Final Project Presentation
ENSE 622

Pandemic Simulation

(Based on Available Covid-19 Data)

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Analysis Goals

- To simulate the pandemic spread in the United States of America. Spread refers to the total number of confirmed cases and causalities one can expect to see based on available data and trend.

- To decide on the best course of action between opening up the economy and social distancing.

- To explore how hard the decision making process is.

Key Metrics and Factors

- Number of Cumulative Confirmed Cases (N(d))

Denotes the total number of confirmed cases of Covid-19 on day d, in United States from the day first case was confirmed (22 January for our case).

- Number of Cumulative Death Cases

Denotes the total number of death cases of Covid-19 on day d, in United States from the day first case was confirmed.

- Number of Cumulative Recovered Cases

Denotes the total number of recovered cases of Covid-19 on day d, in United States from the day first case was confirmed.

- Growth Factor

Factor by which cumulative confirmed cases increases on day d+1, based on the cumulative confirmed cases on day d.

Mathematically,

$$\text{Growth Factor} = N(d+1)/N(d)$$

Key Metrics and Factors

- Infection Probability (p)

Probability of an exposure with a Covid-19 positive person to become an infection.

- Exposure factor (E)

Average Number of people a Covid-19 positive person is exposed to each day.

For the rest of the presentation we would be using **pE** parameter. pE is the product of Infection Probability (p) and Exposure Factor (E). pE is an indication of “lockdown” or “mitigation” measures.

- Initial Unemployment Claims (IUC4)

Initial Claims are an employment report that measures the number of new jobless claims filed by individuals seeking to receive unemployment benefits.

Higher initial claims correlate with a weakening economy. Initial claims typically rise before the economy enters a recession and decline before the economy starts to recover*.

* Credits: Investopedia

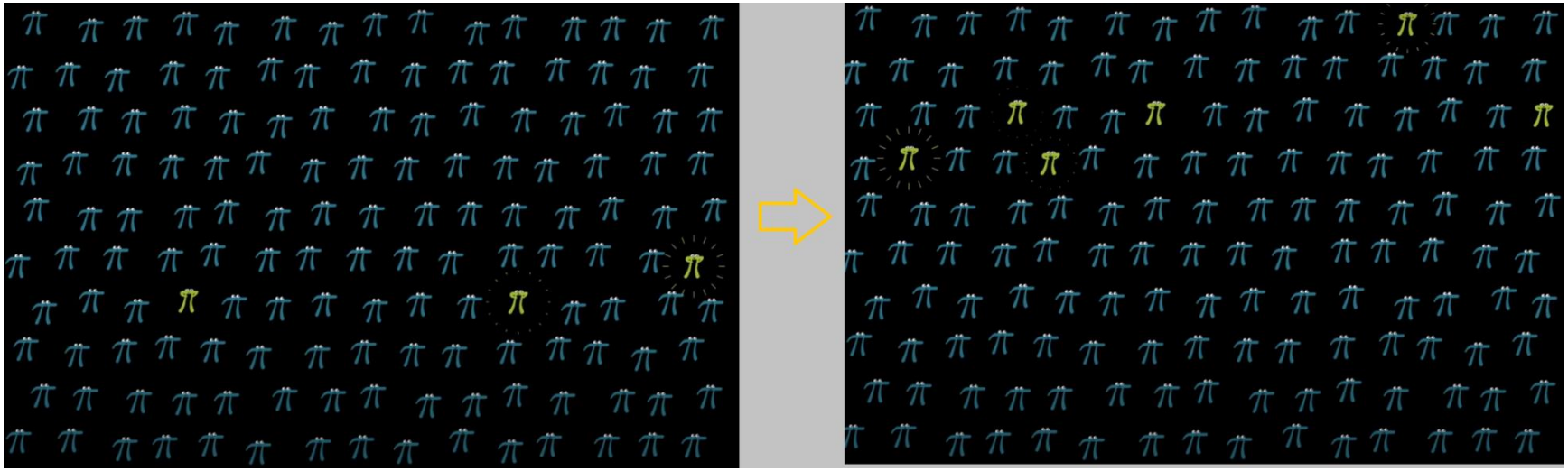
Environment Description

The simulation is based upon random shuffle. For the model it is assumed that a Covid-19 positive person is exposed to a random set of people, who may or may not get infected after the exposure.

The probability of an exposure becoming an infection is given by p, and the average number of people a covid-19 positive person interacts with is given by E.

Please note that for this model, the infected person may interact with any random subset of the US population. But in reality, the population is clustered with limited interaction between them…a more detailed simulation would simulate the effects small clusters based on random shuffle model and then collate the results.

Environment Description



Credits : 3Blue1Brown

Design Options

λ	Cum. Confirmed Cases	Cum. Death Cases	IUC4
0.2	1568642	85107	5000000
0.25	1778621	96562	4550000
0.3	2014024	109404	4100000
0.35	2277616	123783	3650000
0.4	2572426	139866	3200000
0.45	2901767	157832	2750000
0.5	3269260	177880	2300000
0.55	3678859	200224	1850000
0.6	4134870	225101	1400000
0.65	4641980	252765	950000
0.7	5205282	283494	500000

Key Assumptions

- The Simulation is based on Random Shuffle. It assumes that a covid-19 positive person interacts with a random subset of US population.

- The product of infection probability (p) and Exposure Factor (E), represented by “pE” is an indication of lockdown or mitigation efforts. The product pE decreases with the mitigation efforts and increases with the lack of it.

- The mitigation efforts include lockdown orders…tracing , tracking and isolation of covid-19 positive patients.

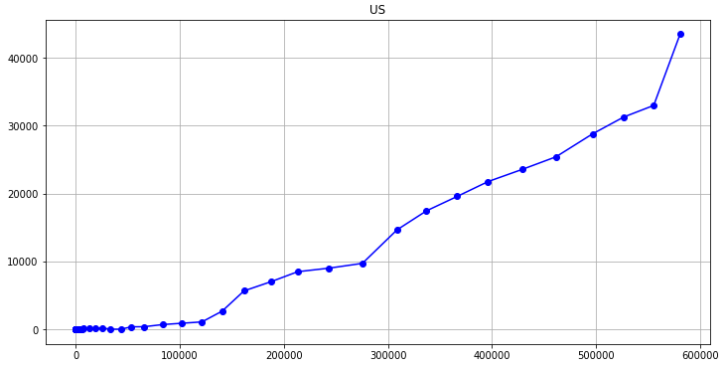
- The Growth Factor decreases with the increase in the mitigation effort.

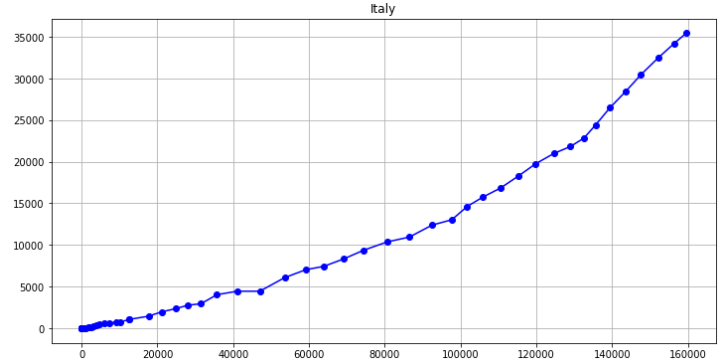
- The Growth factor follows an exponential probability density.

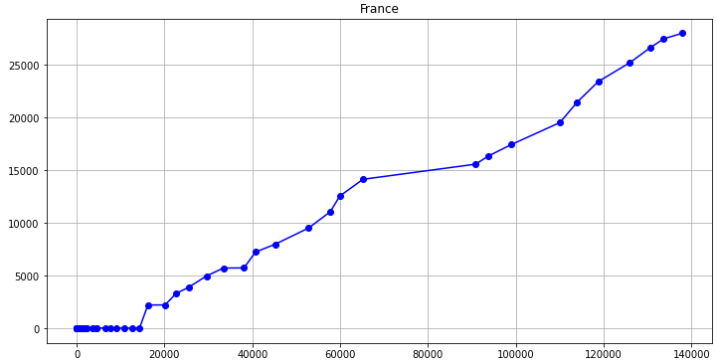
- The cumulative number of recovered and death cases linearly vary with the cumulative number of confirmed cases and number of days since the first confirmed case in the United States.

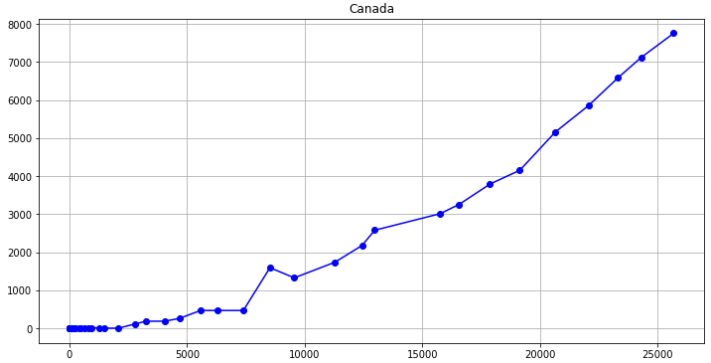
Rationale for Key Assumptions

Cumulative Recovered cases vs Cumulative Confirmed Cases



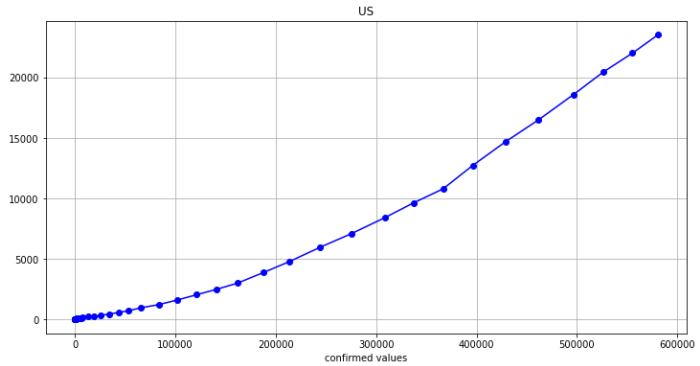


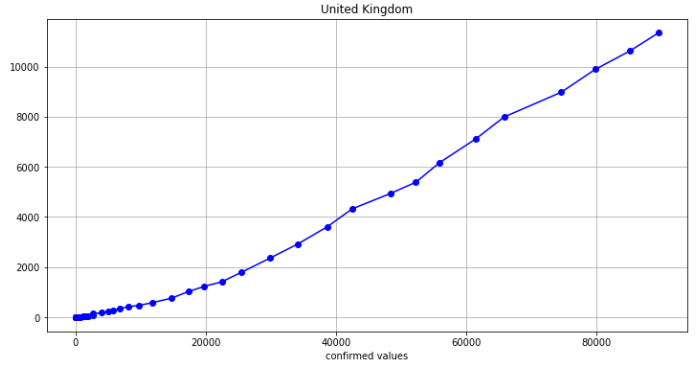


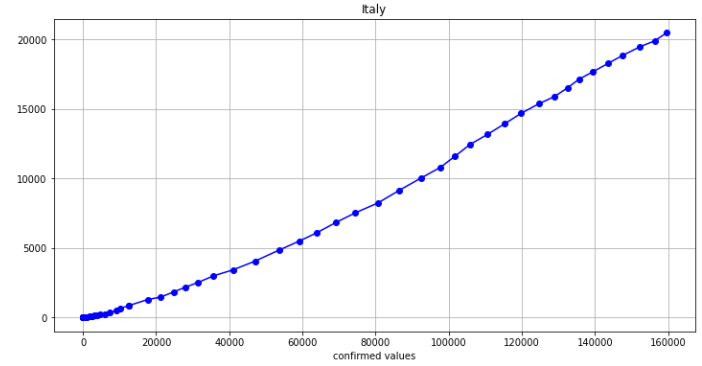


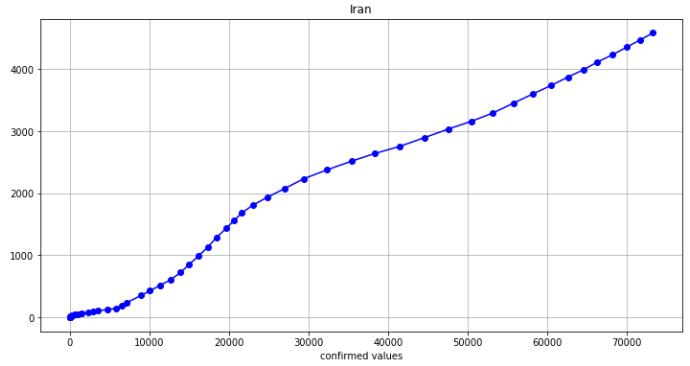
Rationale for Key Assumptions

Cumulative Death cases vs Cumulative Confirmed Cases





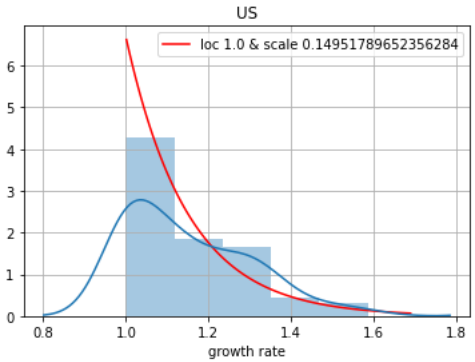


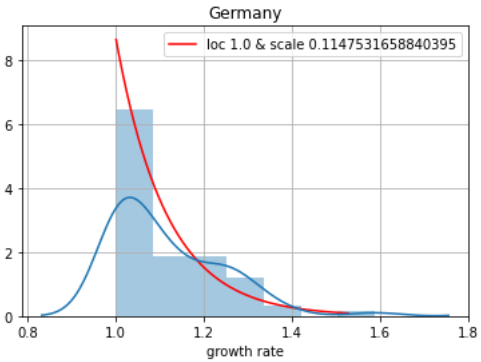


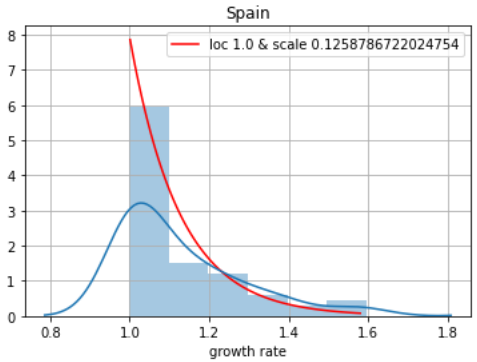
Rationale for Key Assumptions

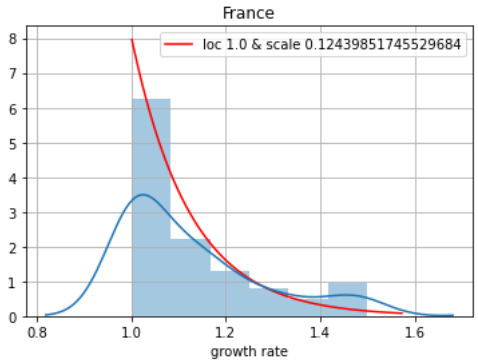
Growth Factor Probability Density

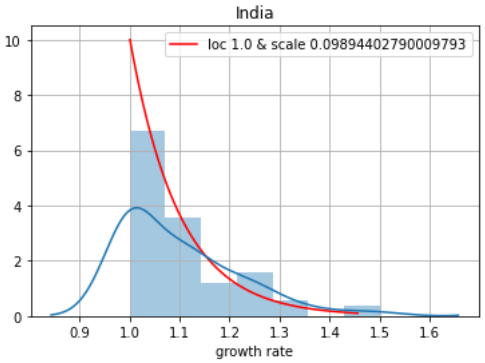
(Histogram shows the actual observed growth factor values and the red plot is an approximation to it)

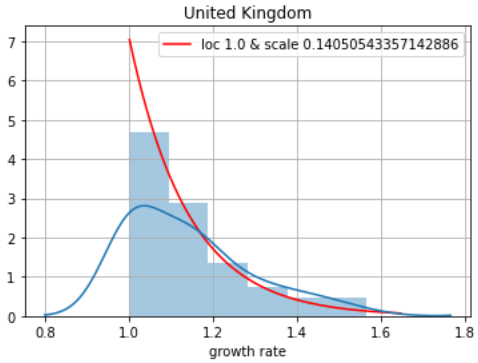












Key Equations

- $N(d+1) = N(d) + \Delta N(d+1)$
- $\Delta N(d+1) = N(d)pE$

N(d+1) is the cumulative confirmed cases on day d+1 and N(d) is the cumulative confirmed cases on day d.

p is the infection probability and E is the exposure factor.

The equation says that the change in cumulative confirmed cases on day d+1 is directly proportional to the cumulative confirmed cases on day d, infection probability and Exposure factor.

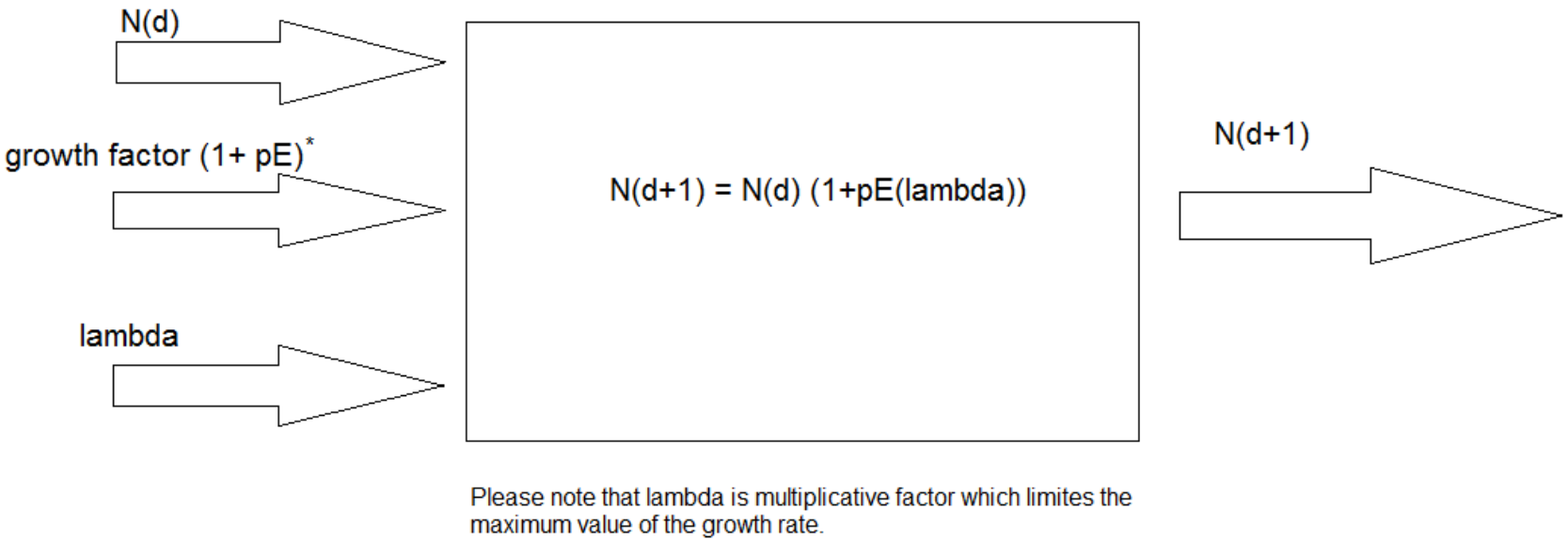
- $N^*(d) = A(N(d)) + B(d) + C,$

where, A, B and C are constant. N*(d) is the number of death cases or recovered cases. This essentially tells that the cumulative number of death cases or recovered cases is a linear combination of cumulative confirmed cases and number of days since the first case was confirmed.

- Growth Factor = $N(d+1) / N(d) = 1+pE(\boldsymbol{\lambda})^*$

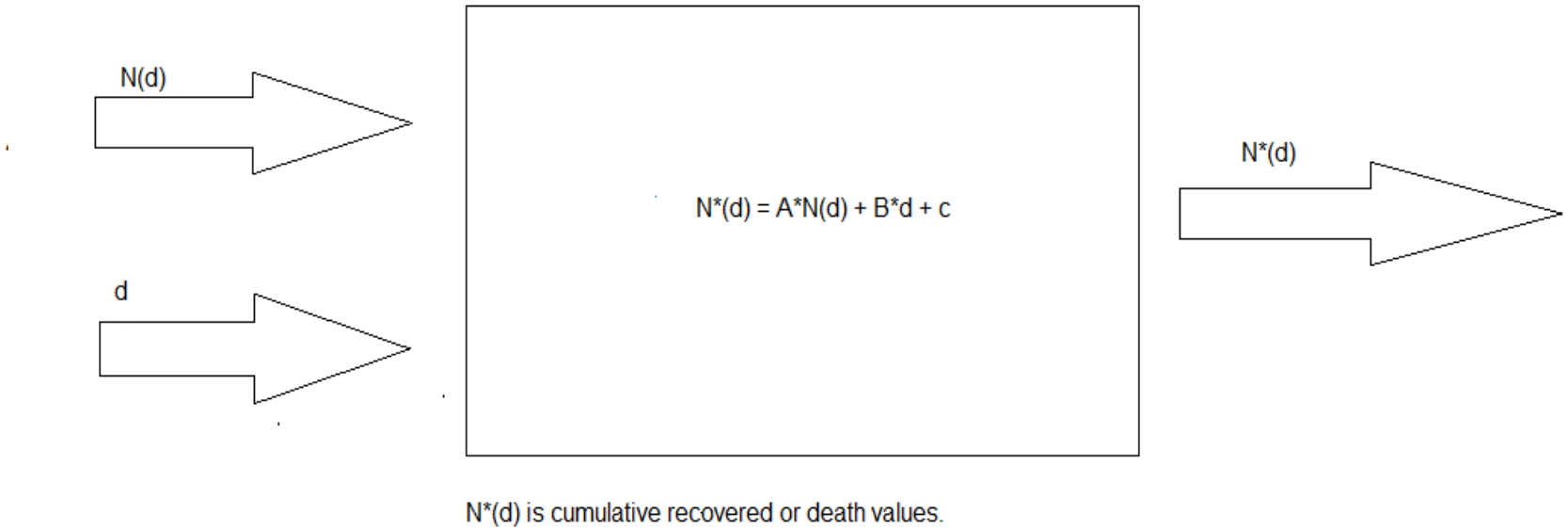
Lambda is a multiplicative factor that limits the max value of pE. The Growth factor obtained is from a probability density that is based on the past data. The lambda is assumed to be equal to 1 for past cases. It is assumed that with the proper mitigation efforts, the max value of growth factor would decrease in the future…to take that into account pE is multiplied by $\boldsymbol{\lambda}$.

Response Model Diagram



Growth factor is extracted from the probability distribution.

Response Model Diagram



N*(d) is cumulative recovered or death values.

Analysis Approach

- The growth factor on day d+1, is extracted from the exponential probability density. The parameters for the probability density are obtained using the available data for covid-19 pandemic.

- The growth factor on day d+1 is randomly selected from the exponential probability density.

- Based on the cumulative number of confirmed cases and number of days since the first case was confirmed in the United States, cumulative number of death and recovered cases is approximated based on Linear Regression.

- The regression parameters are also calculated based upon the data available for covid-19 pandemic.

- The simulation assumes a fixed number of confirmed cases on day0*, then draws growth factor randomly from the exponential probability density to calculate the cumulative number of confirmed cases on day1, this process is then subsequently repeated for d days.

*Please note that the number of cases on day 0 is a hyper parameter that is adjusted and provided by the user.

Analysis Approach

- The number of death cases and recovered cases are derived from the cumulative confirmed cases predicted by the model. (using the Linear Regression parameters calculated earlier)

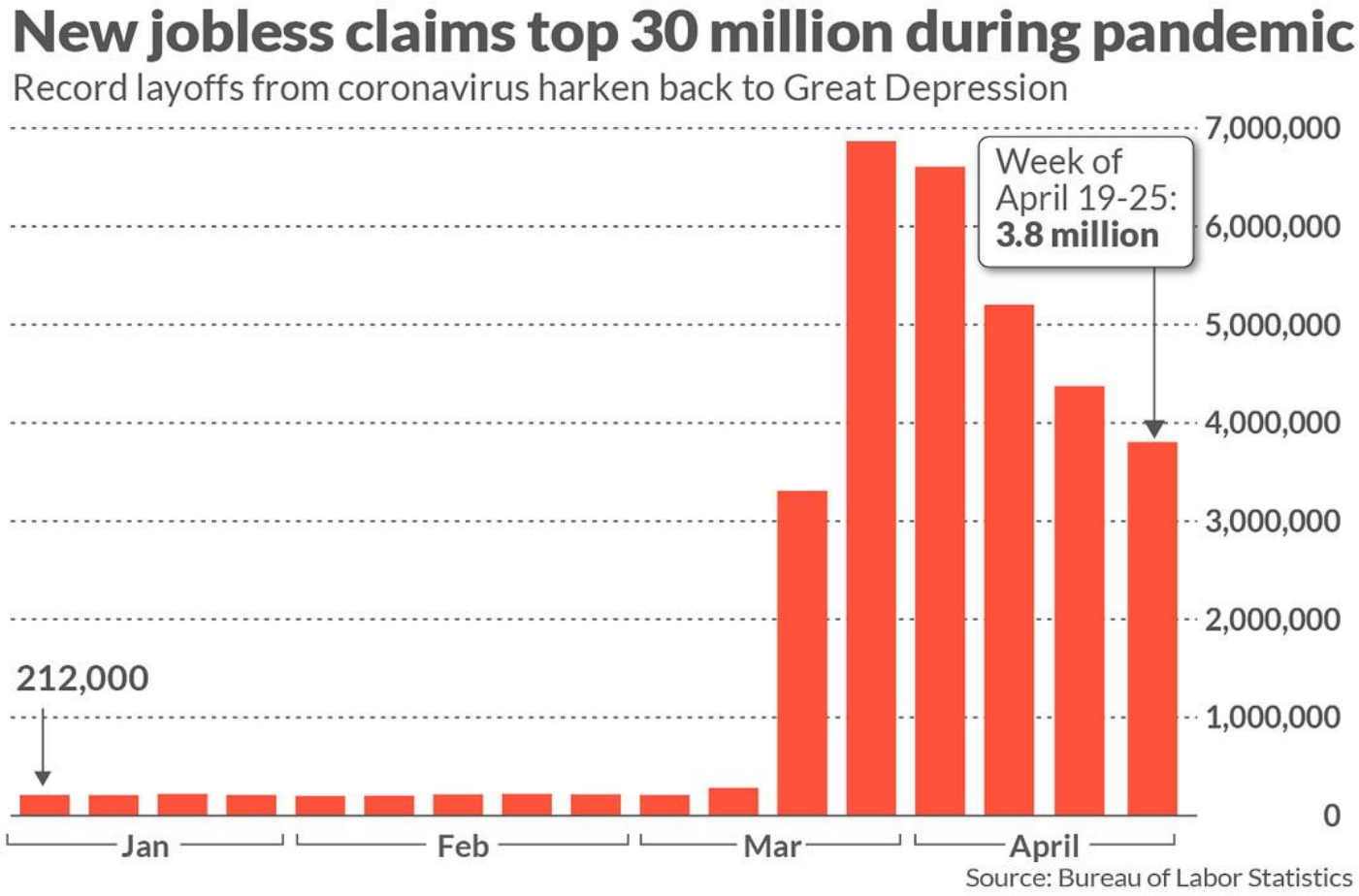
- The trade-off analysis is done between the Initial Unemployment claims (4 weeks moving average) and number of death cases calculated by the model.

- The 4 week moving average of initial unemployment claims is taken from the Bureau of Labour Statistics. It is assumed that the numbers reported by the BLS are for the present scenario (last week of March to April first week) when all the mitigation efforts are in place and enforced severely.

- The trade- off analysis explores the scenario after 28 days (from day93)…it models confirmed values, death values and unemployment claims at the 4 week end with different $\boldsymbol{\lambda}$ parameters.

*Please note that the $\boldsymbol{\lambda}$ parameter reflects the mitigation efforts. If economy is opened up the $\boldsymbol{\lambda}$ parameter increases and IUC4 values decline.

Analysis Approach



4 weeks moving average April 25, 2020 5,035.00 * 1000

Models, Simulation and Techniques Overview

- Monte – Carlo Simulation

The Monte Carlo simulation is used to calculate the cumulative number of confirmed cases (CC) on a given day. The model starts with a constant value of confirmed cases on Day0, then draws the growth factor from the exponential probability distribution to calculate the CC value on next day.

- Linear- Regression Model

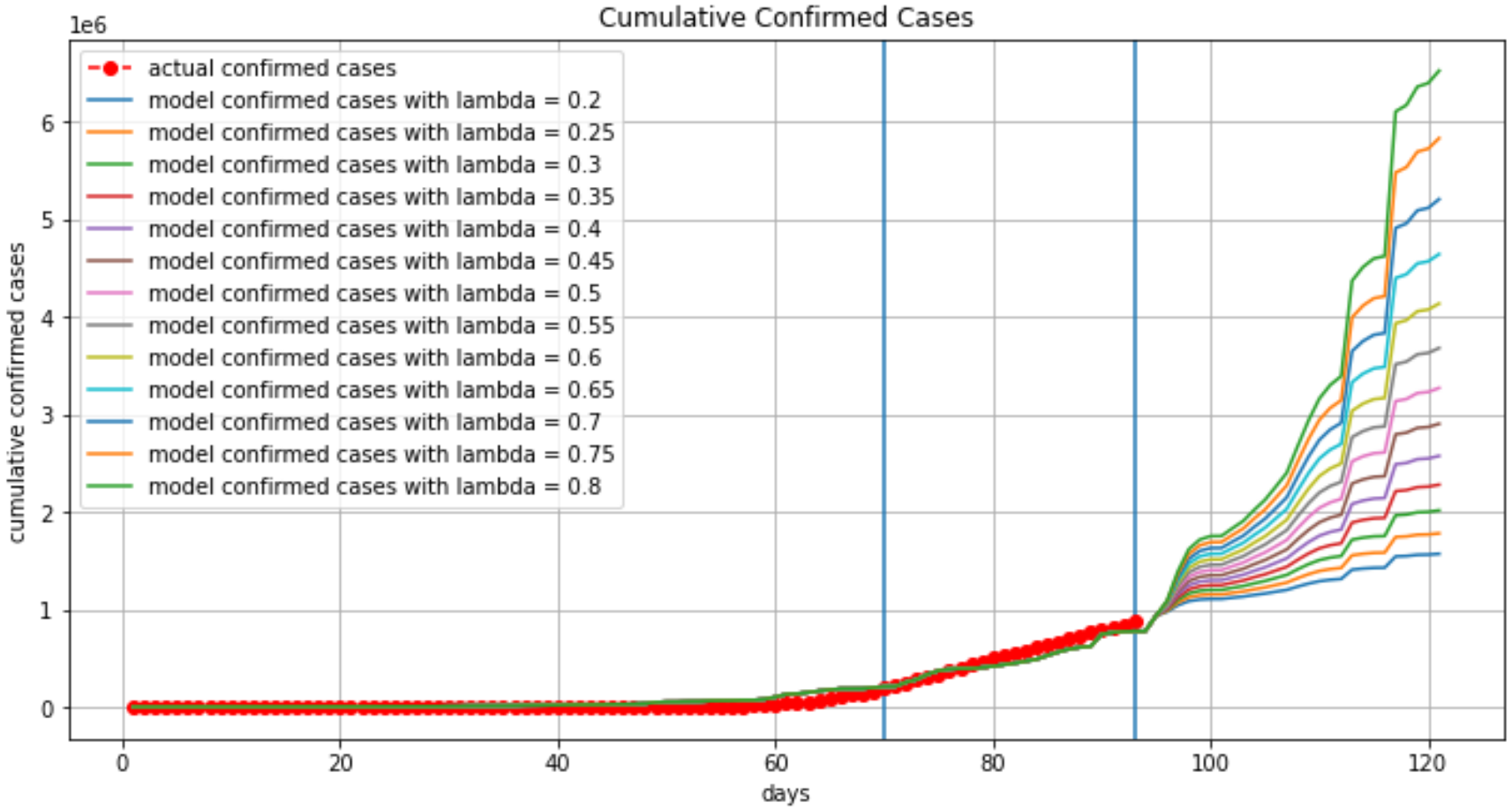
The number of death and recovered values are calculated using linear regression. The parameters for the regression are calculated based on the present available data. The regression model takes the cumulative number of confirmed cases and number of days as input and outputs the cumulative number of death or recovered cases.

- Inv-Proportional Model

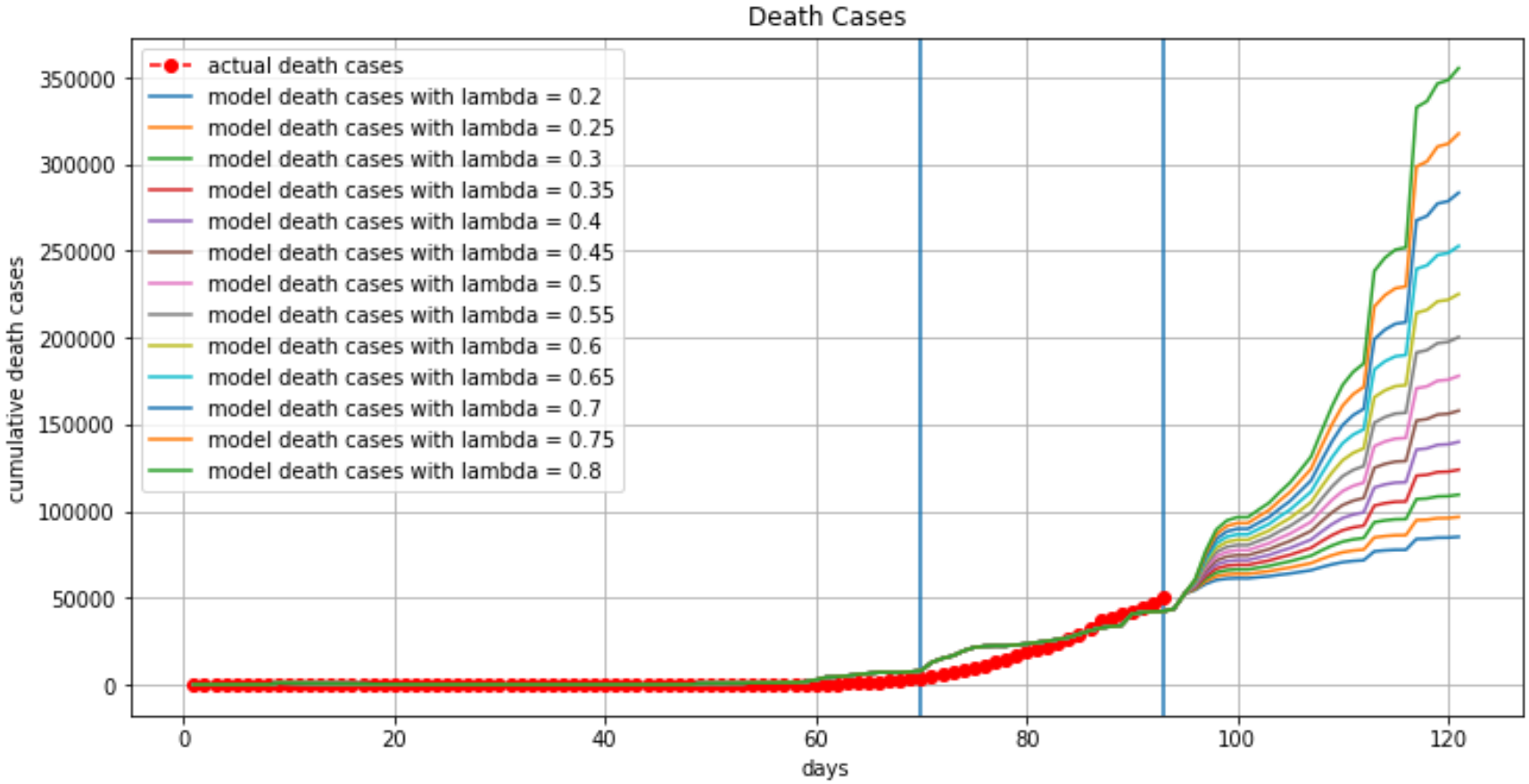
The IUC4 value for the state when the full lockdown and mitigation measures are into effect are taken from the data reported by BLS on 25th April 2020. These numbers reflect the IUC4 values when the state is under full lock-down ($\boldsymbol{\lambda}$ <= 0.2).

The max value of $\boldsymbol{\lambda}$ is taken to be equal to or greater than 0.7…that reflects the case when all the restrictions by the state are lifted.

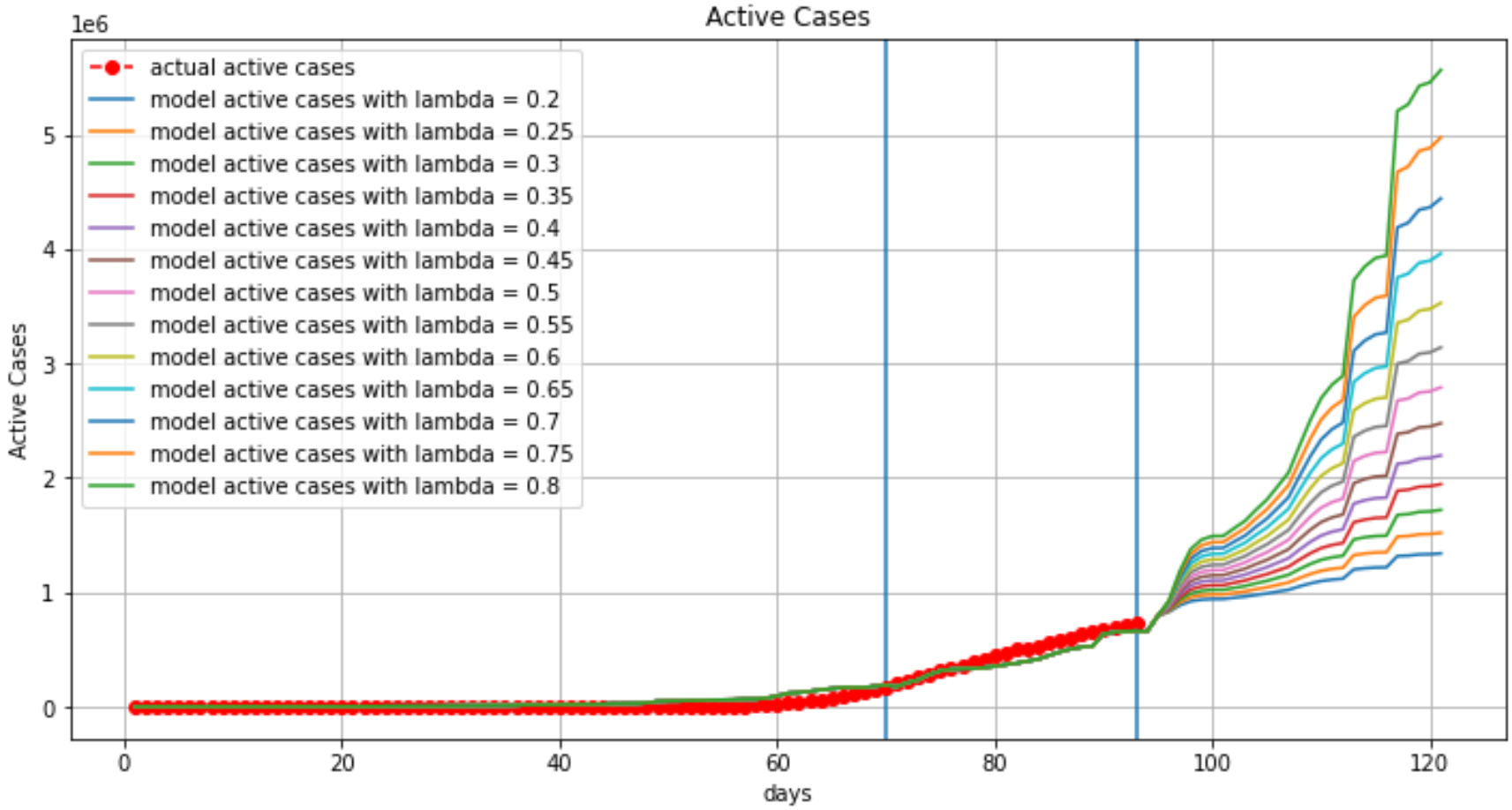
Summary of Analysis Results



Summary of Analysis Results



Summary of Analysis Results



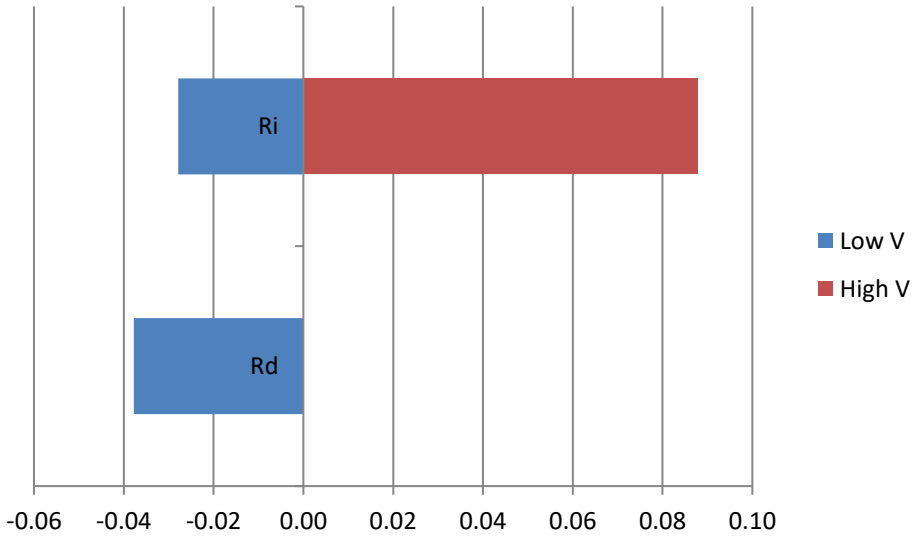
Summary of Analysis Results

lambda	CC	Deaths	IUC4	Vd	Vi	Wd	Wi	V
0.2	1568642	85107	5000000	1	0	0.625	0.375	0.625
0.25	1778621	96562	4550000	0.942259	0.1	0.625	0.375	0.626412
0.3	2014024	109404	4100000	0.877527	0.2	0.625	0.375	0.623455
0.35	2277616	123783	3650000	0.805048	0.3	0.625	0.375	0.615655
0.4	2572426	139866	3200000	0.723979	0.4	0.625	0.375	0.602487
0.45	2901767	157832	2750000	0.633419	0.5	0.625	0.375	0.583387
0.5	3269260	177880	2300000	0.532364	0.6	0.625	0.375	0.557727
0.55	3678859	200224	1850000	0.419735	0.7	0.625	0.375	0.524834
0.6	4134870	225101	1400000	0.294339	0.8	0.625	0.375	0.483962
0.65	4641980	252765	950000	0.154894	0.9	0.625	0.375	0.434309
0.7	5205282	283494	500000	0	1	0.625	0.375	0.375

Summary of Analysis Results

Tornado Table and Chart (Sensitivity to Rank assigned)

	Base MAVF =	0.63	Rd = 100, Ri = 60	
	Low V	High V	High Rank	Low Rank
Rd	-0.04	0.00	100	70
Ri	-0.03	0.09	70	40



Recommended Courses of Action

- The recommended course of action based on the simulation done and the ranks assumed is not to rush into opening up places at ones. The restrictions should be lifted but in a very gradual manner.

QUESTIONS?