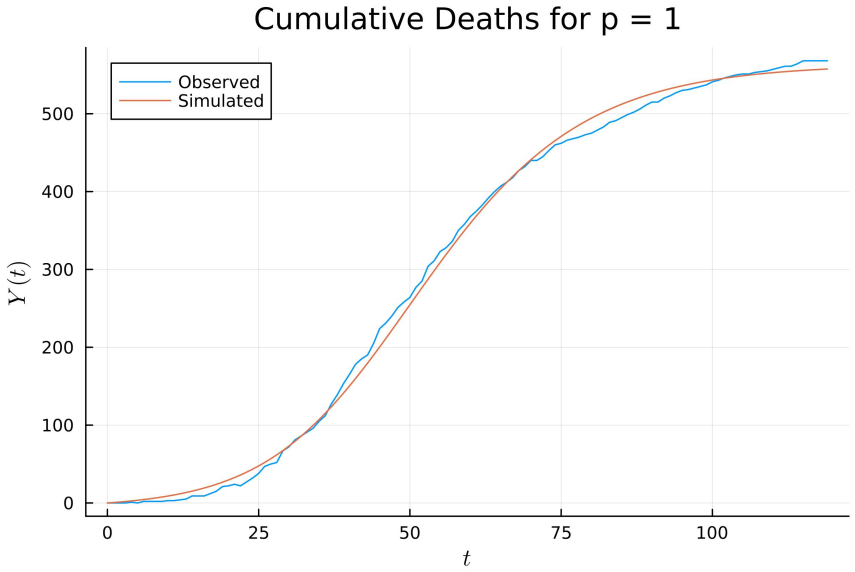
	P = 1	**P = 2**	**P = ∞**
α	0.2	0.25	0.3
β	0.36	0.475	0.54
	1.8	1.9	1.8
	4%	5%	6%
γ	0.062	0.041	0.033
J	216,304	396,530,443	4038

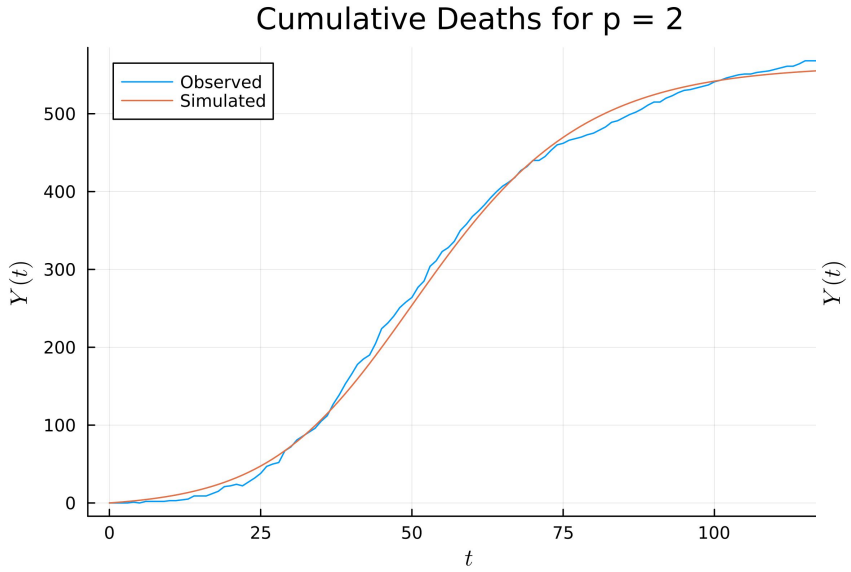
SIR Model Validation

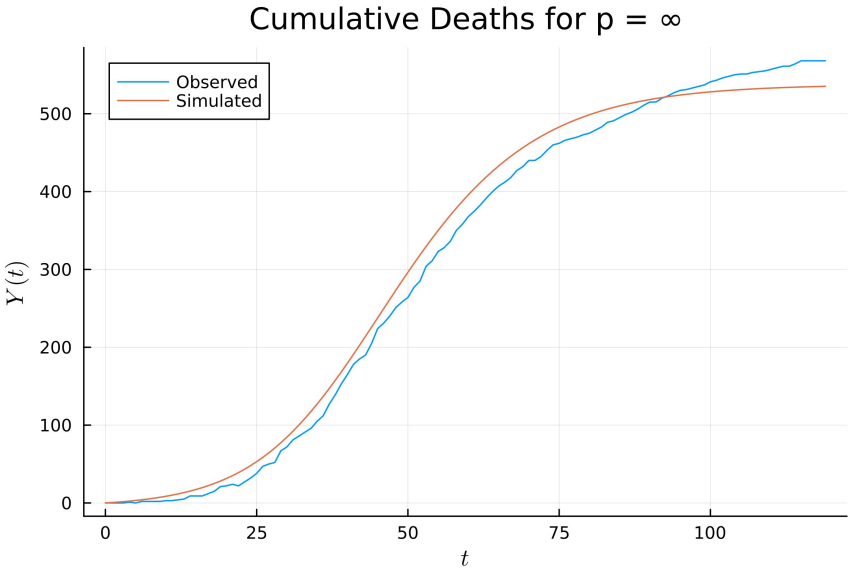








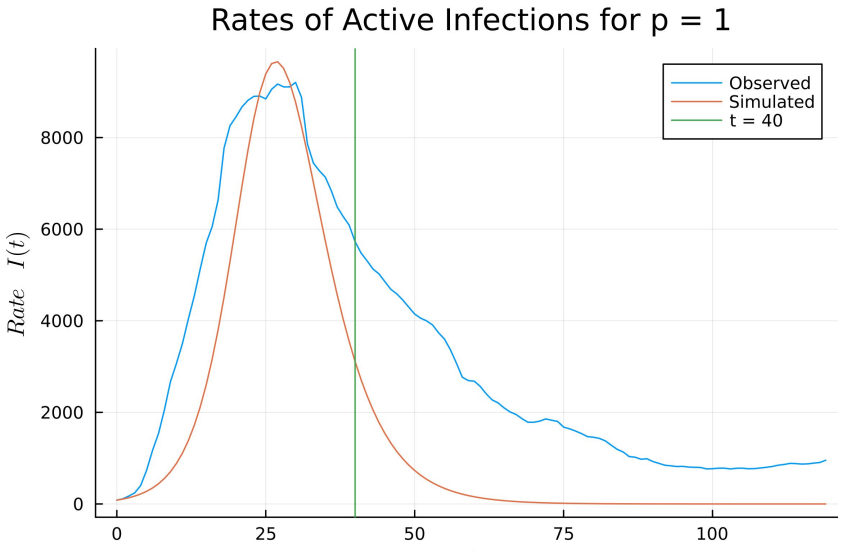


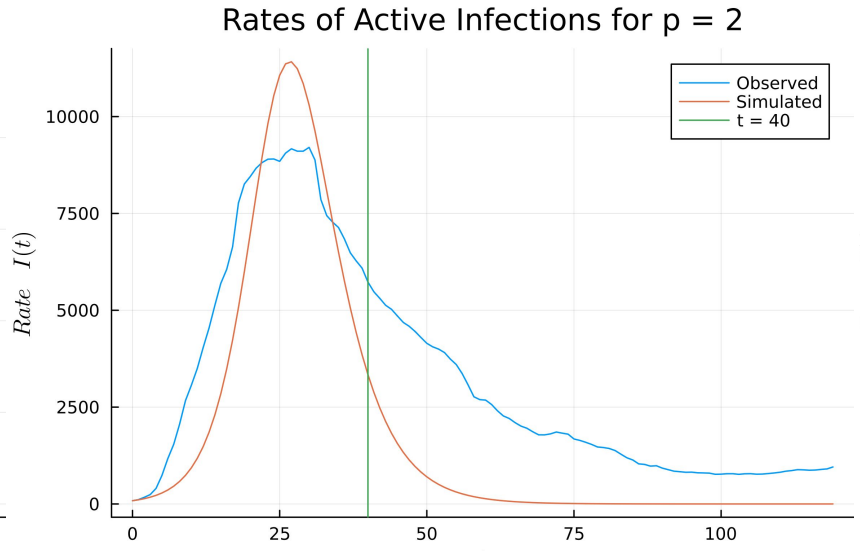


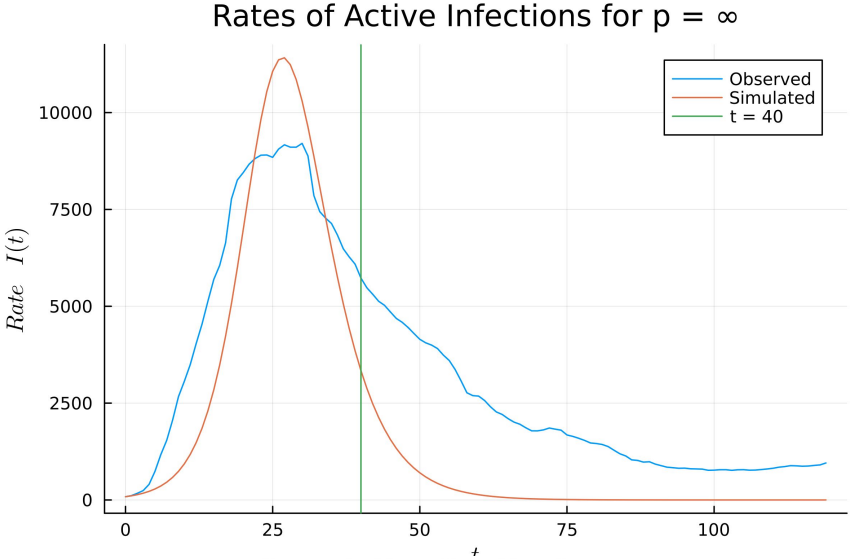
SIR Model Parameters Validation

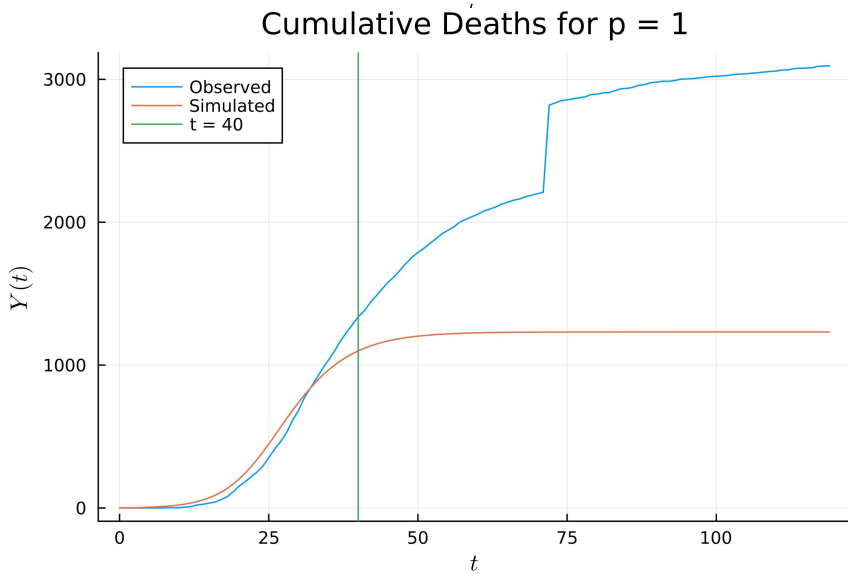
	P = 1	**P = 2**	**P = ∞**
α	0.15	0.15	0.15
β	0.24	0.24	0.255
	1.6	1.6	1.7
	4%	4%	4%
γ	0.031	0.031	0.027
J	35198	16,992,100	815

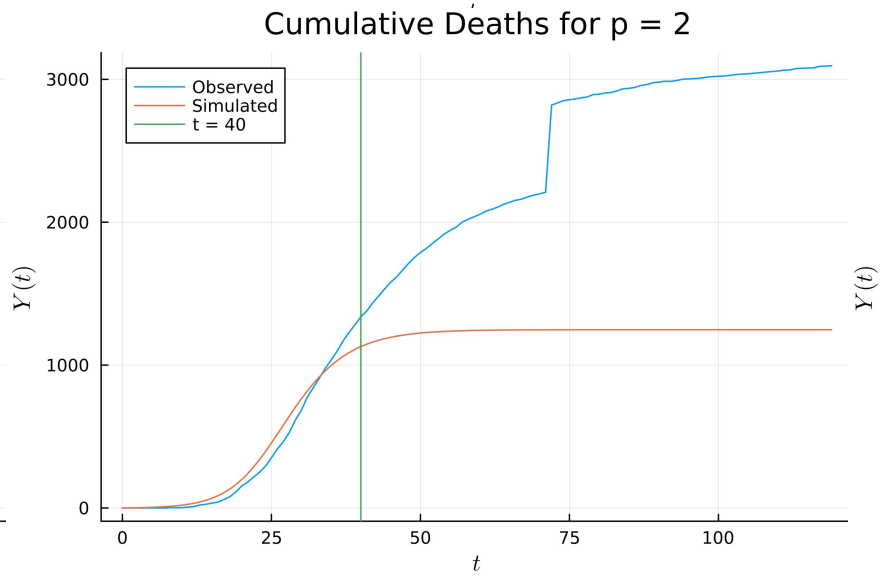
SIR Model Prediction

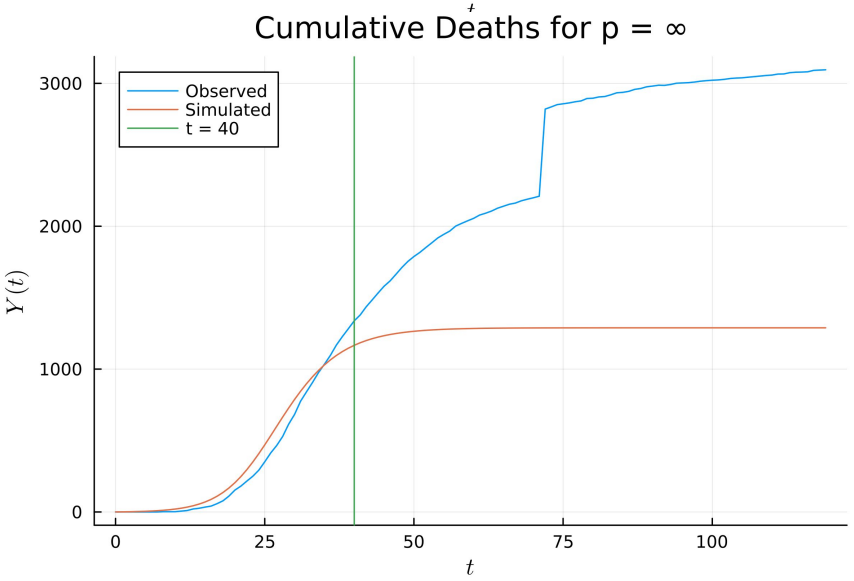








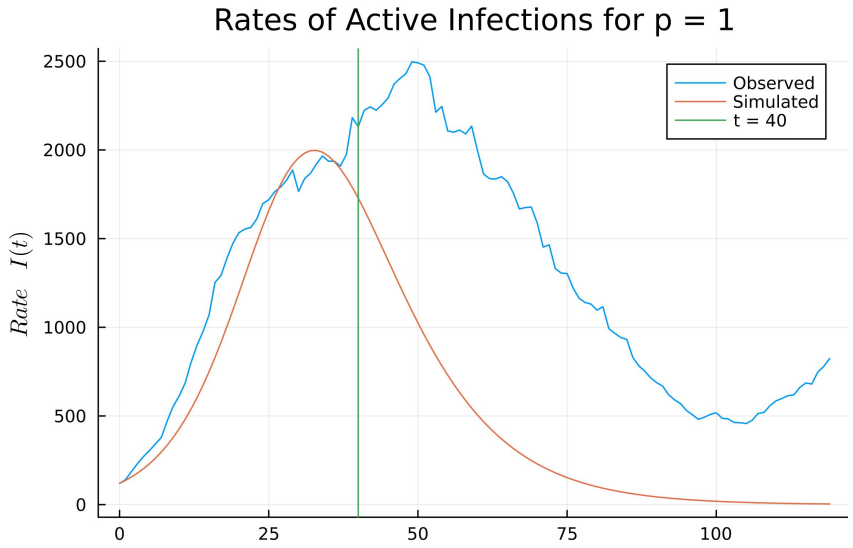


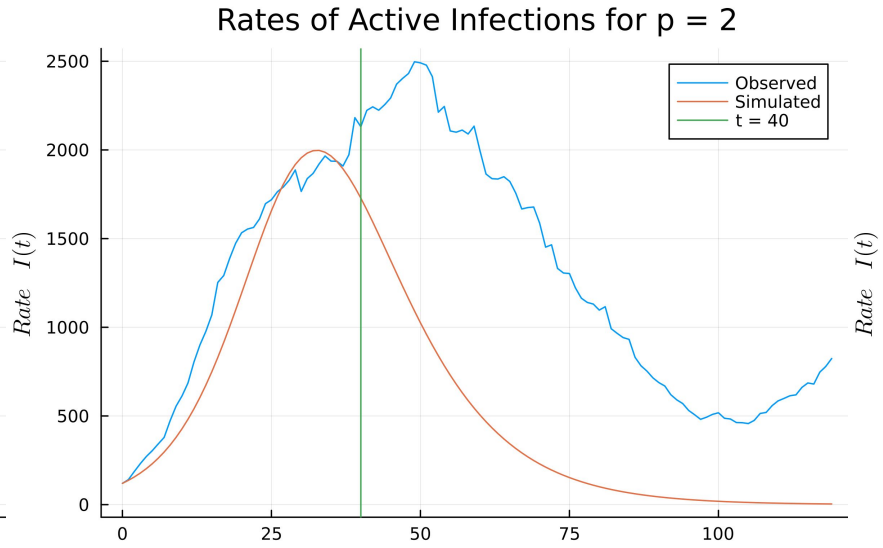


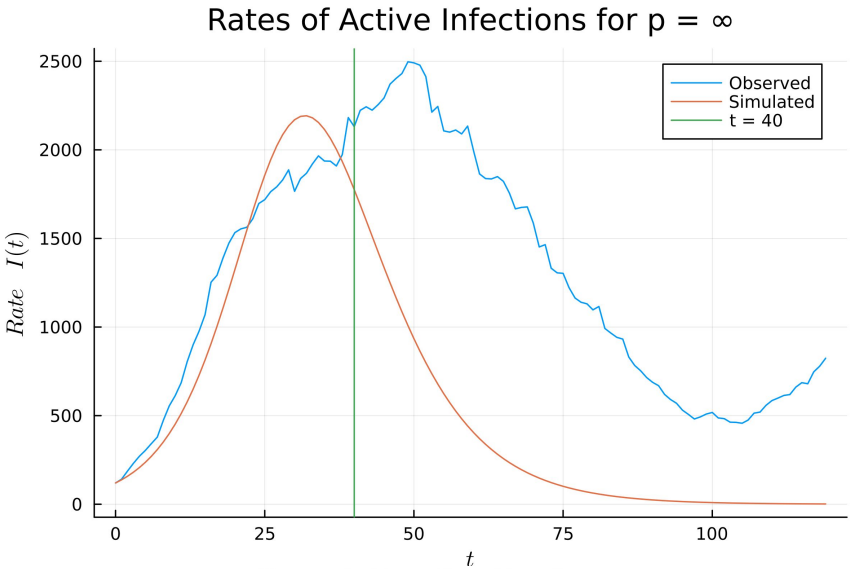
SIR Model Parameters Prediction

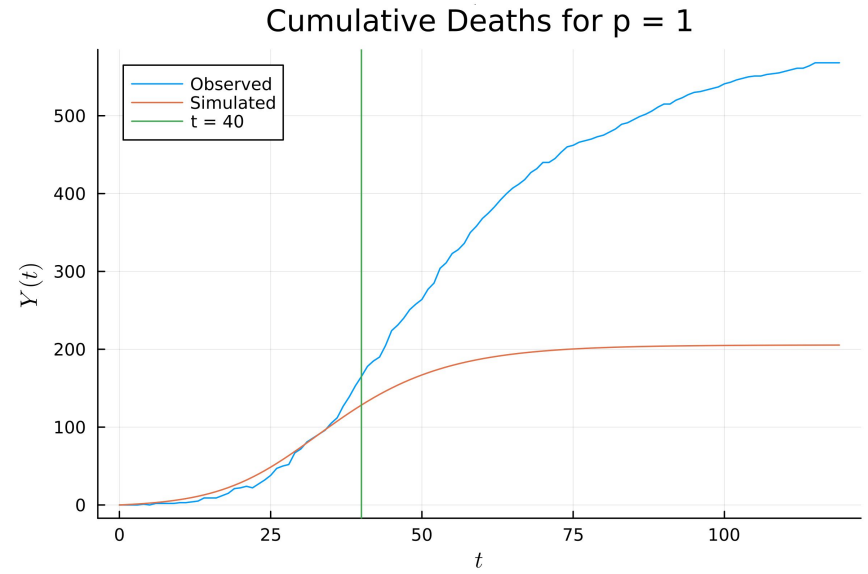
	P = 1	P = 2	P = ∞
α	0.3	0.35	0.35
β	0.54	0.595	0.595
	1.8	1.7	1.7
	5%	7%	7%
γ	0.021	0.016	0.016
J	56,546	117,061,673	2986
	84	81	81

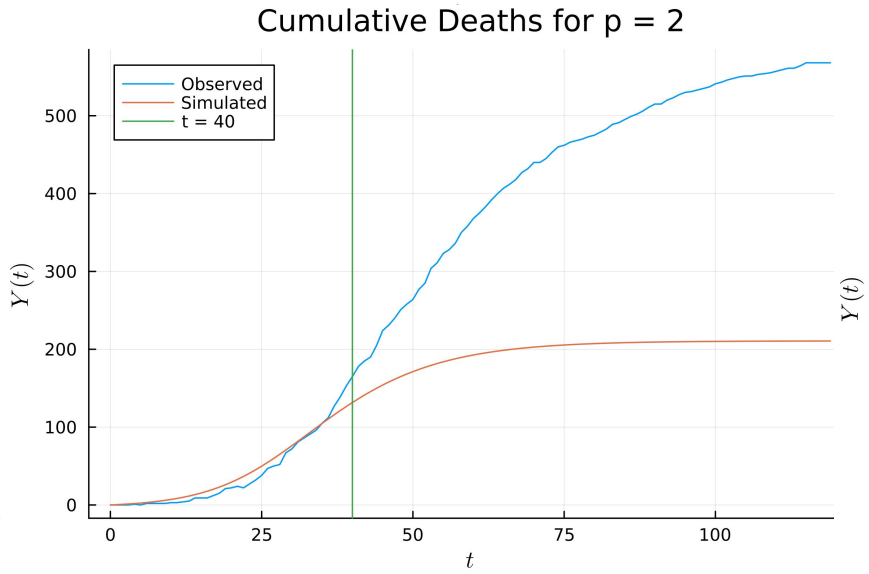
SIR Model Prediction Validation

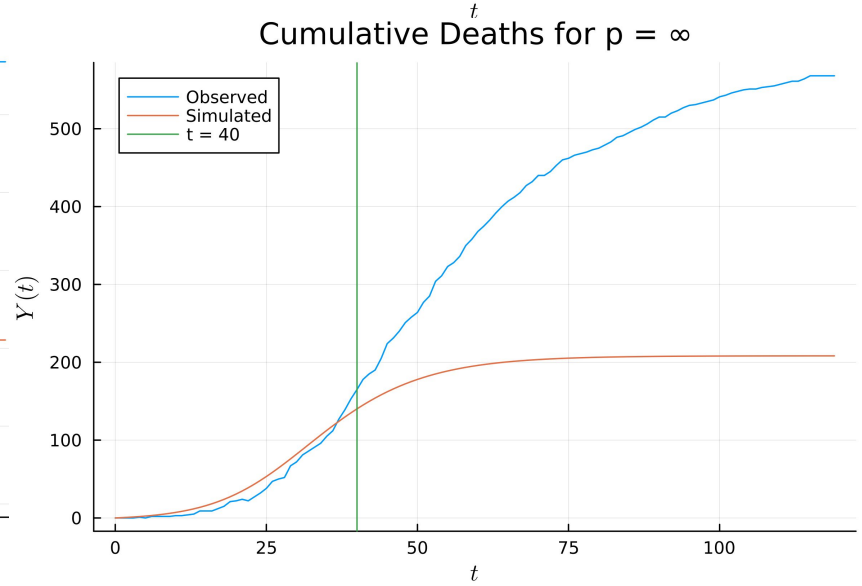








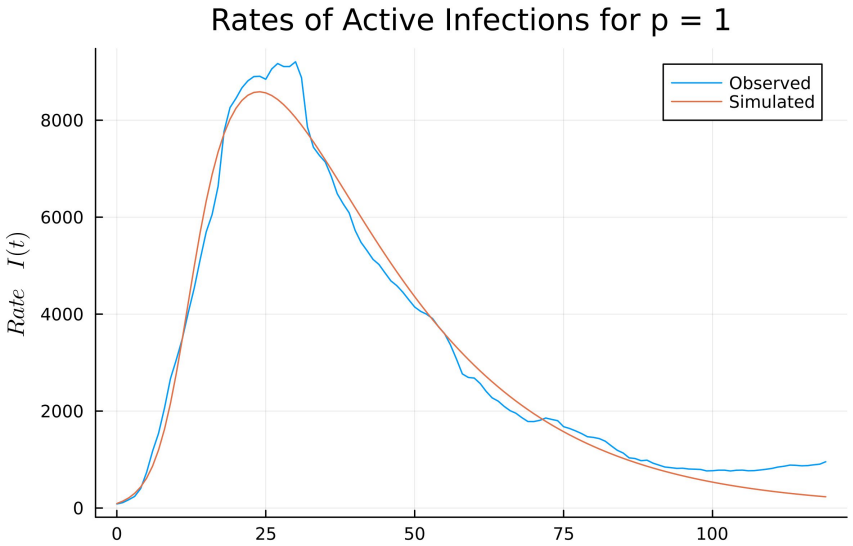


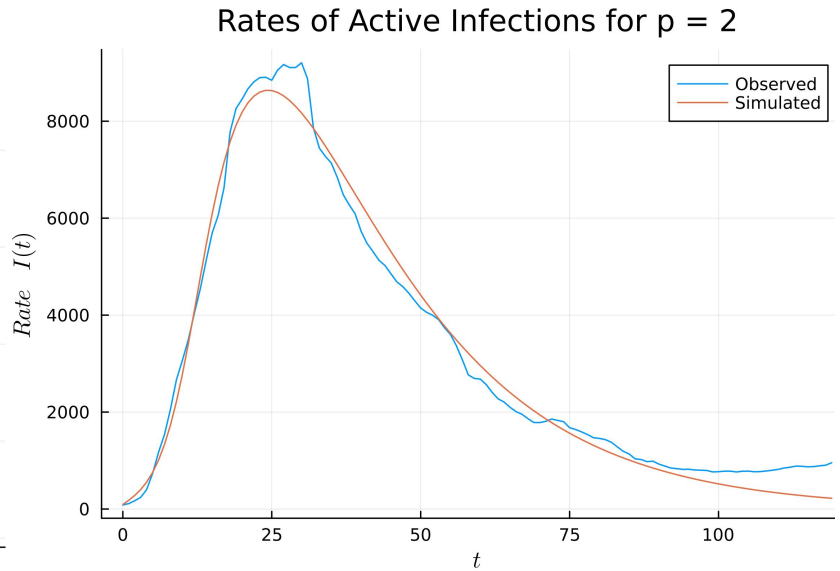


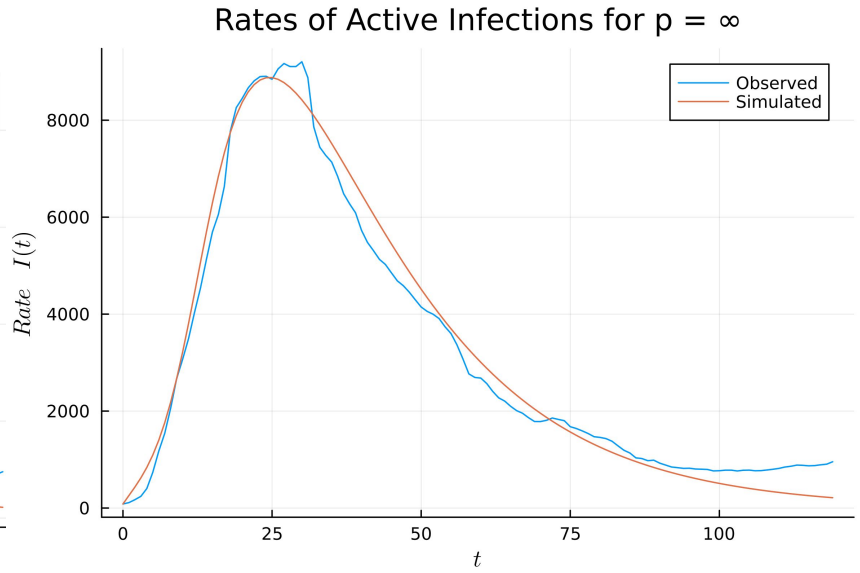
SIR Model Parameters Prediction Validation

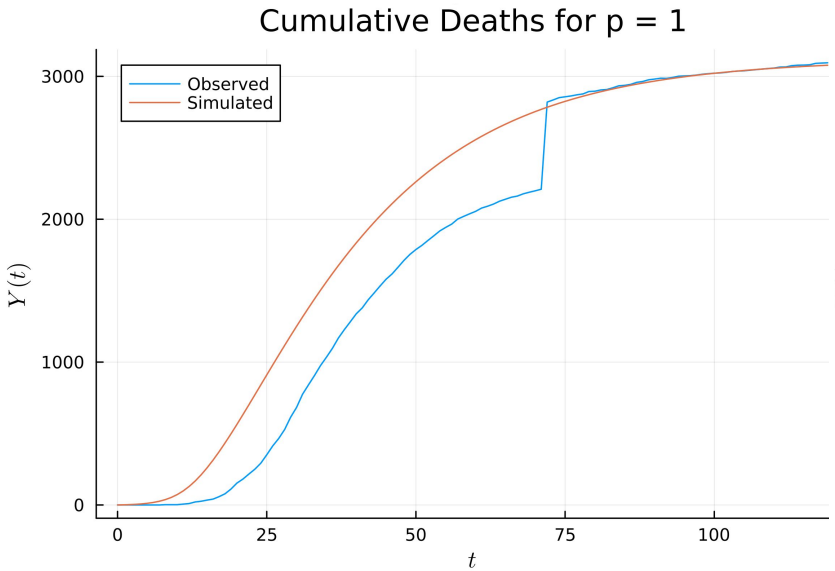
	P = 1	P = 2	P = ∞
α	0.15	0.15	0.2
β	0.285	0.285	0.34
	1.9	1.9	1.7
	2%	2%	3%
γ	0.019	0.019	0.014
J	6,419	1,626,286	422
	117	117	108

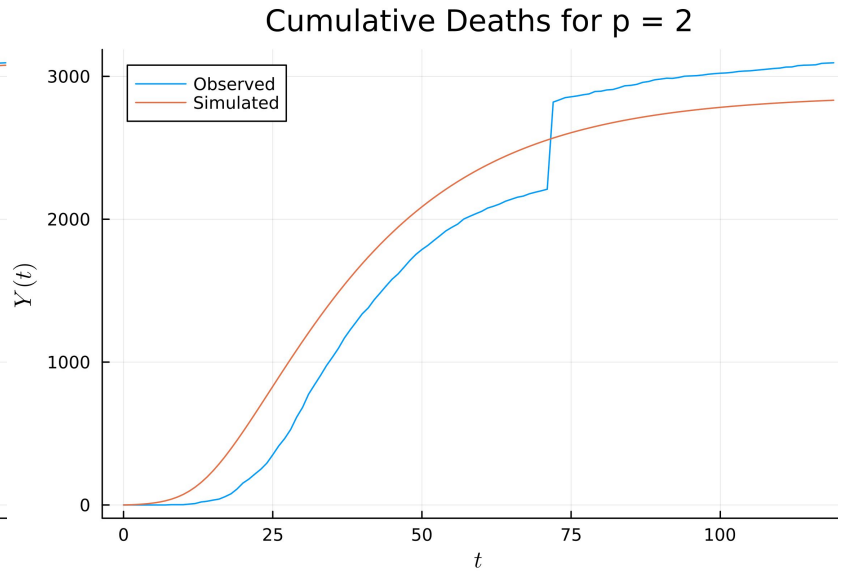
SEIR Model

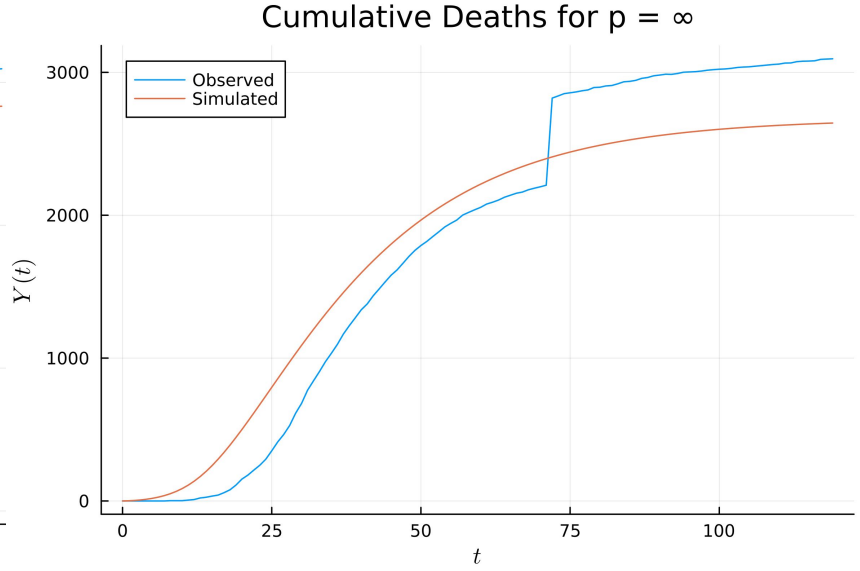

Rates of Active Infections for p = 1
Observed
Simulated
Rate I(t)
0
2000
4000
6000
8000
0
25
50
75
100


Rates of Active Infections for p = 2
Observed
Simulated
Rate I(t)
0
2000
4000
6000
8000
0
25
50
75
100
t


Rates of Active Infections for p = ∞
Observed
Simulated
Rate I(t)
0
2000
4000
6000
8000
0
25
50
75
100
t


Cumulative Deaths for p = 1
Observed
Simulated
Y(t)
0
1000
2000
3000
0
25
50
75
100
t


Cumulative Deaths for p = 2
Observed
Simulated
Y(t)
0
1000
2000
3000
0
25
50
75
100
t


Cumulative Deaths for p = ∞
Observed
Simulated
Y(t)
0
1000
2000
3000
0
25
50
75
100
t

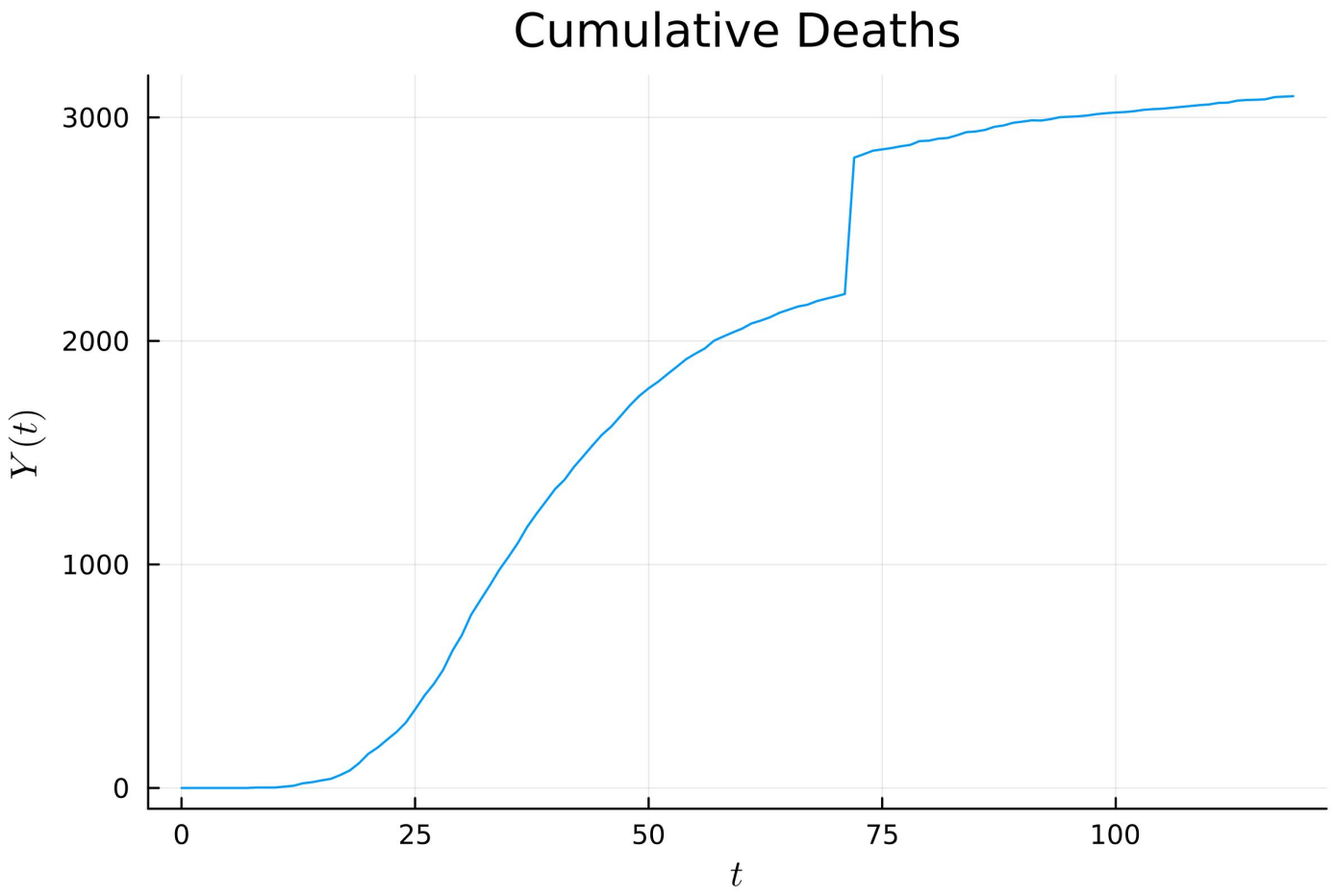
Range of parameters tested SEIR

- α: [0.03, 0.4]
- R_0: [1.5, 50]
- δ = 0.1
- N / N_{max} = $[0.005, 0.1]$
- E(0) / I(t_0) = [1, 30]
- I(0) / I(t_0) = [1, 30]

SEIR Model Parameters

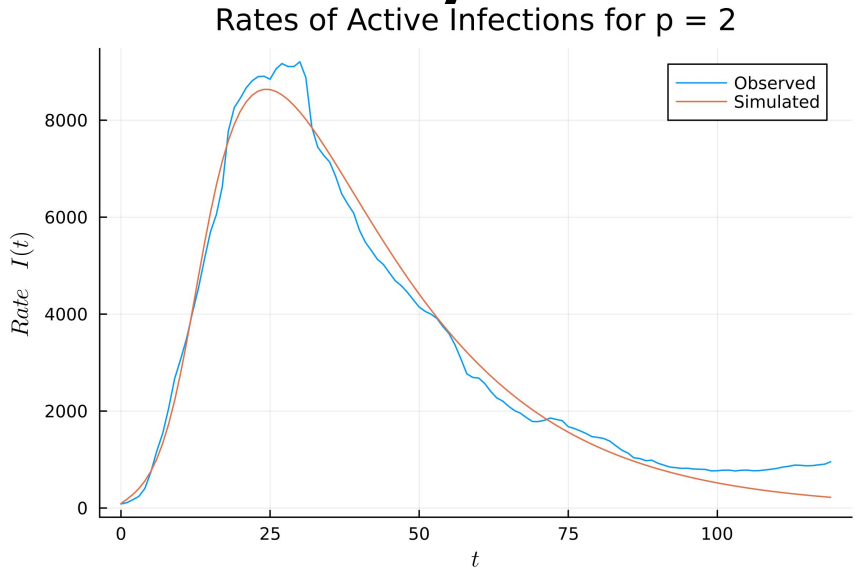
	P = 1	**P = 2**	**P = ∞**
α	0.044	0.045	0.046
β	1.98	1.53	1.16
	45	34	25
δ (fixed)	0.1	0.1	0.1
	1%	1%	1%
γ	0.185	0.166	0.147
	1.1	1.1	1
	5.6	10.8	25.2
J	65,083	26,010,112	1236

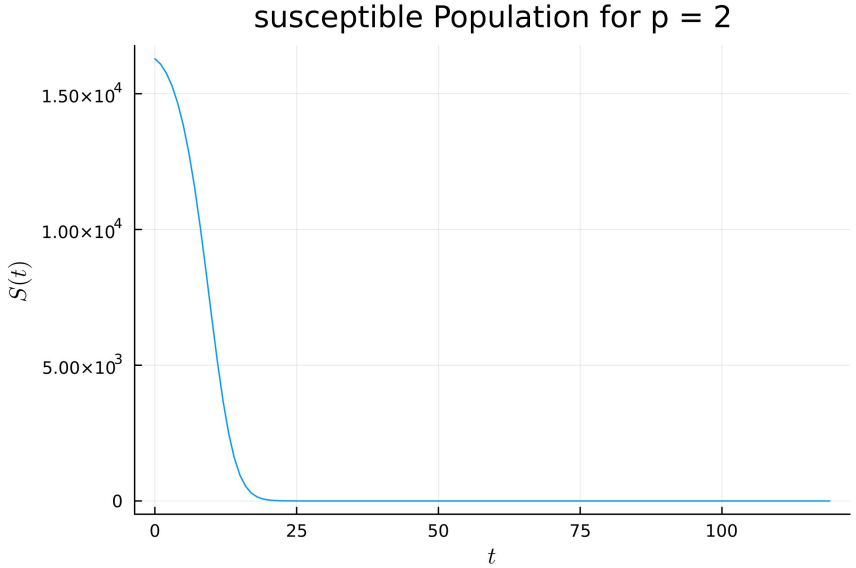
Large Jump in Death Data



- Increase of 610 deaths between May 17, 2020 and May 18, 2020
- Unlikely to be a normal increase unable to find exact reason for Manhattan
- Similar jumps in data from other places have been caused by only reporting deaths with a positive PCR test as opposed to the cheaper and faster antigen test
- One explanation is a change in which deaths are reported from not including deaths with a positive antigen test to including them

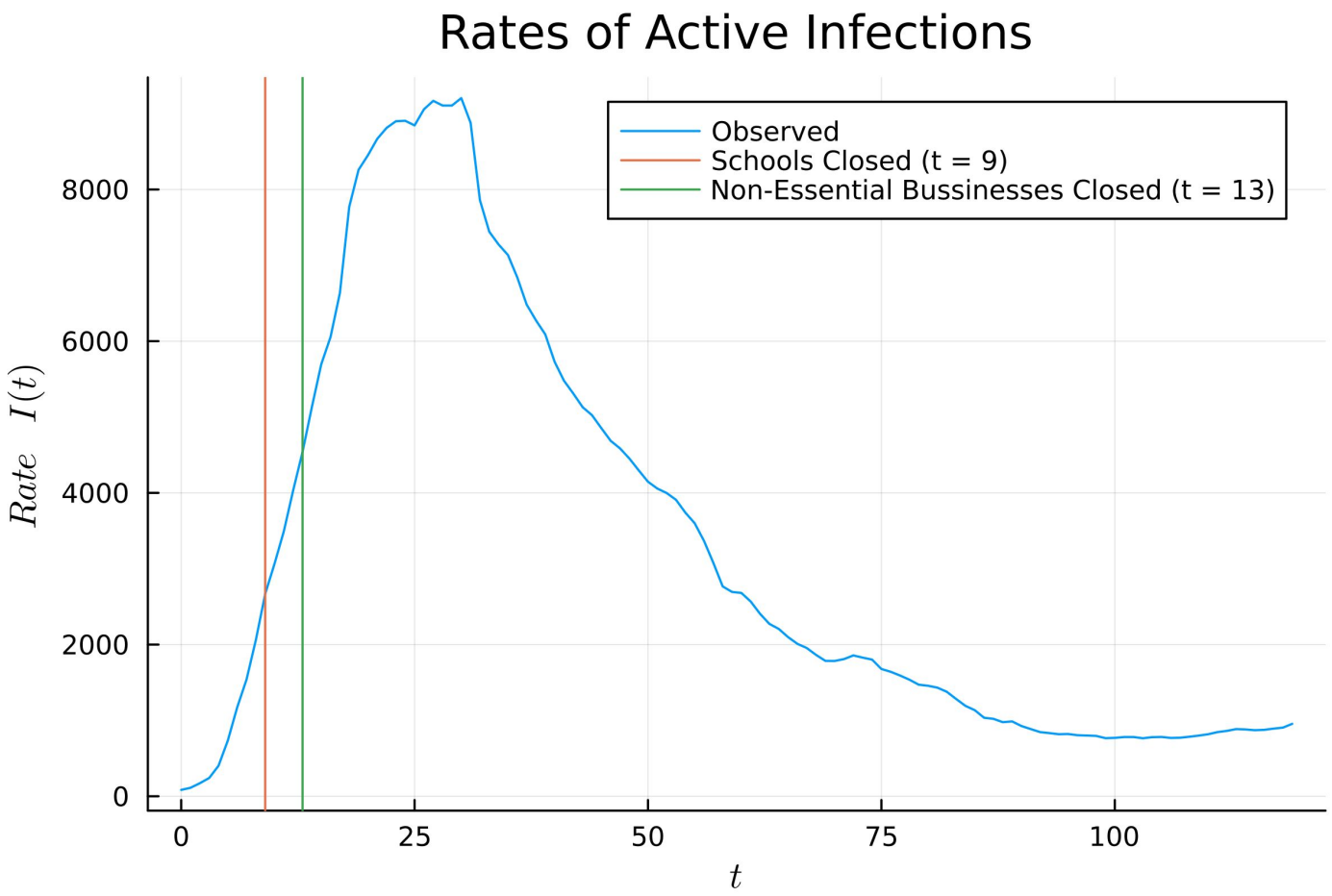
Accuracy of Parameters





- R_0 was very large and varied a lot between 25 and 45 for different values of p, this did not have a large effect on the model because the entire susceptible population is quickly moved into Exposed in each case
- Then the low value of α allowed the infected population to slowly go down over time matching the long tail in the observed data
- This makes the value for R_0 and β unlikely to reflect any real-world values

Reasons for Difficulty

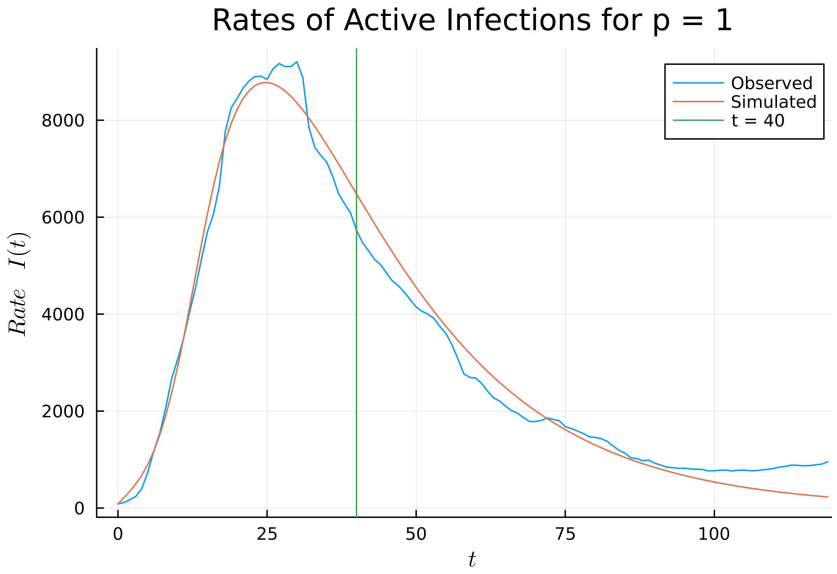


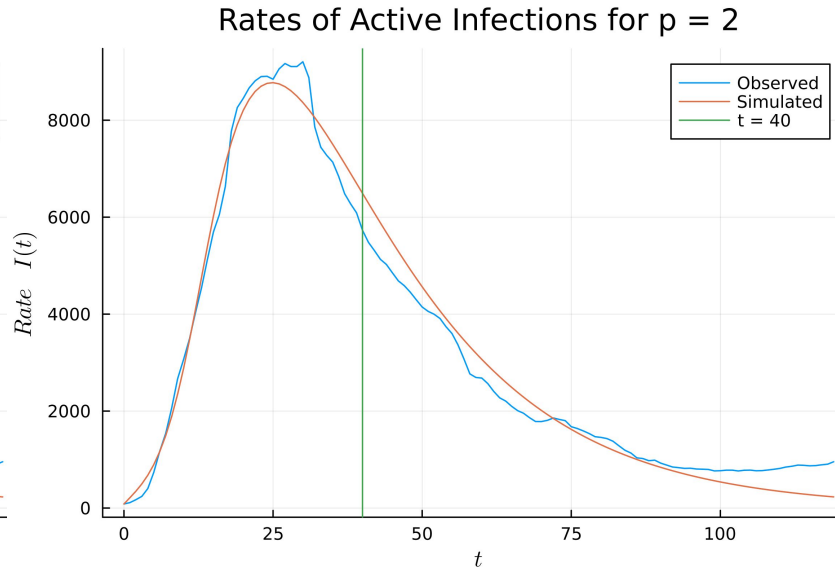
- The model only allows for a constant value of β
- Changes in human behavior such as those due to a lockdown can cause a large change in β
- This makes it difficult to fit the model to the observed data without it doing it in the weird way that we see

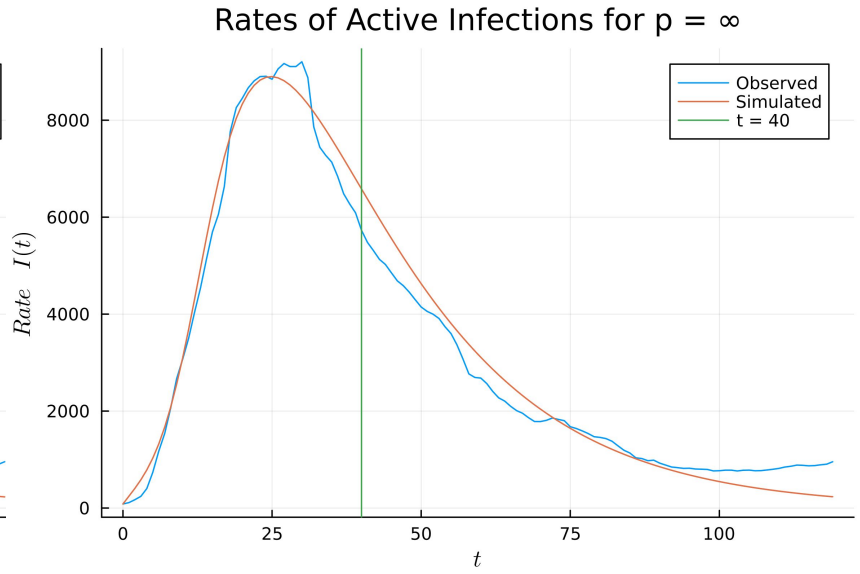
Interpretation of Parameters SEIR

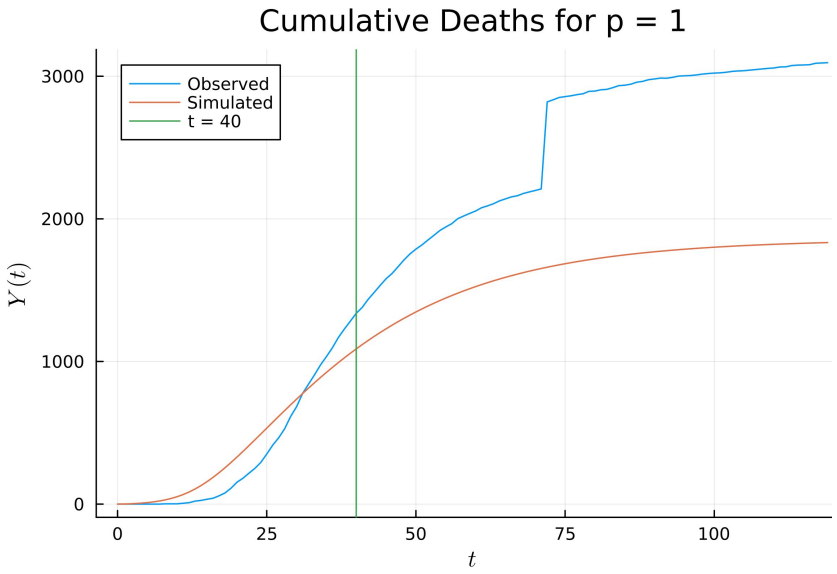
- Average Infectious Period (1/α): 21.7 to 22.7 days
- Average number of close contacts per infected individual (R_0): 25 to 45
- Average Incubation Period (1/δ) : 10 days (we chose this value)
- Death rate (γ): 14.7% to 18.5%

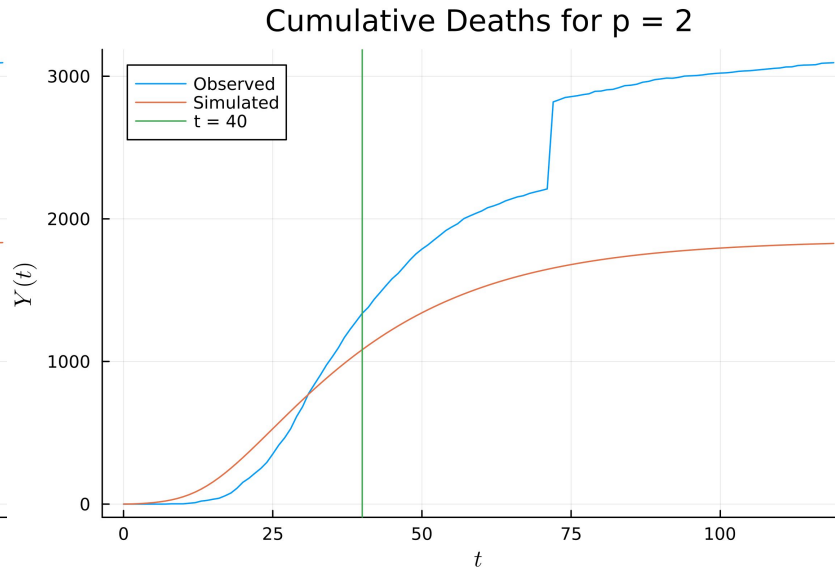
SEIR Model Prediction

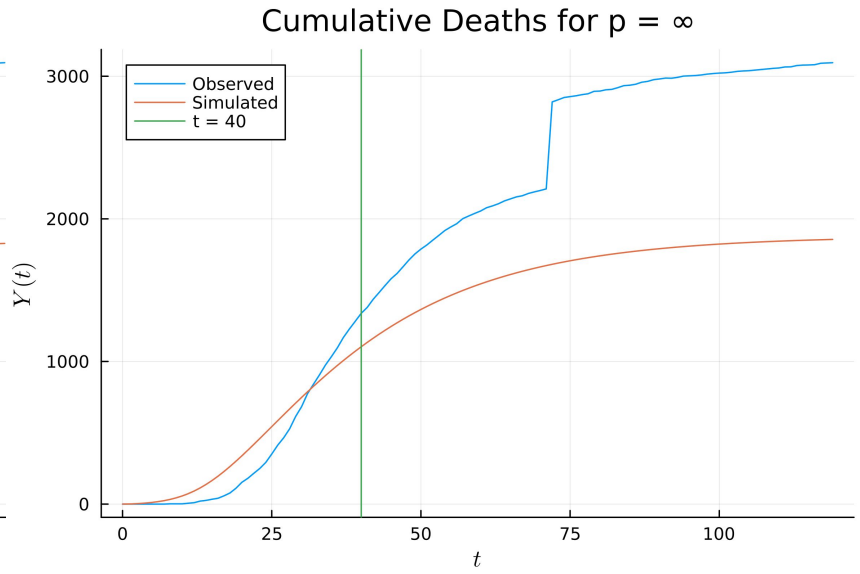












SEIR Model Prediction Parameters

	P = 1	P = 2	P = ∞
α	0.045	0.045	0.045
β	1.28	1.27	1.17
	28.5	28.2	26.0
δ (fixed)	0.1	0.1	0.1
	1%	1%	1%
γ	0.105	0.104	0.104
	1	1	1
	16.1	16.1	20.1
J	16,398	6,122,289	933
	206	206	206

Interpretation of Parameters SEIR Predictions

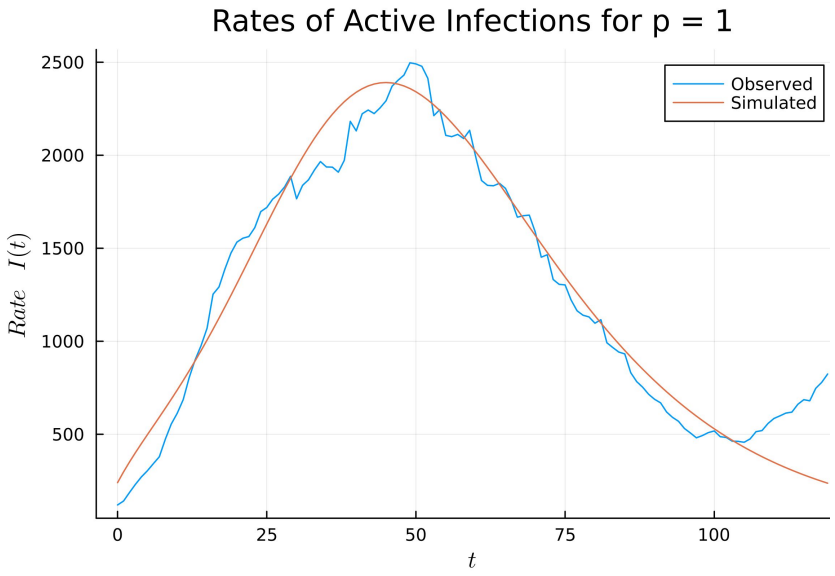
- Average Infectious Period (1/α): 22.2 days

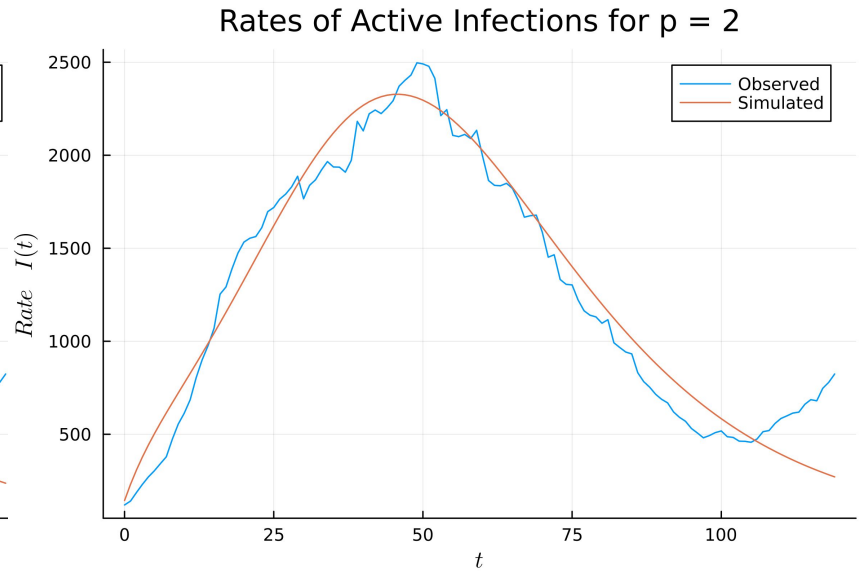
- Average number of close contacts per infected individual (R_0): 26 to 28.5

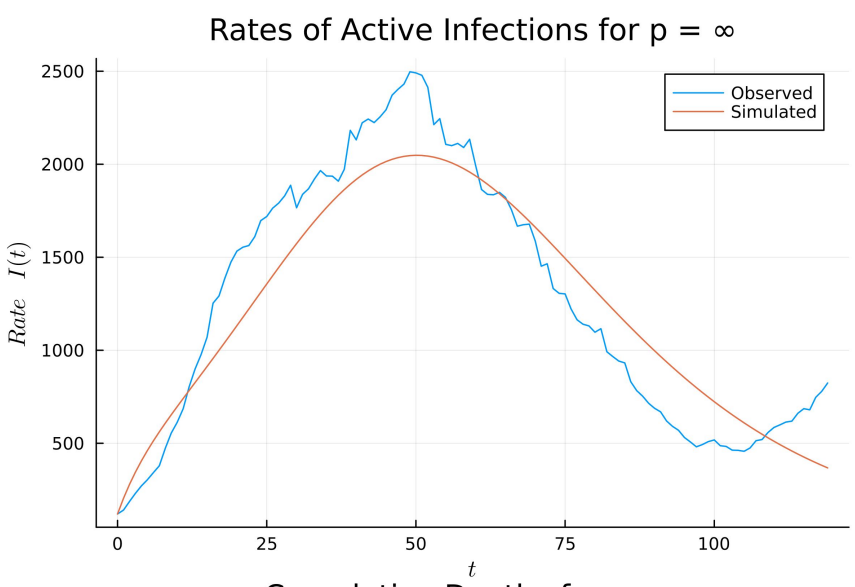
- Average Incubation Period (1/δ) : 10 days (we chose this value)

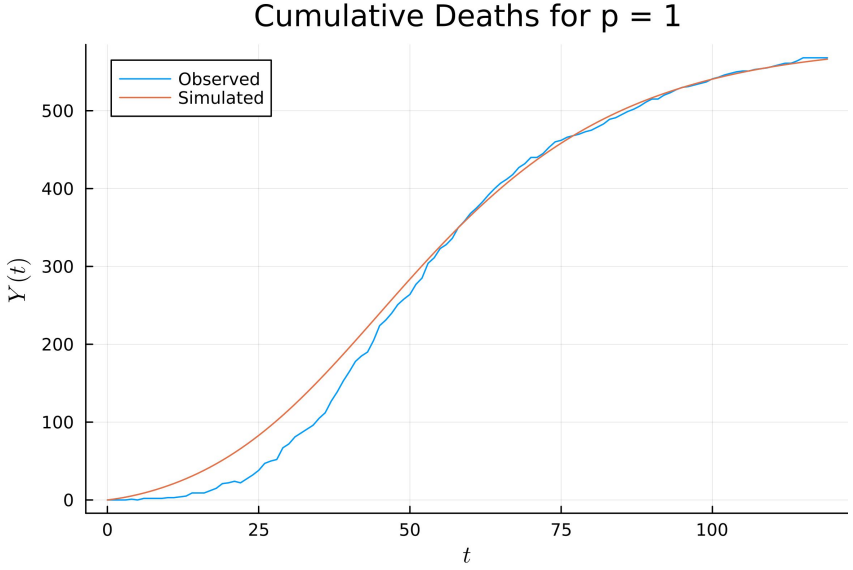
- Death rate (γ): 10.4% to 10.5%

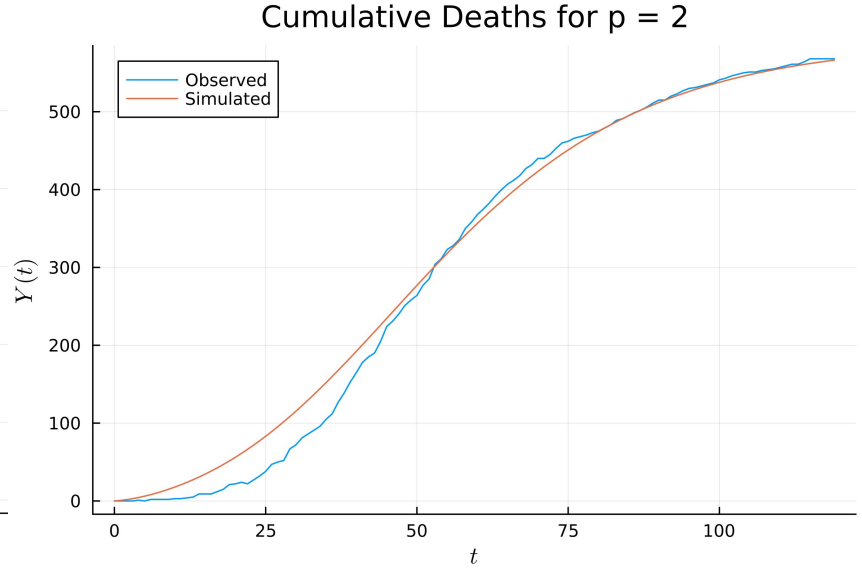
SEIR Model Validation

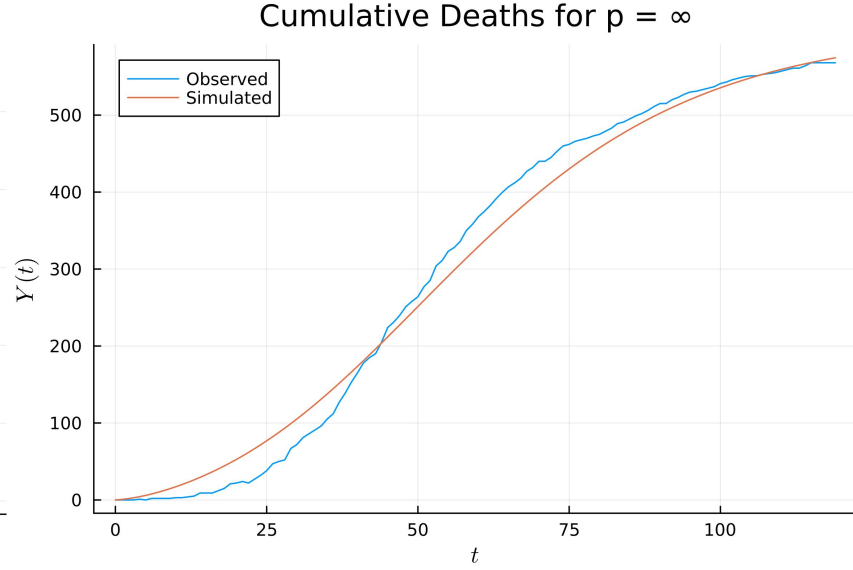








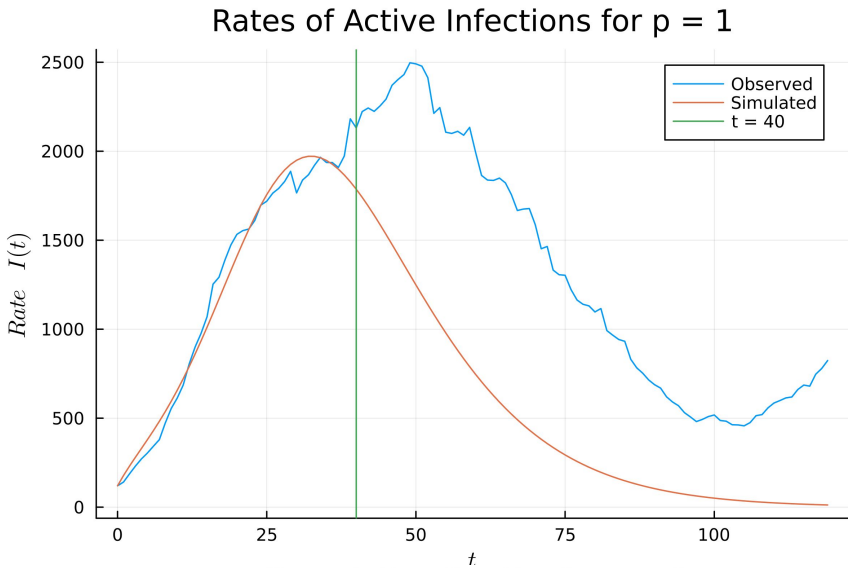


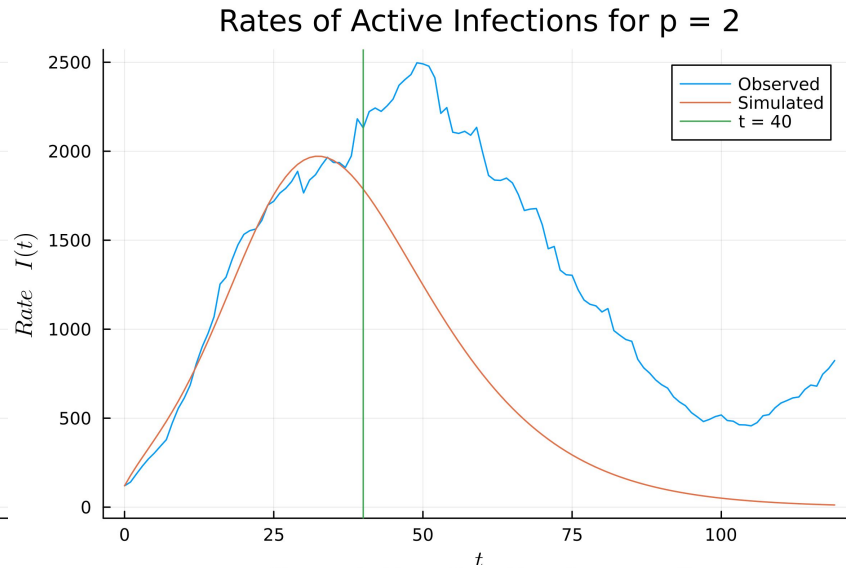


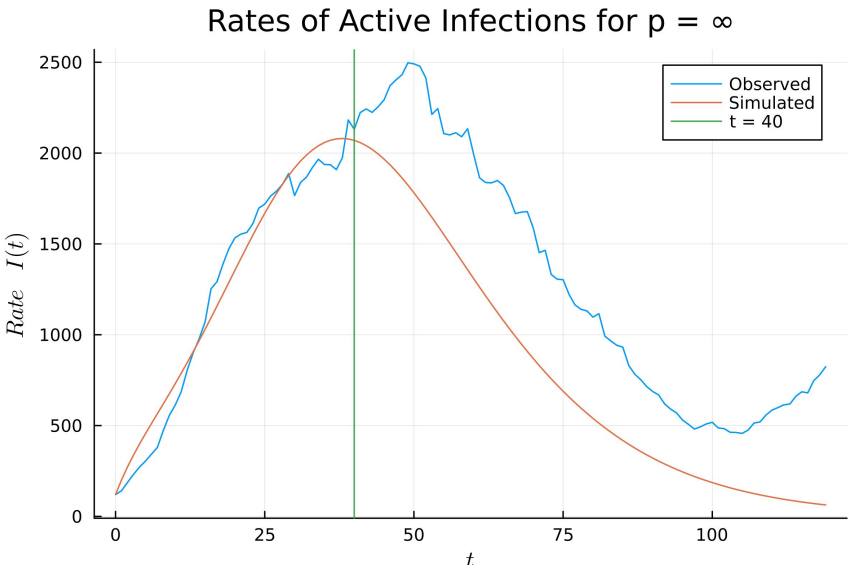
SEIR Model Validation Parameters

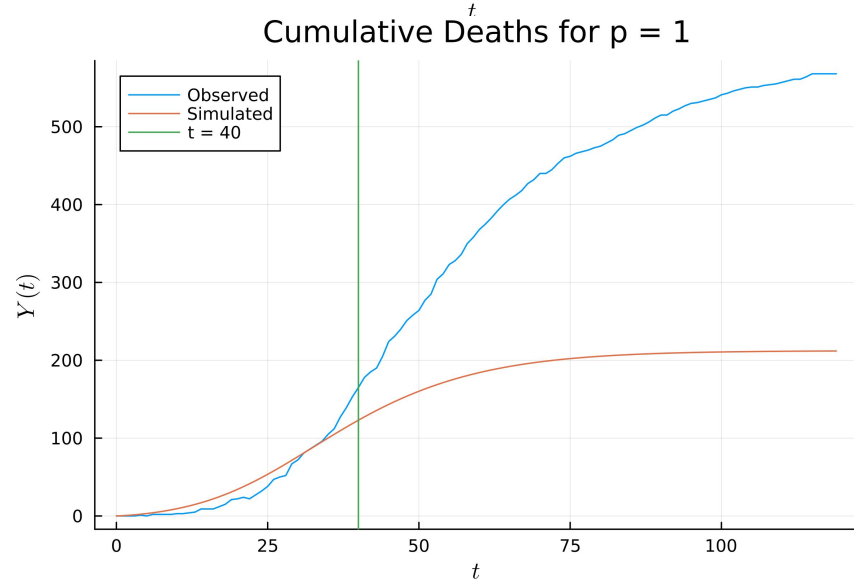
	P = 1	P = 2	P = ∞
α	0.05	0.05	0.05
β	0.22	0.2	0.17
	4.4	4.0	3.4
δ (fixed)	0.1	0.1	0.1
	1%	1%	1%
γ	0.074	0.073	0.078
	2.0	1.2	1.0
	6.0	8.3	8.0
J	16,698	3,170,662	498
	132	132	163

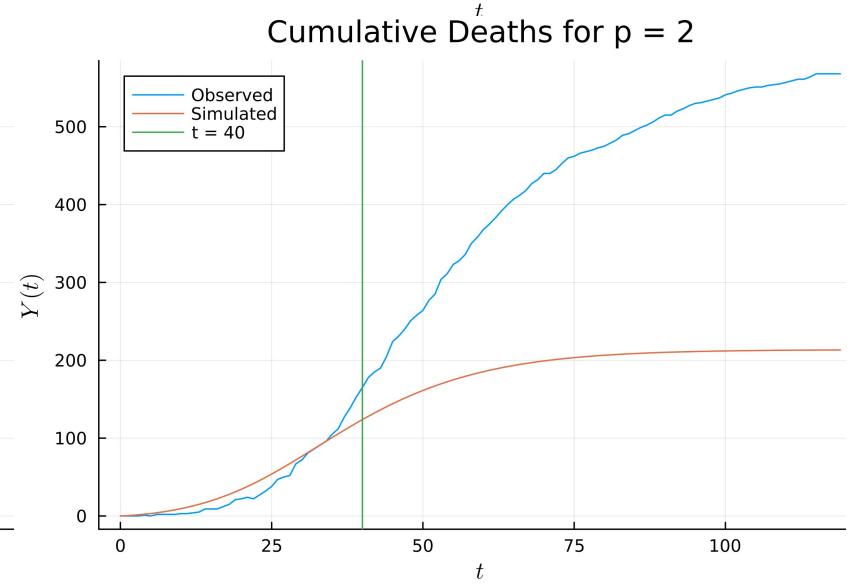
SEIR Model Validation Prediction

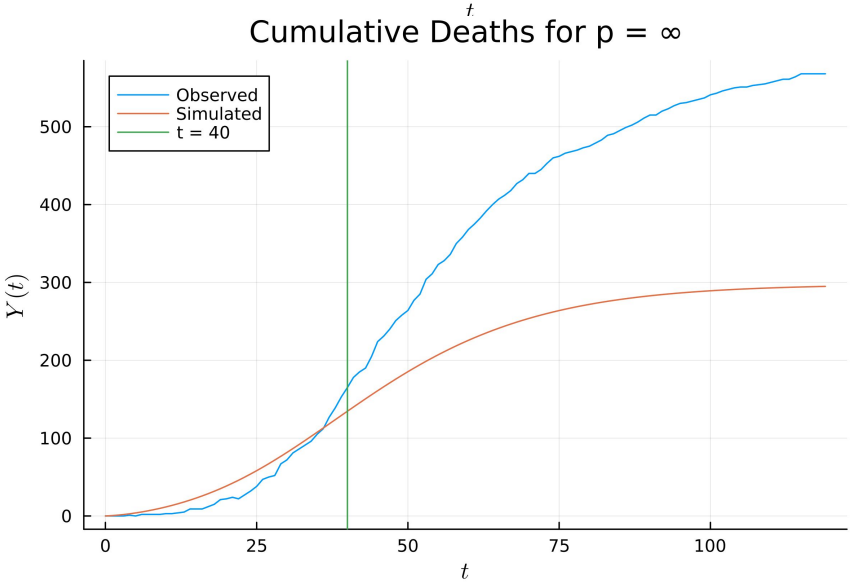












SEIR Model Validation Prediction Parameters

	P = 1	P = 2	P = ∞
α	0.09	0.09	0.07
β	0.45	0.45	0.29
	5.0	5.0	4.2
δ (fixed)	0.1	0.1	0.1
	1%	1%	1%
γ	0.027	0.027	0.037
	1.0	1.0	1.0
	6.0	6.0	7.9
J	3,136	368,520	210

Challenges With Implementation

- Initially were not dividing by the total population when computing the Euler method solution to the differential equation

- Code was running slow for the p=1 case. Finally solved by making it thread-safe and multi-threading