BIO Capstone

Research Question

What is the effect of social distancing (average number of people met per day) on the projected length of COVID-19 epidemic according to the SIRD model (measured in days to end of epidemic)?

Hypothesis

The projected length of the COVID-19 epidemic according to the SIRD model increases with the number of people met per day on average.

The Model

Assumptions

1. Everyone untouched by the virus is initially susceptible.
2. People who recovered from the virus are immune to it forever.
3. The population mixes homogeneously every day.
4. Newborns and death from other causes can be ignored because of their relative significance.
5. All members of the population are identical in likelihood of contracting, spreading, recovering from, or dying from the virus at any time of year.
6. The system is assumed to be closed, meaning there is no influx or outflow of persons.

Mathematical Representation

The SIRD model can be represented by the following equations:

$N=S(t)+I(t)+R(t) +D(t)$

Rate of Change of $S(t) = -\beta I$

Rate of Change of $I(t) = \beta I - \gamma I - \mu I$

Rate of Change of $R(t) = \gamma I$

Rate of Change of $D(t) = \mu I$

$\beta = abS / (N - D) = (abS) / (N - D)$

Independent Variables

b is the number of people an infected person can contact each day. It is used to calculate β and the other rates of change.

Controlled Variables

N is the total population at the beginning of the pandemic. (US Population)

γ is the recovery rate of this disease. $\gamma = 1/D = 1/7.5$ Source of 7.5 day recovery

μ is the mortality rate of this disease. 0.0599 (mortality rate in all cases) / 40 (the data was collected over 40 days) = 0.0014975

a represents the probability a susceptible person is infected after close contact. On average 6.6% of close contacts become infected

Dependent Variable

The dependent variable is the projected length of the epidemic, measured in days. The epidemic is considered to be over when the Infectious population drops below 1000 persons. 1000 persons was chosen because of its relative insignificance to the US population.

Mathematical Functions Explained

S(t) is the population size susceptible to the new disease at given time t measured in persons. The initial starting value is the current estimate of susceptible population. It changes each day according to the equations given above: each day, a certain percentage of the susceptible population gets infected by a member of the infectious population.

I(t) is the population infectious with the new disease at given time t. This initial value is based on current extrapolation of the population that has been tested. Each day, it increases by the new susceptible people infected by the infectious population and decreases by the population that just died or got better that day.

R(t) is the population recovered (and no longer susceptible) to the new disease at the given time t due to immunity. 154000 recovered Each day it increases by the new amount of newly recovered members of the infectious population.

D(t) is the population no longer susceptible to the new disease at given time t due to death. This is the current reported death toll. Each day it increases by the new amount of newly deceased members of the infectious population.

Methodology

The methodology is to use the constants and the independent variable to create estimations of the values for each day for each function. The resulting function values will be parsed for the dependent variable, the day the infectious population decreases below 1000 persons.

A python script written in Python 3.8 using built-in libraries would be used to do the calculations stated above for different values of the independent variable and print the output in CSV format. A copy of the script can be found in the Appendix 1

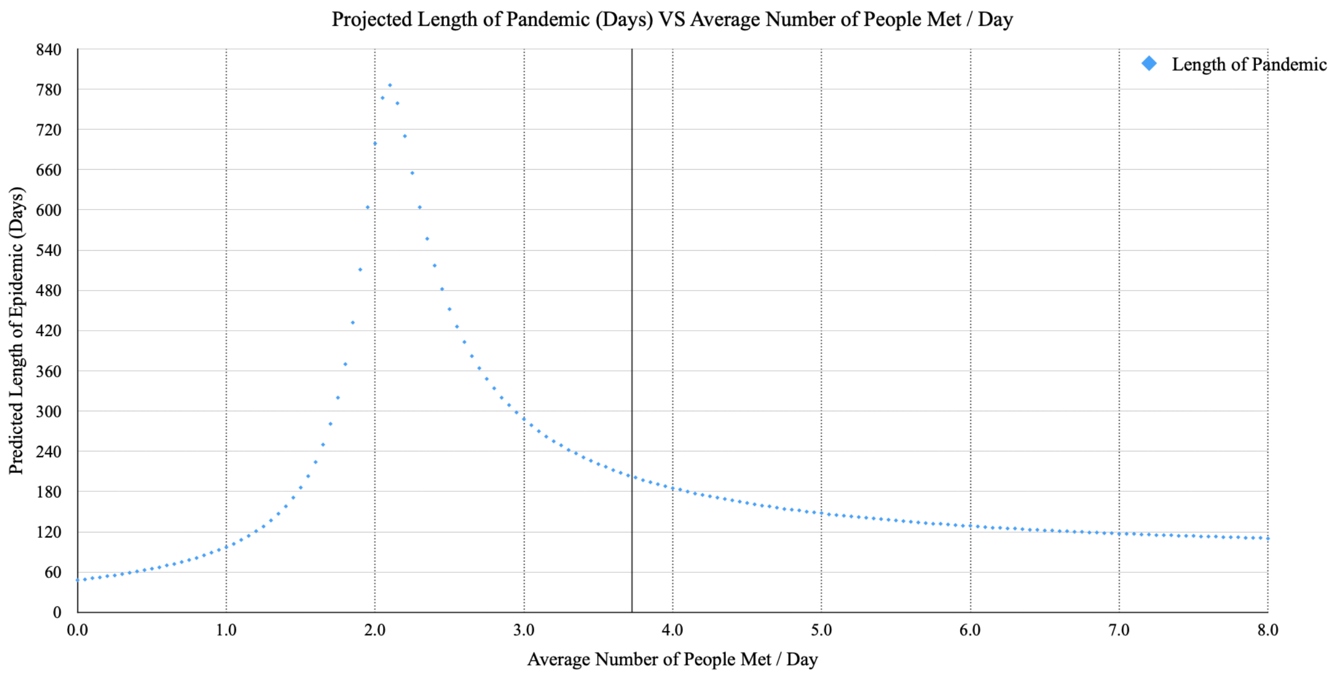
Data Collected

Projected Length of Epidemic VS Average Number of People Met (Partial)

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
0.0	48	Herd Immunity Not Achieved
0.05	49	Herd Immunity Not Achieved
0.1	51	Herd Immunity Not Achieved
0.15	52	Herd Immunity Not Achieved
0.2	54	Herd Immunity Not Achieved
0.25	55	Herd Immunity Not Achieved
0.3	57	Herd Immunity Not Achieved
0.35	59	Herd Immunity Not Achieved
0.4	61	Herd Immunity Not Achieved
0.45	63	Herd Immunity Not Achieved
0.5	65	Herd Immunity Not Achieved

*** The full data table can be found below in Appendix 2**

Graphs



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Claim 1:

The length of the epidemic initially increases when the average number of persons met per day increases because it increases the chances for the virus to spread but not quickly enough to increase the immune population to slow its spread.

Evidence 1:

The projected length of the pandemic is lowest when each member of the population meet less than 1 person on average per day. The projected length of the pandemic is the highest when each member of the population meet about 2.1 persons on average per day.

Reasoning 1:

When people interact very little, the virus has very little chance to spread, thereby the infectious population quickly decreases below 1000 persons because little to no people are infected as the infectious recover. This matches with the data showing that the pandemic is projected to be over the quickest if everyone isolated themselves completely. However, as people meet about 2 other people per day, the virus is able to sustain the infectious population the longest as the newly infectious per day is closest to the number of people deceased or recovered per day initially. This allows the virus to last longer as it delays herd immunity in the country by the longest possible while maintaining a steady number of infectious people.

Claim 2:

The projected length of the epidemic decreases when the avg. amount of people met per day increases above 2.1 persons because herd immunity occurs sooner.

Evidence 2:

The projected length of the pandemic decreases as the amount of people met per day increase above 2.1 persons per day.

Reasoning 2:

Because the increased contact between persons spreads the virus easier, a greater number of people become infected initially but recover and remain immune to the disease. Because of the initial outbreak infects more people, more people are rendered immune to the disease. This slows and eventually halts the spread of the virus, preventing the epidemic from lasting too long. However, this causes a sudden surge in projected infectious population and risks overwhelming hospitals, as well as exposing more people to the virus, increasing total projected deaths.

Strengths & Limitations

Strength

1. It is a simplified model, allow users to make good projections without having to simulate the complex behaviors of a society. This allows the model to be faster and more lightweight.

2. It can accurately predict effects of a new infectious disease in a large population.

Limitations

1. It doesn't account for births or deaths from other causes.

2. It does not account for susceptibility differences in different age groups

3. It cannot model the unique behaviors of a community, which is an issue since the population does not mix homogeneously.

4. It does not account for self-isolation and contact tracing.

Appendix 1

```
import array
 #total population
N = 328200000
#initial Infectious population
initialInfectious = 1470000-260000-88199
#initial Recovered population
initialRecovered = 260000
#Probability at which people recover each day. Symptoms end on average after
7.5 days with a (1 - 5.3%) chance of recovery
gamma = 1/7.5
#Probability at which people die each day. Symptoms end on average after 7.5
days with a 5.3% chance of death
mu = 0.0599/40
#Probability person gets infected after close contact
a = 0.066

HIT=0.74

def sim(b_input,N,initialInfectious,initialRecovered,gamma,mu,a):
    Susceptible = array.array('d', [N-initialInfectious-initialRecovered])
#Initial Population of succeptible persons
    Infectious = array.array('d', [initialInfectious])
    Recovered = array.array('d', [initialRecovered])
    Deceased = array.array('d', [0])
    days=0
#    if b_input != 0:
#        R0=a*b_input*14
#        HIT=1-1/float(R0)
#    else:
#        HIT=0
    #simulate a day of interactions if the count of Infectious population >= 1
    for i in range(1,36500):
        #calculate changes in each population
        beta = float(a * b_input * Susceptible[len(Susceptible)-1]) / (N -
Deceased[len(Deceased)-1])
        newSusceptible = Susceptible[len(Susceptible)-1] - round(beta *
Infectious[len(Infectious)-1])
        newRemoved = round(gamma * Infectious[len(Infectious)-1]) + round(mu *
Infectious[len(Infectious)-1])
        newInfectious = Infectious[len(Infectious)-1] + round(beta *
Infectious[len(Infectious)-1]) - newRemoved
        newRecovered = Recovered[len(Recovered)-1] + round(gamma *
Infectious[len(Infectious)-1])
        newDeceased = Deceased[len(Deceased)-1] + round(mu *
Infectious[len(Infectious)-1])
```

```
        #record resulting statistic of each population of that day
        Susceptible.append(newSusceptible)
        Infectious.append(newInfectious)
        Recovered.append(newRecovered)
        Deceased.append(newDeceased)
        if(Infectious[len(Infectious)-1] > 1000):
        #if(newInfectious > 100) and (Recovered[len(Recovered)-1]<=HIT*N):
            days=days+ 1
        else:
            if (Recovered[len(Recovered)-1]<=HIT*N):
                print(","+str(b_input) + ","+ str(days) + ",Herd Immunity Not
Achieved" +
                      +", about
"+str(round(Deceased[len(Deceased)-1]/float(24280000)*100,4)) + "% the Shanghai
population died")
                break
            #print( str(float(b_input)) + "," + str(days) + ","+
str(round(Deceased[len(Deceased)-1],0)) )
            else:
                print(","+str(b_input) + ","+ str(days) + ",Herd Immunity
Achieved"
                      +", about
"+str(round(Deceased[len(Deceased)-1]/float(24280000)*100,4)) + "% the Shanghai
population died")
                break

#print the contact/day, total days until infection ends, maximum infectious
population, deceased population increase in CSV format

#simulate contact/day from 0 to 500 per day
for i in range(0,161):
    sim(float(i)/20,N,initialInfectious,initialRecovered,gamma,mu,a)
```

Appendix 2

Projected Length of Epidemic VS Average Number of People Met (Full)

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
0.0	48	Herd Immunity Not Achieved
0.05	49	Herd Immunity Not Achieved
0.1	51	Herd Immunity Not Achieved
0.15	52	Herd Immunity Not Achieved
0.2	54	Herd Immunity Not Achieved
0.25	55	Herd Immunity Not Achieved
0.3	57	Herd Immunity Not Achieved
0.35	59	Herd Immunity Not Achieved
0.4	61	Herd Immunity Not Achieved
0.45	63	Herd Immunity Not Achieved
0.5	65	Herd Immunity Not Achieved
0.55	67	Herd Immunity Not Achieved
0.6	70	Herd Immunity Not Achieved
0.65	72	Herd Immunity Not Achieved

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
0.7	75	Herd Immunity Not Achieved
0.75	78	Herd Immunity Not Achieved
0.8	81	Herd Immunity Not Achieved
0.85	85	Herd Immunity Not Achieved
0.9	89	Herd Immunity Not Achieved
0.95	93	Herd Immunity Not Achieved
1.0	97	Herd Immunity Not Achieved
1.05	102	Herd Immunity Not Achieved
1.1	108	Herd Immunity Not Achieved
1.15	114	Herd Immunity Not Achieved
1.2	121	Herd Immunity Not Achieved
1.25	128	Herd Immunity Not Achieved
1.3	137	Herd Immunity Not Achieved
1.35	147	Herd Immunity Not Achieved

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
1.4	158	Herd Immunity Not Achieved
1.45	171	Herd Immunity Not Achieved
1.5	186	Herd Immunity Not Achieved
1.55	203	Herd Immunity Not Achieved
1.6	224	Herd Immunity Not Achieved
1.65	250	Herd Immunity Not Achieved
1.7	281	Herd Immunity Not Achieved
1.75	320	Herd Immunity Not Achieved
1.8	370	Herd Immunity Not Achieved
1.85	432	Herd Immunity Not Achieved
1.9	511	Herd Immunity Not Achieved
1.95	604	Herd Immunity Not Achieved
2.0	699	Herd Immunity Not Achieved
2.05	767	Herd Immunity Not Achieved

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
2.1	786	Herd Immunity Not Achieved
2.15	759	Herd Immunity Not Achieved
2.2	710	Herd Immunity Not Achieved
2.25	655	Herd Immunity Not Achieved
2.3	604	Herd Immunity Not Achieved
2.35	557	Herd Immunity Not Achieved
2.4	517	Herd Immunity Not Achieved
2.45	482	Herd Immunity Not Achieved
2.5	452	Herd Immunity Not Achieved
2.55	426	Herd Immunity Not Achieved
2.6	403	Herd Immunity Not Achieved
2.65	382	Herd Immunity Not Achieved
2.7	364	Herd Immunity Not Achieved
2.75	348	Herd Immunity Not Achieved

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
2.8	334	Herd Immunity Not Achieved
2.85	320	Herd Immunity Not Achieved
2.9	309	Herd Immunity Not Achieved
2.95	298	Herd Immunity Not Achieved
3.0	288	Herd Immunity Not Achieved
3.05	279	Herd Immunity Not Achieved
3.1	270	Herd Immunity Not Achieved
3.15	262	Herd Immunity Not Achieved
3.2	255	Herd Immunity Not Achieved
3.25	249	Herd Immunity Not Achieved
3.3	242	Herd Immunity Not Achieved
3.35	237	Herd Immunity Not Achieved
3.4	231	Herd Immunity Not Achieved
3.45	226	Herd Immunity Not Achieved

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
3.5	221	Herd Immunity Not Achieved
3.55	217	Herd Immunity Not Achieved
3.6	212	Herd Immunity Not Achieved
3.65	208	Herd Immunity Not Achieved
3.7	204	Herd Immunity Not Achieved
3.75	201	Herd Immunity Achieved
3.8	197	Herd Immunity Achieved
3.85	194	Herd Immunity Achieved
3.9	191	Herd Immunity Achieved
3.95	188	Herd Immunity Achieved
4.0	185	Herd Immunity Achieved
4.05	183	Herd Immunity Achieved
4.1	180	Herd Immunity Achieved
4.15	177	Herd Immunity Achieved
4.2	175	Herd Immunity Achieved
4.25	173	Herd Immunity Achieved
4.3	171	Herd Immunity Achieved
4.35	169	Herd Immunity Achieved
4.4	167	Herd Immunity Achieved
4.45	165	Herd Immunity Achieved
4.5	163	Herd Immunity Achieved

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
4.55	161	Herd Immunity Achieved
4.6	159	Herd Immunity Achieved
4.65	158	Herd Immunity Achieved
4.7	156	Herd Immunity Achieved
4.75	154	Herd Immunity Achieved
4.8	153	Herd Immunity Achieved
4.85	152	Herd Immunity Achieved
4.9	150	Herd Immunity Achieved
4.95	149	Herd Immunity Achieved
5.0	148	Herd Immunity Achieved
5.05	146	Herd Immunity Achieved
5.1	145	Herd Immunity Achieved
5.15	144	Herd Immunity Achieved
5.2	143	Herd Immunity Achieved
5.25	142	Herd Immunity Achieved
5.3	141	Herd Immunity Achieved
5.35	140	Herd Immunity Achieved
5.4	139	Herd Immunity Achieved
5.45	138	Herd Immunity Achieved
5.5	137	Herd Immunity Achieved
5.55	136	Herd Immunity Achieved
5.6	135	Herd Immunity Achieved
5.65	134	Herd Immunity Achieved
5.7	133	Herd Immunity Achieved

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
5.75	132	Herd Immunity Achieved
5.8	132	Herd Immunity Achieved
5.85	131	Herd Immunity Achieved
5.9	130	Herd Immunity Achieved
5.95	129	Herd Immunity Achieved
6.0	129	Herd Immunity Achieved
6.05	128	Herd Immunity Achieved
6.1	127	Herd Immunity Achieved
6.15	126	Herd Immunity Achieved
6.2	126	Herd Immunity Achieved
6.25	125	Herd Immunity Achieved
6.3	125	Herd Immunity Achieved
6.35	124	Herd Immunity Achieved
6.4	123	Herd Immunity Achieved
6.45	123	Herd Immunity Achieved
6.5	122	Herd Immunity Achieved
6.55	122	Herd Immunity Achieved
6.6	121	Herd Immunity Achieved
6.65	121	Herd Immunity Achieved
6.7	120	Herd Immunity Achieved
6.75	120	Herd Immunity Achieved
6.8	119	Herd Immunity Achieved
6.85	119	Herd Immunity Achieved
6.9	118	Herd Immunity Achieved

Avg. People Met/Day	Predicted Length of Epidemic (Days)	Observations
6.95	118	Herd Immunity Achieved
7.0	117	Herd Immunity Achieved
7.05	117	Herd Immunity Achieved
7.1	117	Herd Immunity Achieved
7.15	116	Herd Immunity Achieved
7.2	116	Herd Immunity Achieved
7.25	115	Herd Immunity Achieved
7.3	115	Herd Immunity Achieved
7.35	115	Herd Immunity Achieved
7.4	114	Herd Immunity Achieved
7.45	114	Herd Immunity Achieved
7.5	114	Herd Immunity Achieved
7.55	113	Herd Immunity Achieved
7.6	113	Herd Immunity Achieved
7.65	113	Herd Immunity Achieved
7.7	112	Herd Immunity Achieved
7.75	112	Herd Immunity Achieved
7.8	112	Herd Immunity Achieved
7.85	111	Herd Immunity Achieved
7.9	111	Herd Immunity Achieved
7.95	111	Herd Immunity Achieved
8.0	110	Herd Immunity Achieved