

EXAMINING DISEASE PREVENTION MEASURES WITHIN HETEROGENEOUS COMMUNITIES

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Motivations and Inspirations:

- Effect of migration between states or cities.
- To see the effect of heterogeneity in cities and regions in terms of lockdown and hygiene habits.

Some Research Questions:

- How the positioning and working hours of hubs (supermarket and essential services) be, to minimize the spread?
- To find the possibility of controlled migration.
- The effect of heterogeneity in size of families in the spread.

India's Coronavirus Lockdown Leaves Vast Numbers Stranded and Hungry

NEW DELHI — In one of the biggest migrations in India's modern history, hundreds of thousands of migrant laborers have begun long journeys on foot to get home, having been rendered homeless and jobless by Prime Minister Narendra Modi's [nationwide lockdown](#) to contain the spread of the coronavirus.

Some previously done work and what's new with our project?

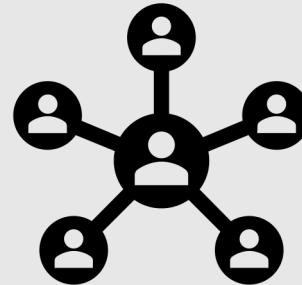
- Qingchu Wu, Tarik Hadzibeganovic (2020), An individual-based modeling framework for infectious disease spreading in clustered complex networks.
- Yong Yang , Peter M Atkinson and Dick Ettema (2011), Analysis of CDC social control measures using an agent-based simulation of an influenza epidemic in a city.

What's new?

- Heterogeneity in measures across cities and;
- Presence of central locations and their effect on spread while migration is going on.

About the model and Overview

Agents
are
citizens of
each city



Effect of
having
hubs and
centers

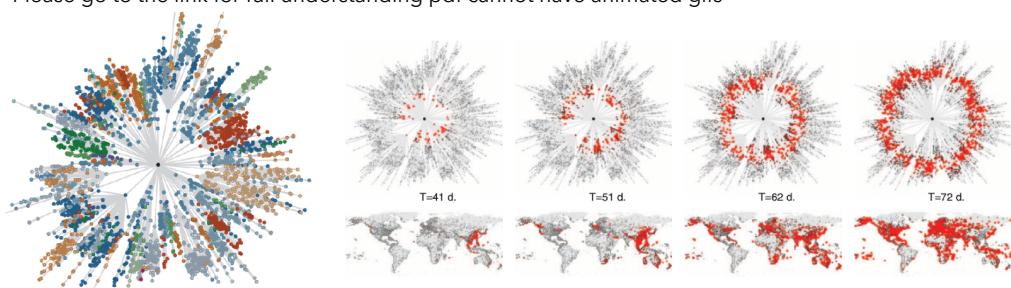
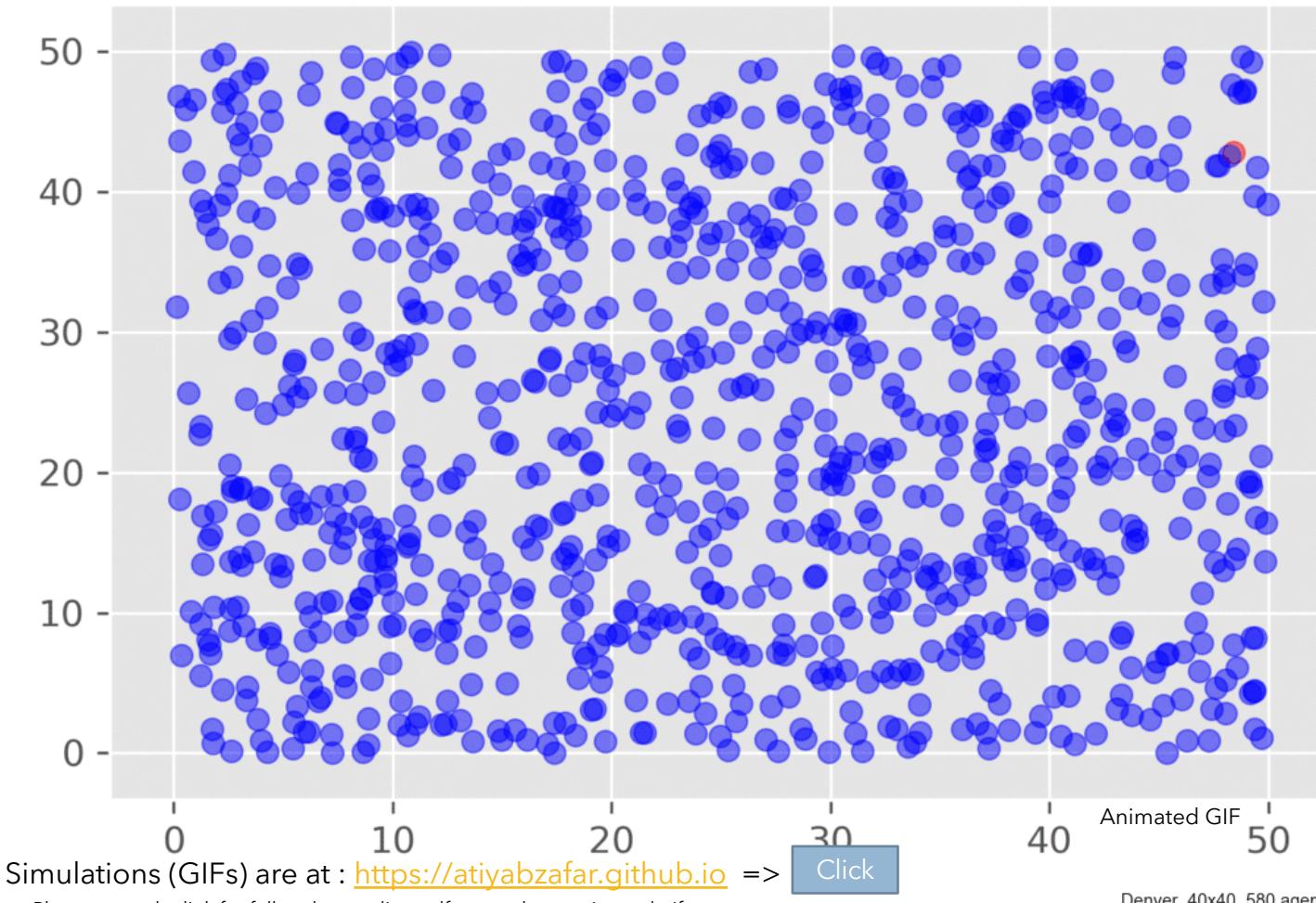


Simulate
travel and
migration

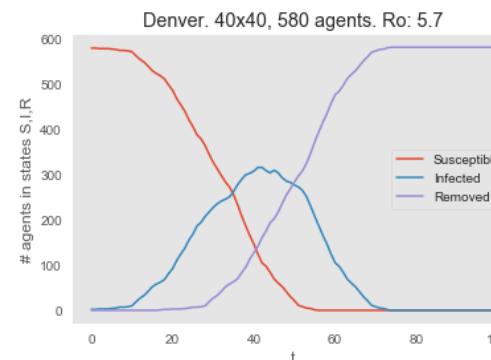


RANDOM MOVEMENT OF AGENTS

An Agent Based model

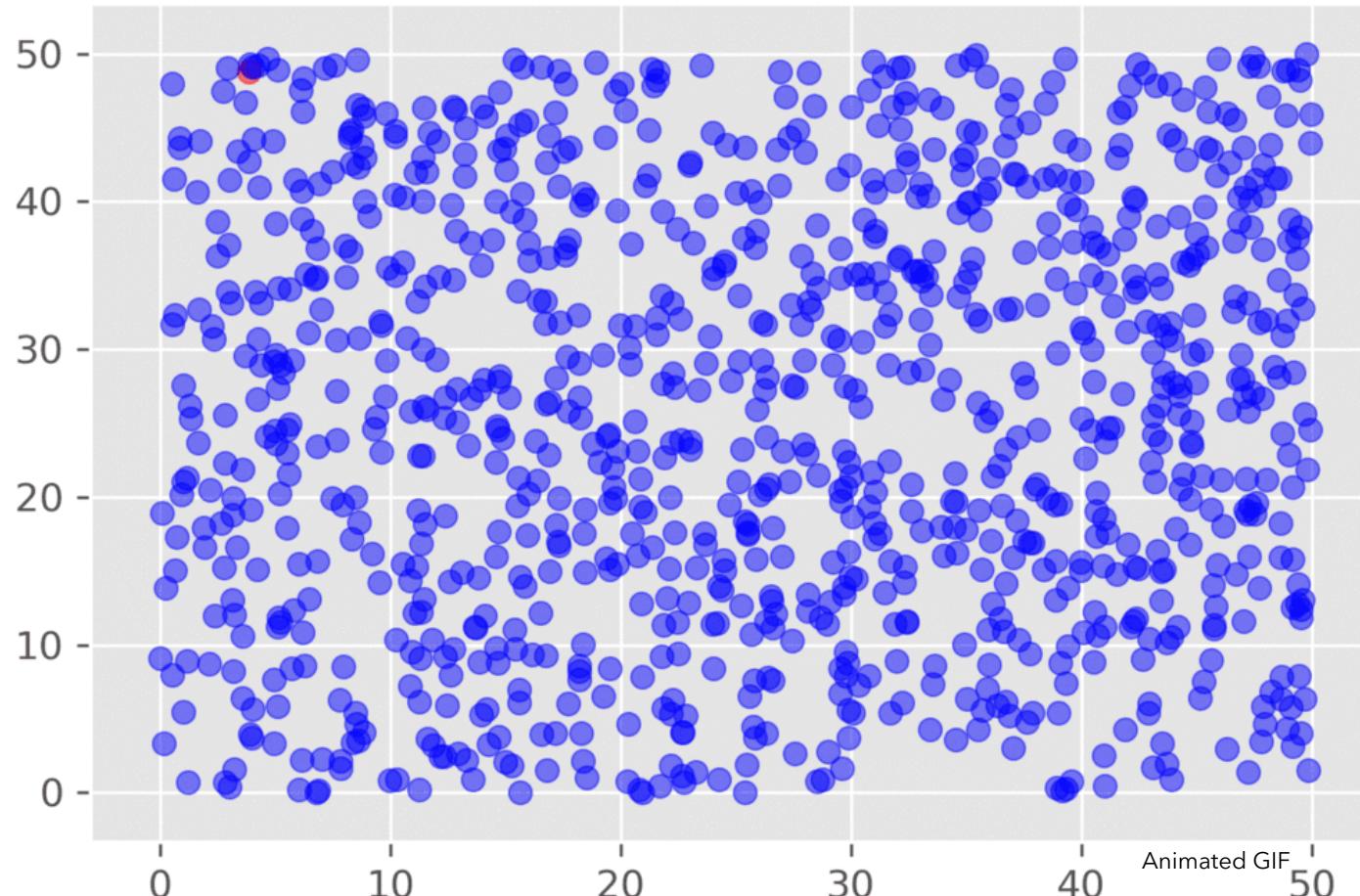


Brockmann, Dirk, and Dirk Helbing. "The hidden geometry of complex, network-driven contagion phenomena." science 342.6164 (2013): 1337-1342.



Random Movement for agents

- In our model agents move randomly
- Each agent can either be
 - Susceptible (Blue Dot)
 - Infected (Red Dots)
 - Removed/Recovered (Green)
- Each infected agent can infect the susceptible neighbours if there exists an S-I link in the corresponding graph within a proximity radius.

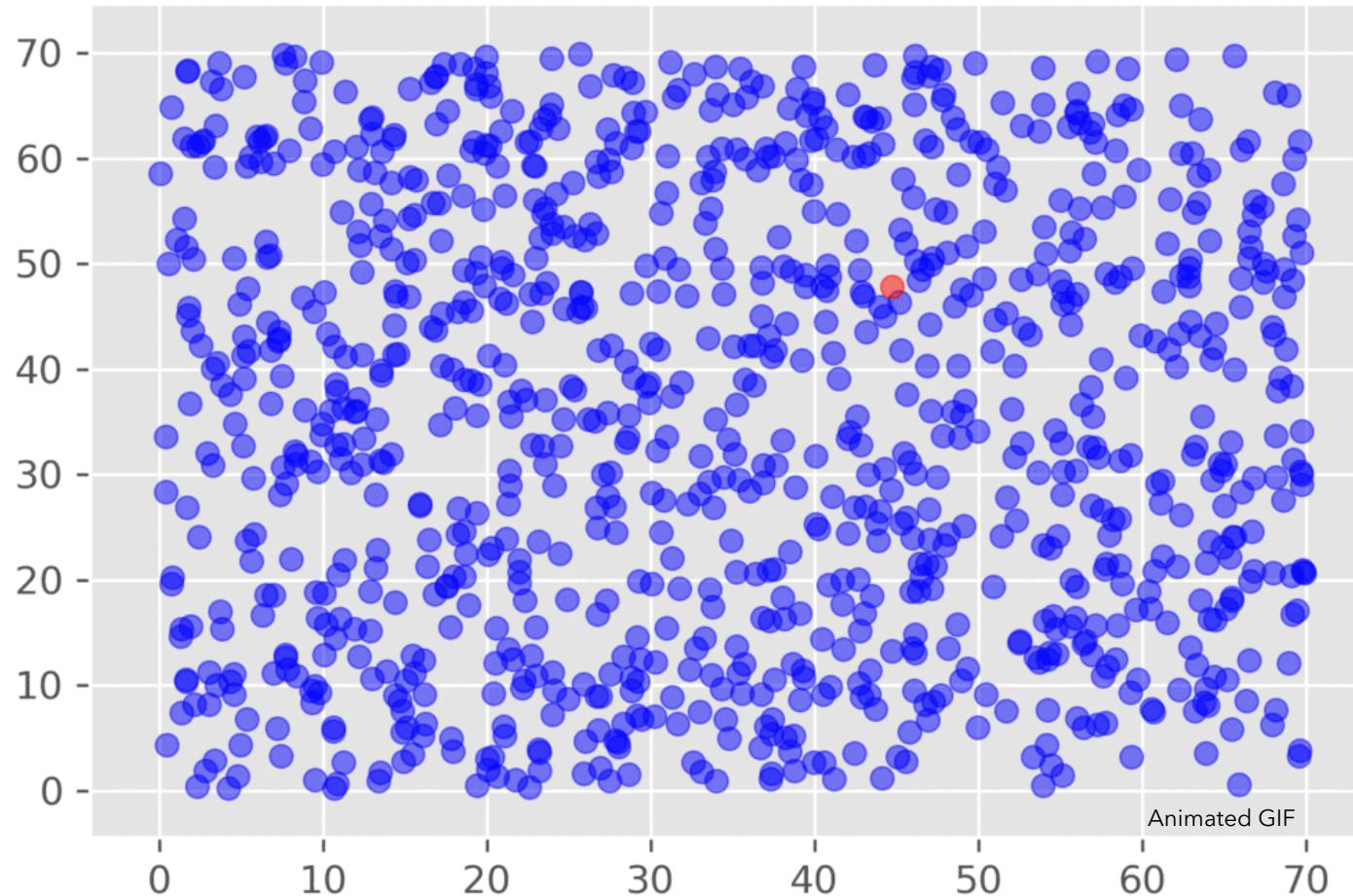


Effect of Migration

We studied the effect of Migration across the cities. In the next simulation we sampled 4 cities and initially had one agent infected in each city, we randomly choose a fixed number of people from the city and allow them to migrate from one city to another. The following simulations are the result:

We see

- Faster spreading

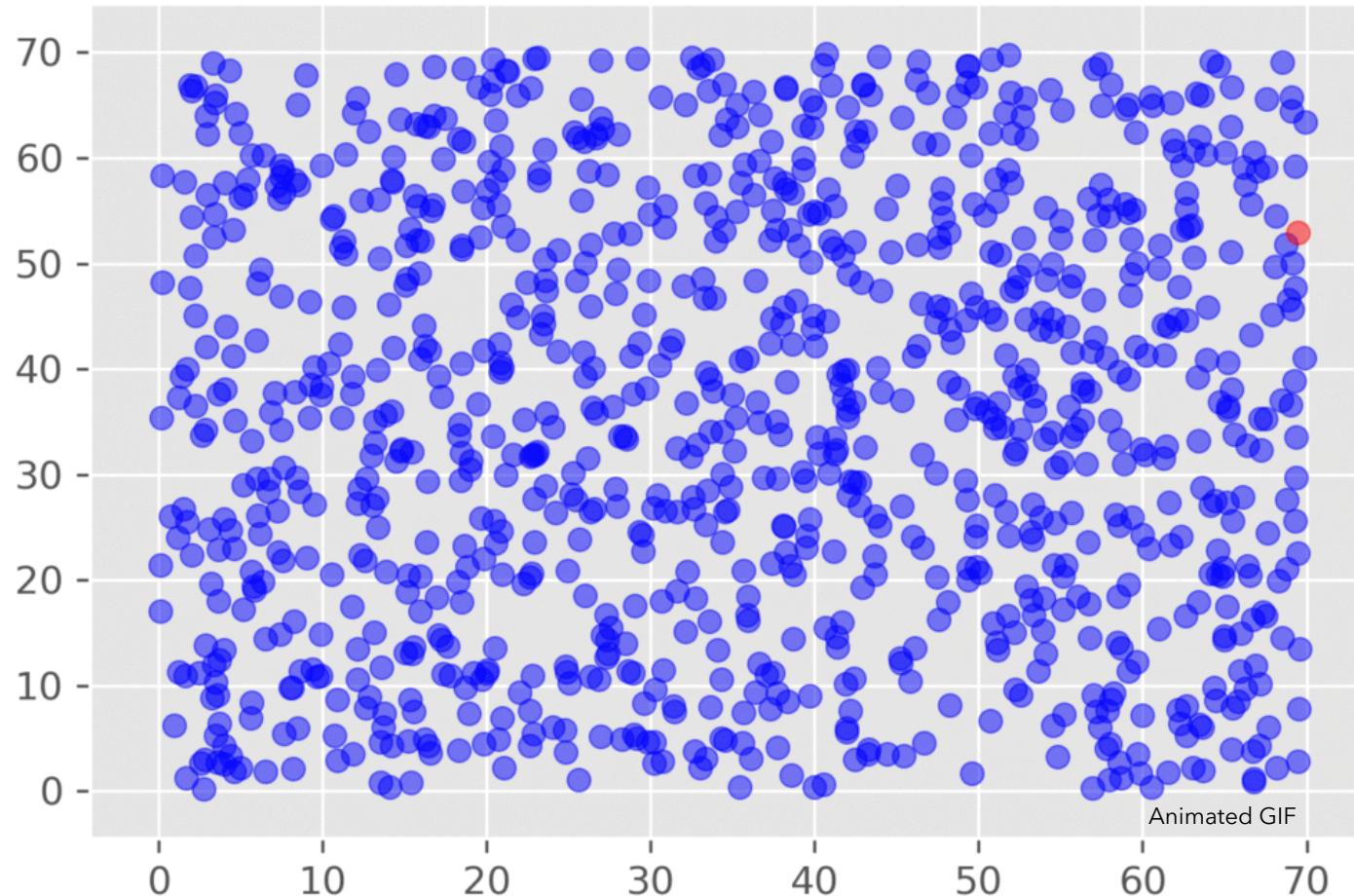


Effect of Migration

- Faster spreading
- More hotspots appear

More hotspots appearing across the city (not just one where the infection started)

The effect of *Seeding* the infection

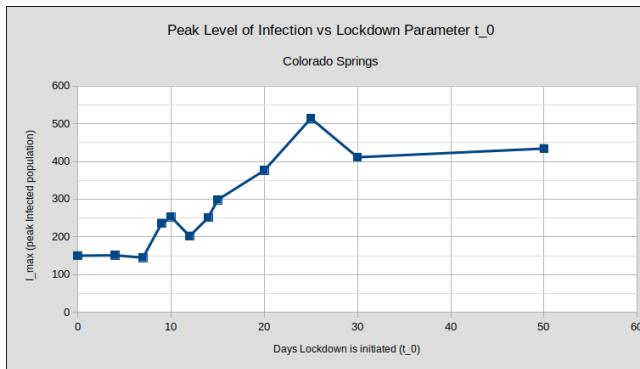
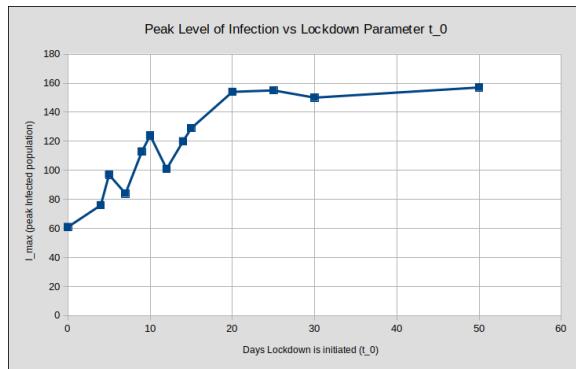
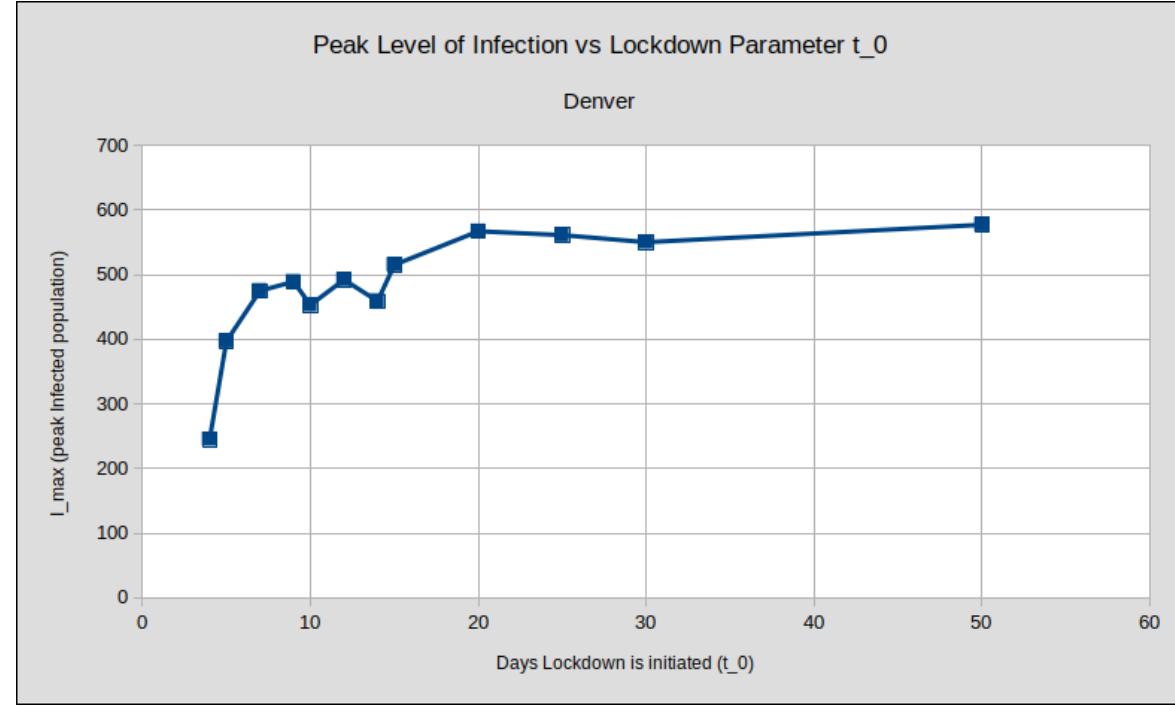


Animated GIF

Effect of Migration

- Faster spreading
- More hotspots appear
- Quickly covers the whole city

The infection spans the city quickly, hastening the process of infection at an alarming rate.



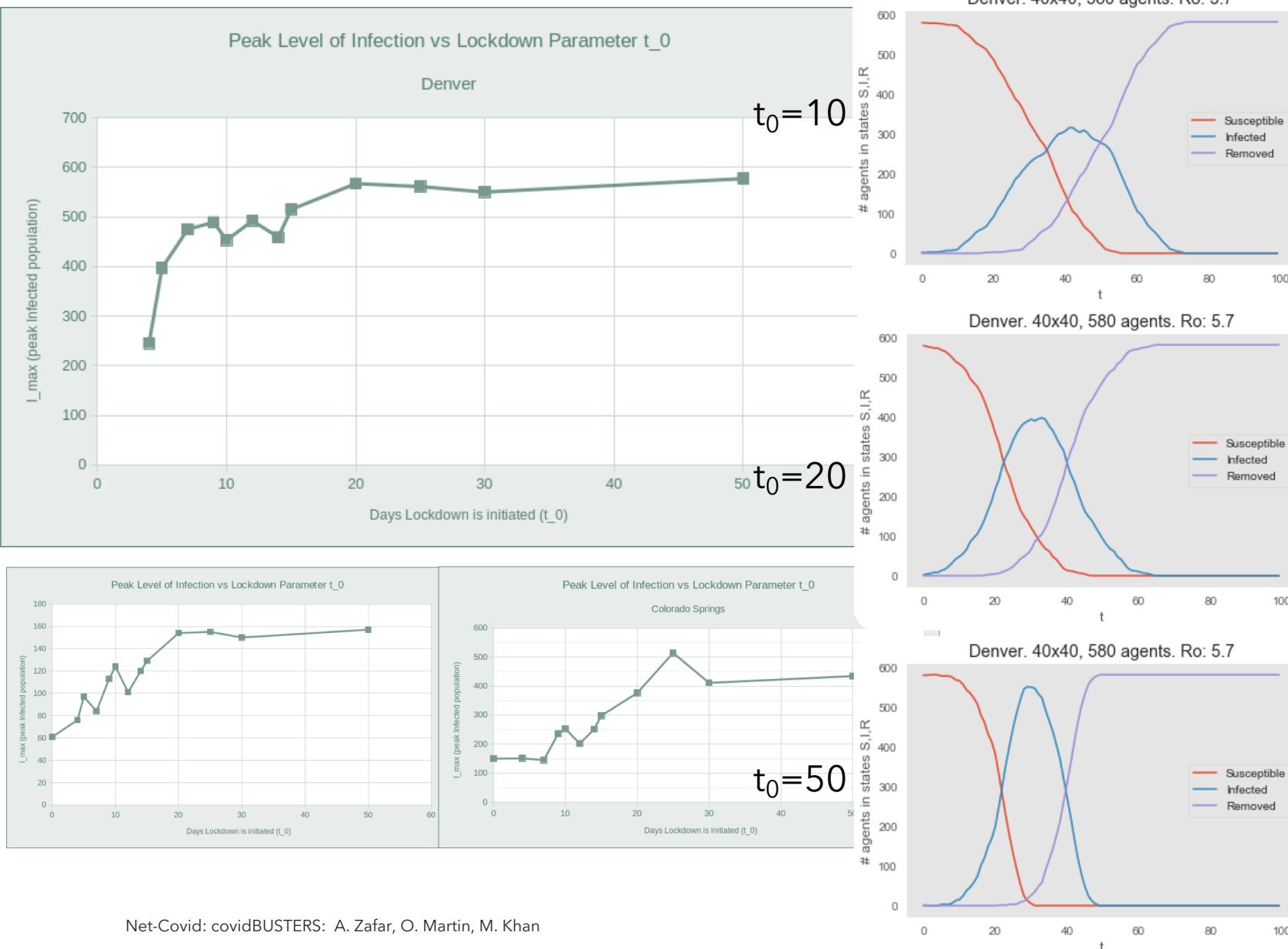
Effect of Inter-city lockdown at different time

- We define t_0 as the time at which Lockdown commences. i.e. Migration is stopped.
- You can think of this as the time when government decides to close state/city borders to stop the spread.
- Y-axis: Peak infected I_{max}
- If the lockdown is late
- The peak increases until the whole population is infected.

Effect of Inter-city lockdown at different time

We see that if the lockdown is commenced too late into the infection.

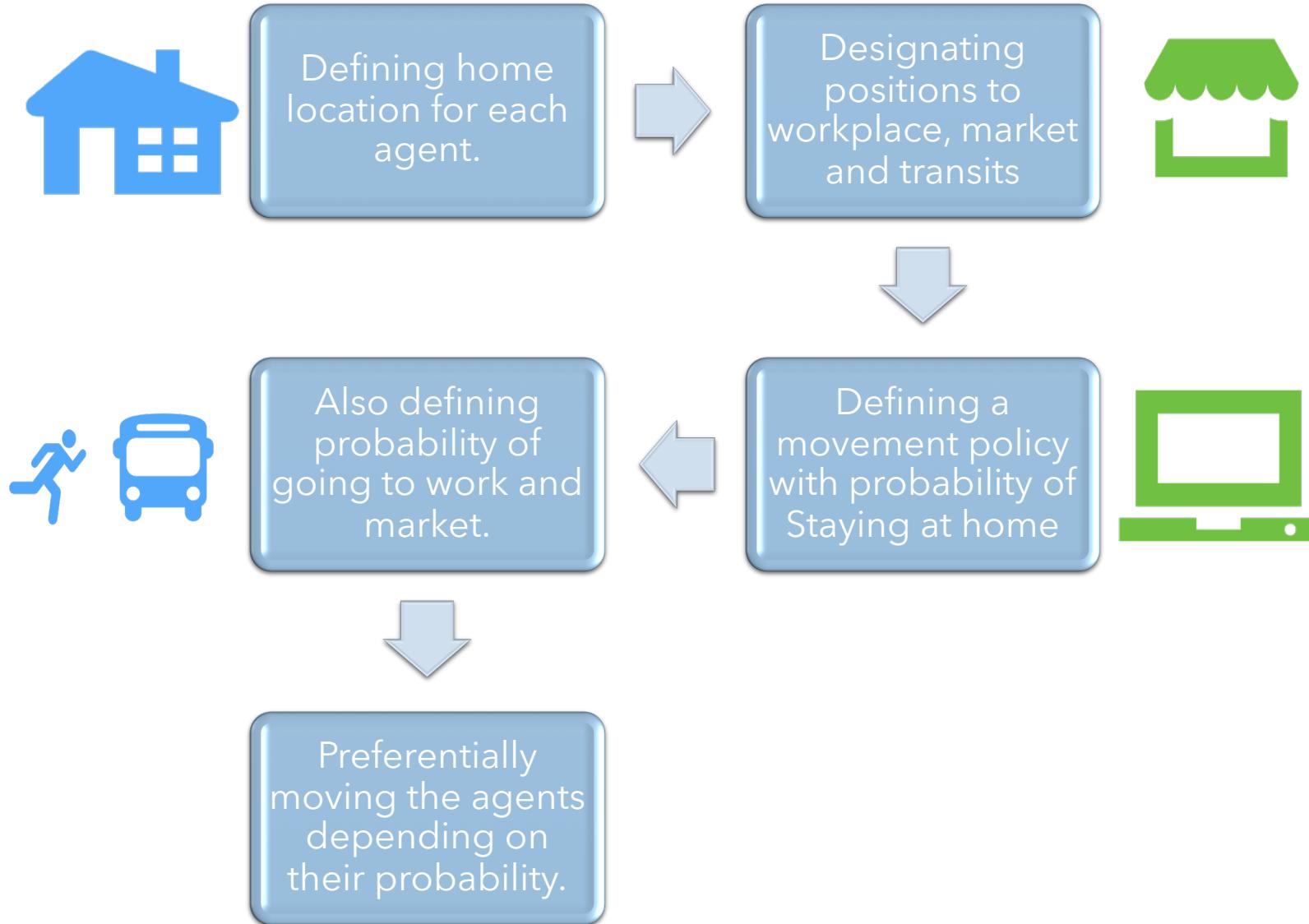
- The peak rises and it puts pressure on our healthcare facilities and available critical care beds in the city.
- It is thus critical in our toy model that the lockdown must start head on.



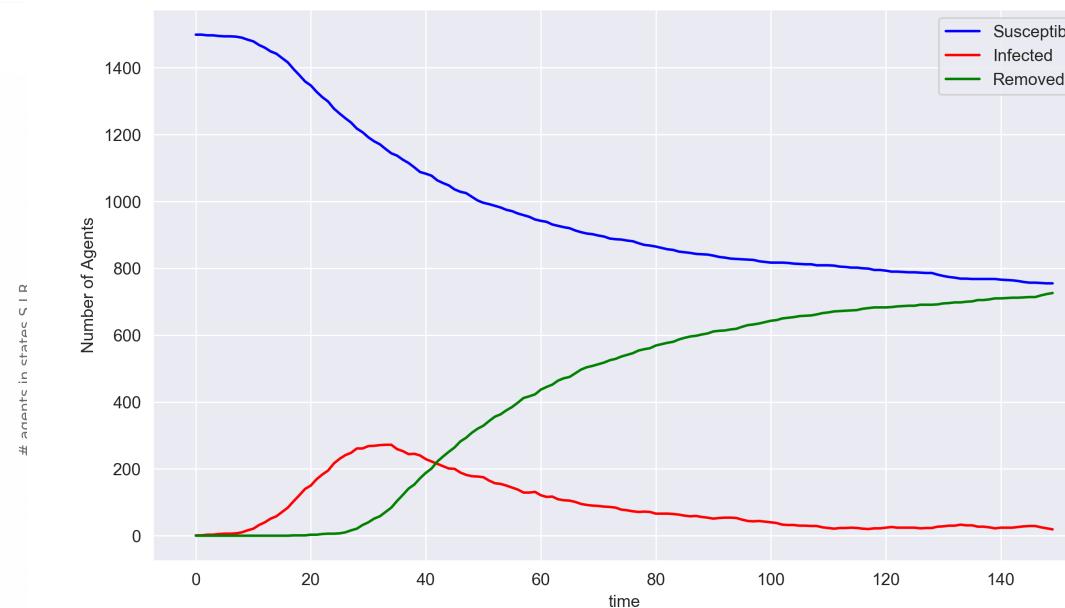
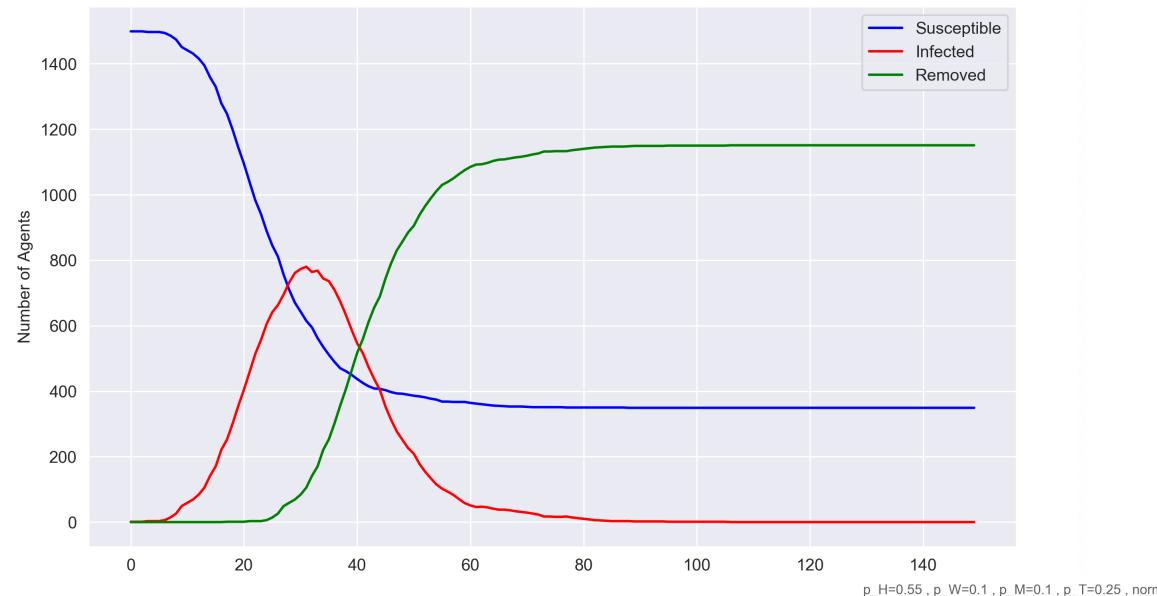


PREFERENTIAL MOVEMENT AND SOCIAL DISTANCING

More Realistic Model with Hubs like Markets and workplaces

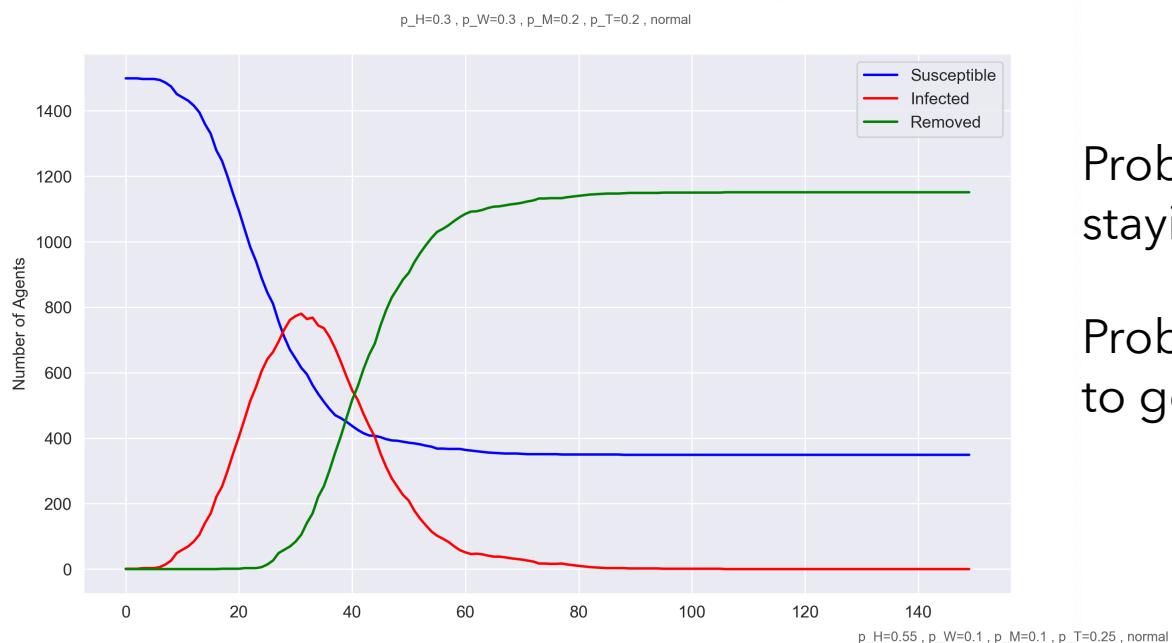


Preferential Movement model



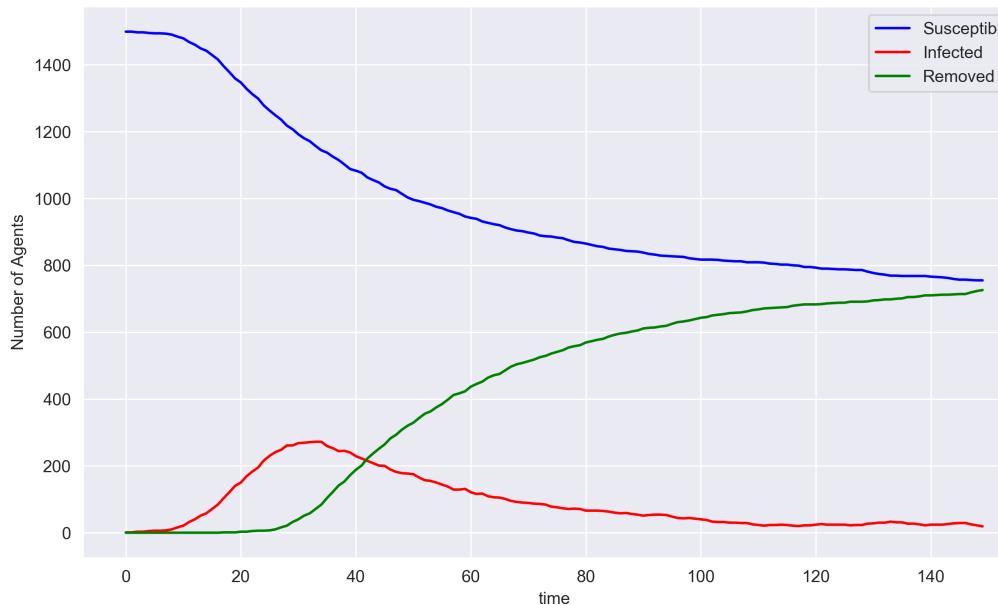
Using Preferential Return Model

- Cities have central locations
- Agents are assigned specific central locations based on their starting points
- Agents visit central locations with certain probability



Probability of Agents staying at home : 0.55

Probability of Agents to go to work: 0.1



The peak decreases

Probability of Agents staying at home : 0.3

Probability of Agents to go to work: 0.3

Using Preferential Return Model

- Cities have central locations
- Agents are assigned specific central locations based on their starting points
- Agents visit central locations with certain probability



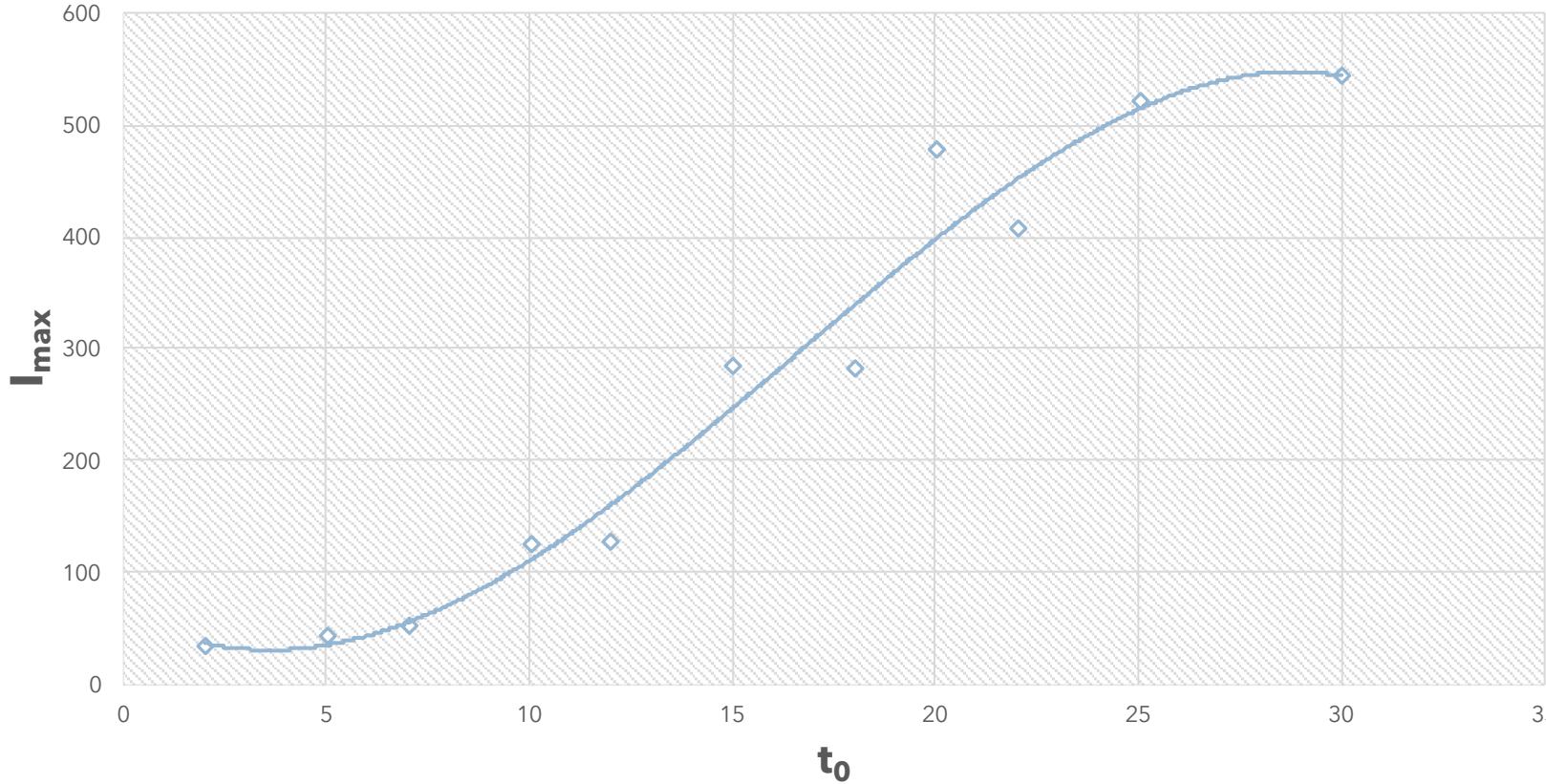
Work from Home Works



ANALYSING DIFFERENT KINDS OF LOCKDOWNS

t_0 vs I_{\max} curve for Stay at Home Policy

$R^2 = 0.9631$



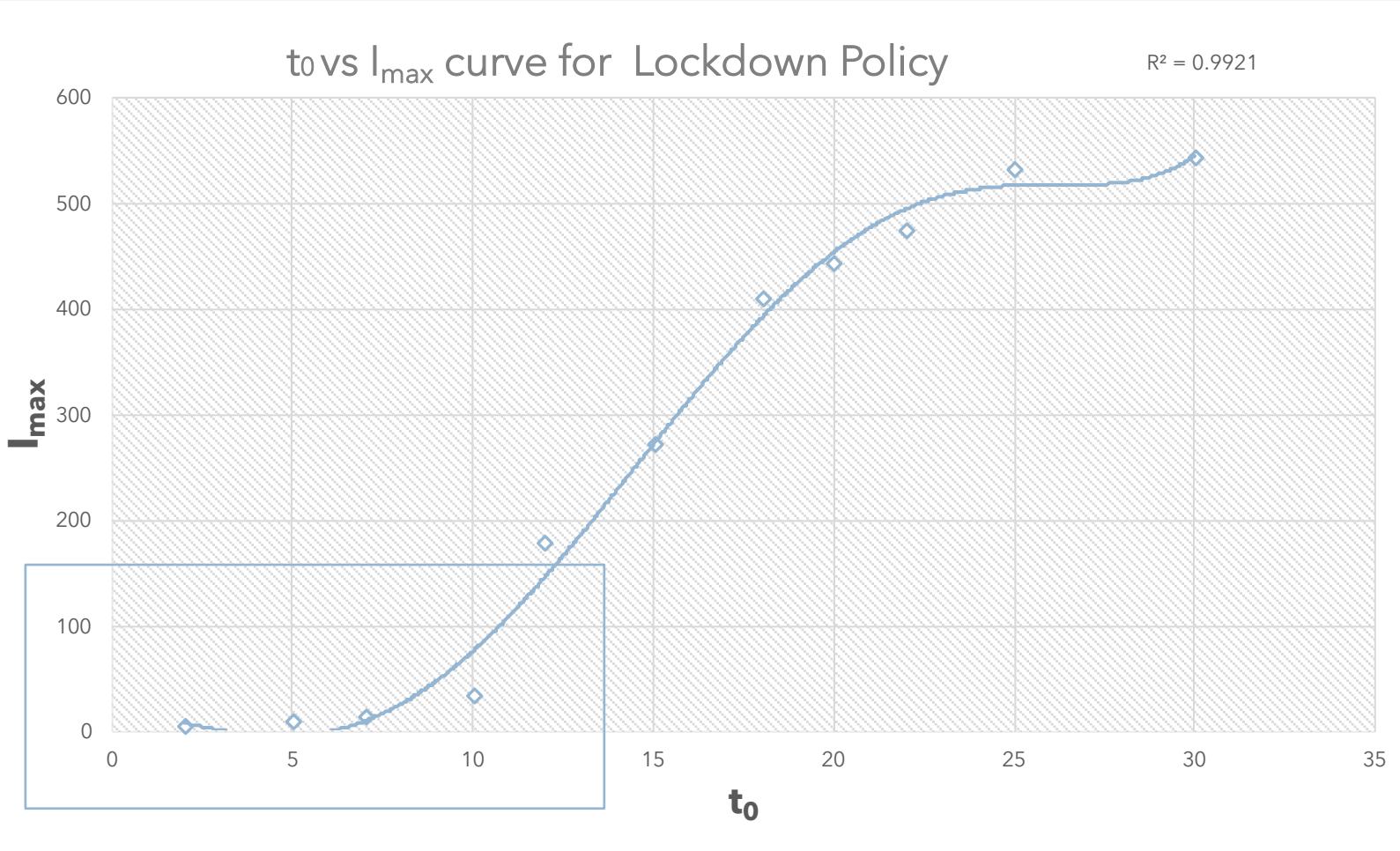
Movement Policy 1: Stay at home

Stay At Home: Probabilities : 'home': 0.9, 'work': 0.00, 'market': 0.05, 'transit': 0.05

- For large value of t_0 , the epidemic peak is found to be large.
- If the stay at home policy is commenced early on we end up with less people infected

Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects
- We again define t_0 to be the time at which lockdown commences.
- Higher the peak for I_{\max} , more pressure is applied on the healthcare system
- The plot shows trend for I_{\max} vs t_0 , Each value of t_0 is average for 10 runs. To remove the effect of Stochasticity of the model.



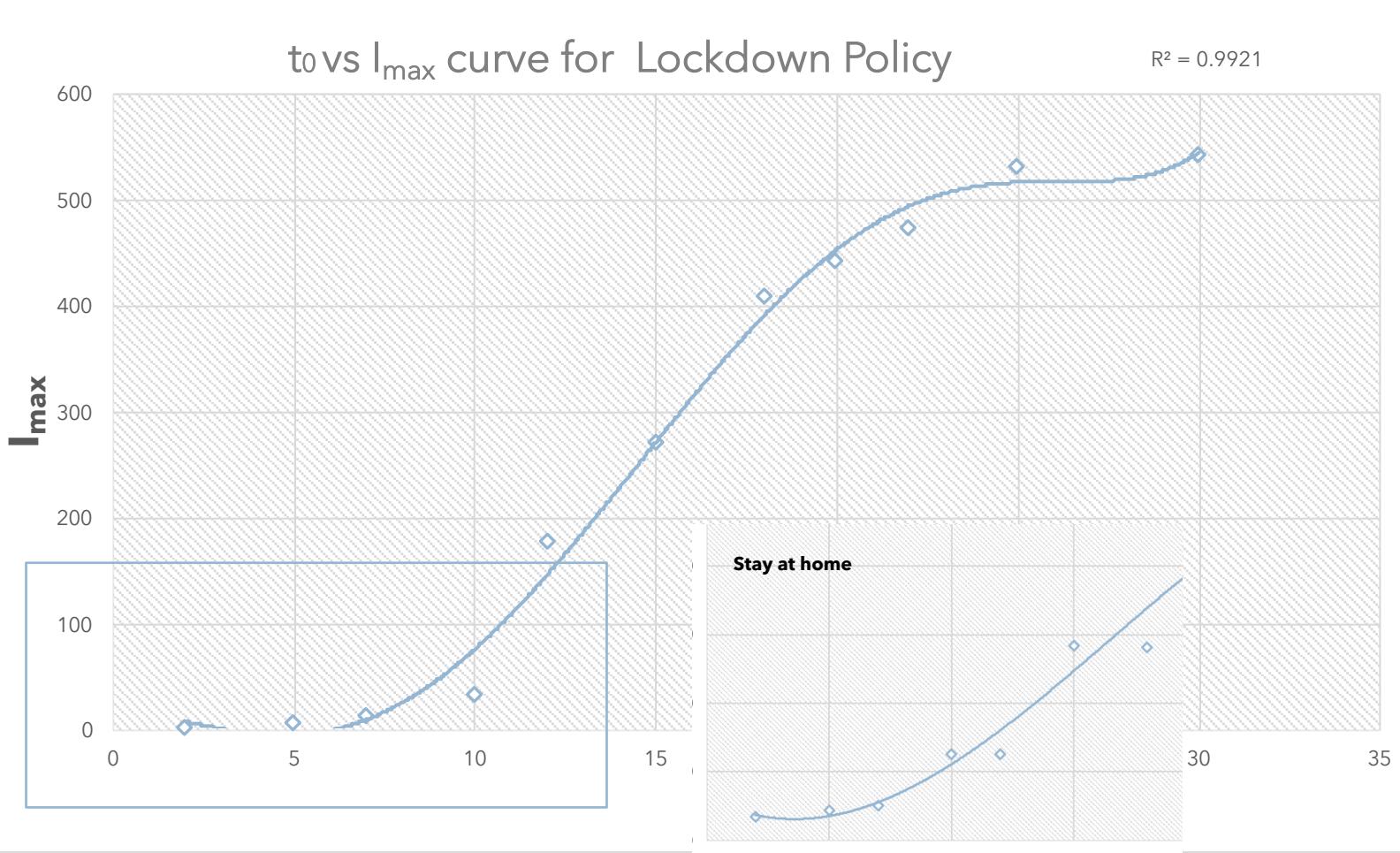
Movement Policy 2: Stay at home

Lockdown: Probabilities :: 'home': 0.95, 'work': 0.00, 'market': 0.04, 'transit': 0.01

We make the lockdown slightly stricter, making sure more agents stay at home by not allowing them to use transit . Looks same, but it's the initial window we must zoom into to analyse actual difference. (Next slide)

Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects on Healthcare pressure
- Higher the peak for I_{max}, more pressure is applied on the healthcare system



Lockdown: Probabilities :: 'home': 0.95, 'work': 0.00, 'market': 0.04, 'transit': 0.01

If we look at the cases when lockdown commences in early stages.

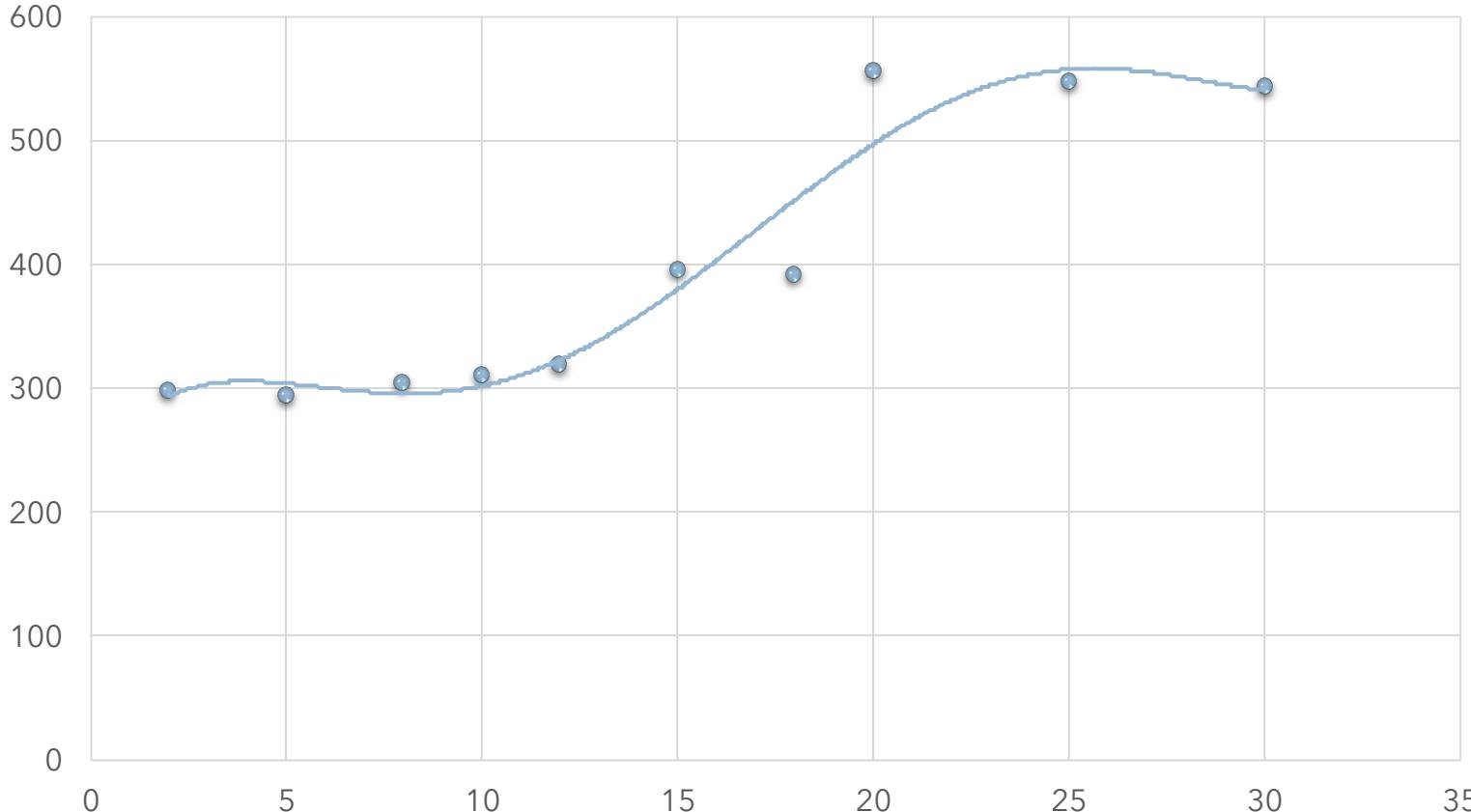
When we use lockdown policy compared to stay at home policy (Slightly more strict restrictions), the peak value decreases by a factor of ~ 3

($t_0=10$, $I_{max}(\text{Stay at home})=124$, $I_{max}(\text{Lockdown})=35$)

Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects on Healthcare pressure
- Higher the peak for I_{max} , more pressure is applied on the healthcare system

t0 vs I_{max} curve for Restricted Movement



Movement Policy 3: Restricted (More relaxed)

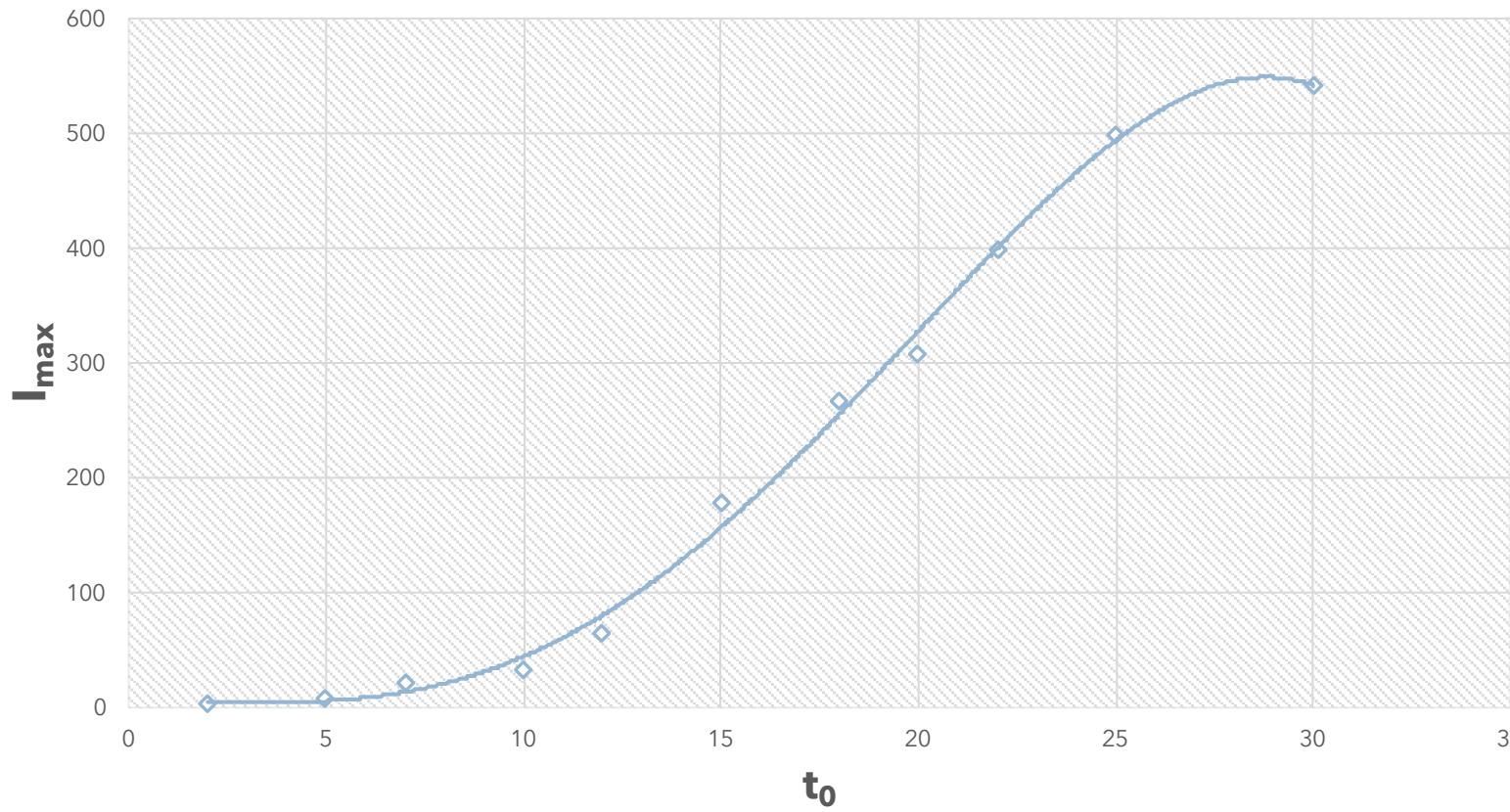
Restricted : Probabilities : 'home': 0.75, 'work': 0.05, 'market': 0.1, 'transit': 0.1

No Matter what Lockdown restriction (strict or lax) you follow if the lockdown is instigated late then it's bad news.

Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects on Healthcare pressure
- Higher the peak for I_{max}, more pressure is applied on the healthcare system

t_0 vs I_{max} curve for Restricted policy + Social Distancing $R^2 = 0.9963$



Restricted : Probabilities : 'home': 0.75, 'work': 0.05, 'market': 0.1, 'transit': 0.1

Simulating Social Distancing by decreasing Proximity Radius

A City with good hygiene habit and who is following Social Distancing well, does not need very strict lockdown as can be seen from this simulation.

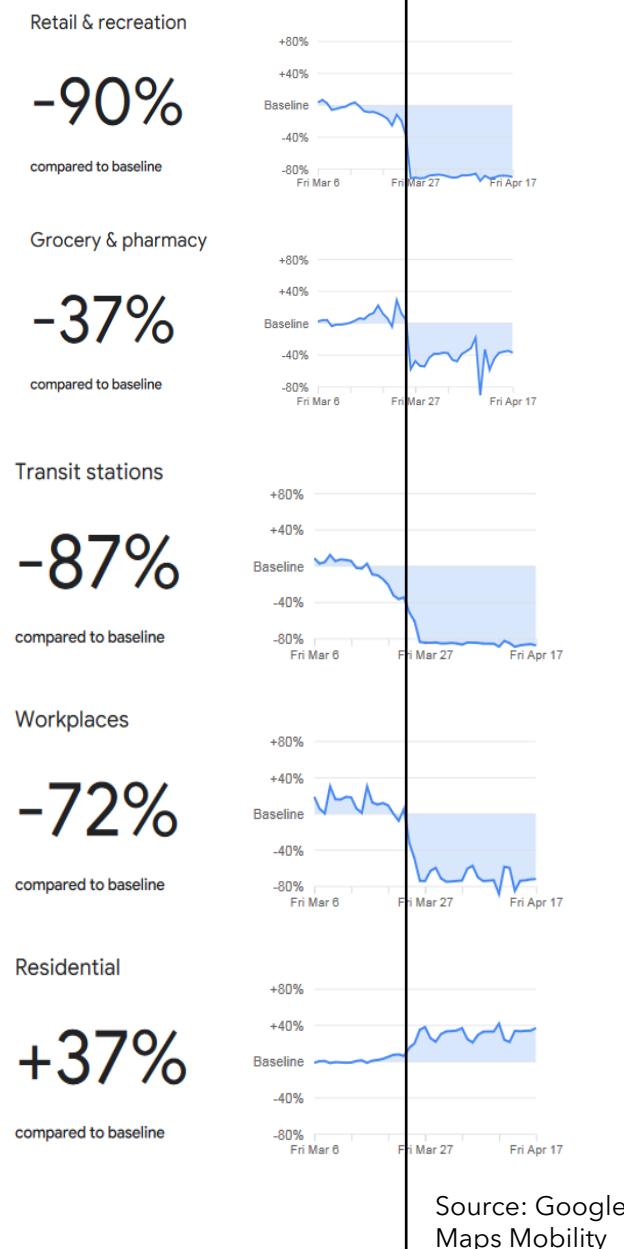
Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects on Healthcare pressure
- Higher the peak for I_{max} , more pressure is applied on the healthcare system

Alert Level	Risk Assessment
Level 4 – Lockdown	<ul style="list-style-type: none"> Community transmission is occurring. Widespread outbreaks and new clusters.
Level 3 – Restrict	<ul style="list-style-type: none"> Community transmission might be happening. New clusters may emerge but can be controlled through testing and contact tracing.
Level 2 – Reduce	<ul style="list-style-type: none"> Household transmission could be occurring. Single or isolated cluster outbreaks.
Level 1 – Prepare	<ul style="list-style-type: none"> COVID-19 is uncontrolled overseas. Isolated household transmission could be occurring in New Zealand.

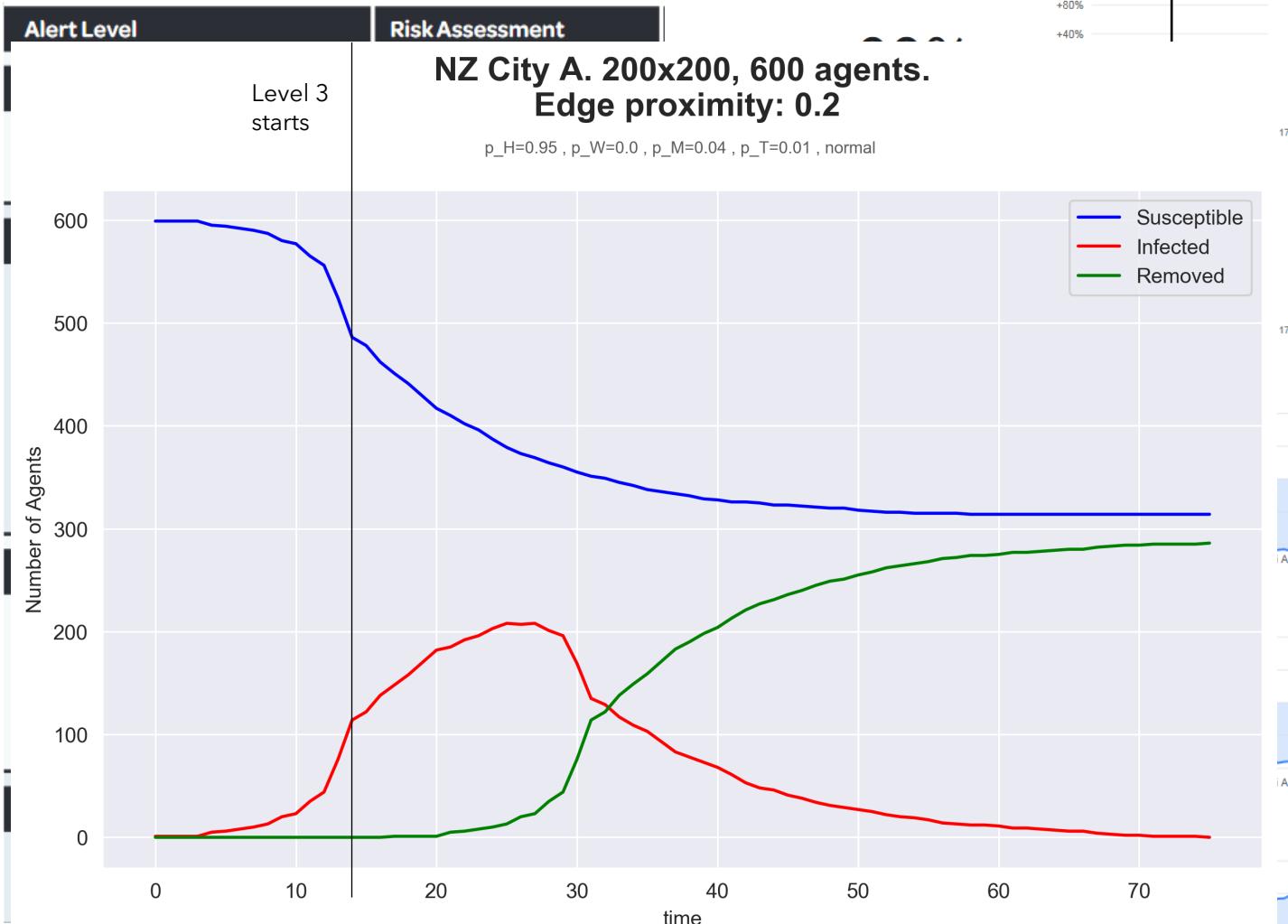
Source: <https://covid19.govt.nz/alert-system/covid-19-alert-system>

26th March



Case Study New Zealand

- Prime Minister of New Zealand Ardern said there was no widespread community transmission now in New Zealand and "we have won that battle".
- They used a 4 level Alert system
- Effective from 26th March Alert level 3
- And from 28th Level 4



Restricted Alert Level 3: Probabilities : 'home': 0.75, 'work': 0.05, 'market': 0.1, 'transit': 0.1

Restricted Alert Level 4: Probabilities : 'home': 0.95, 'work': 0.00, 'market': 0.04, 'transit': 0.01

Net-Covid: covidBUSTERS: A. Zafar, O. Martin, M. Khan

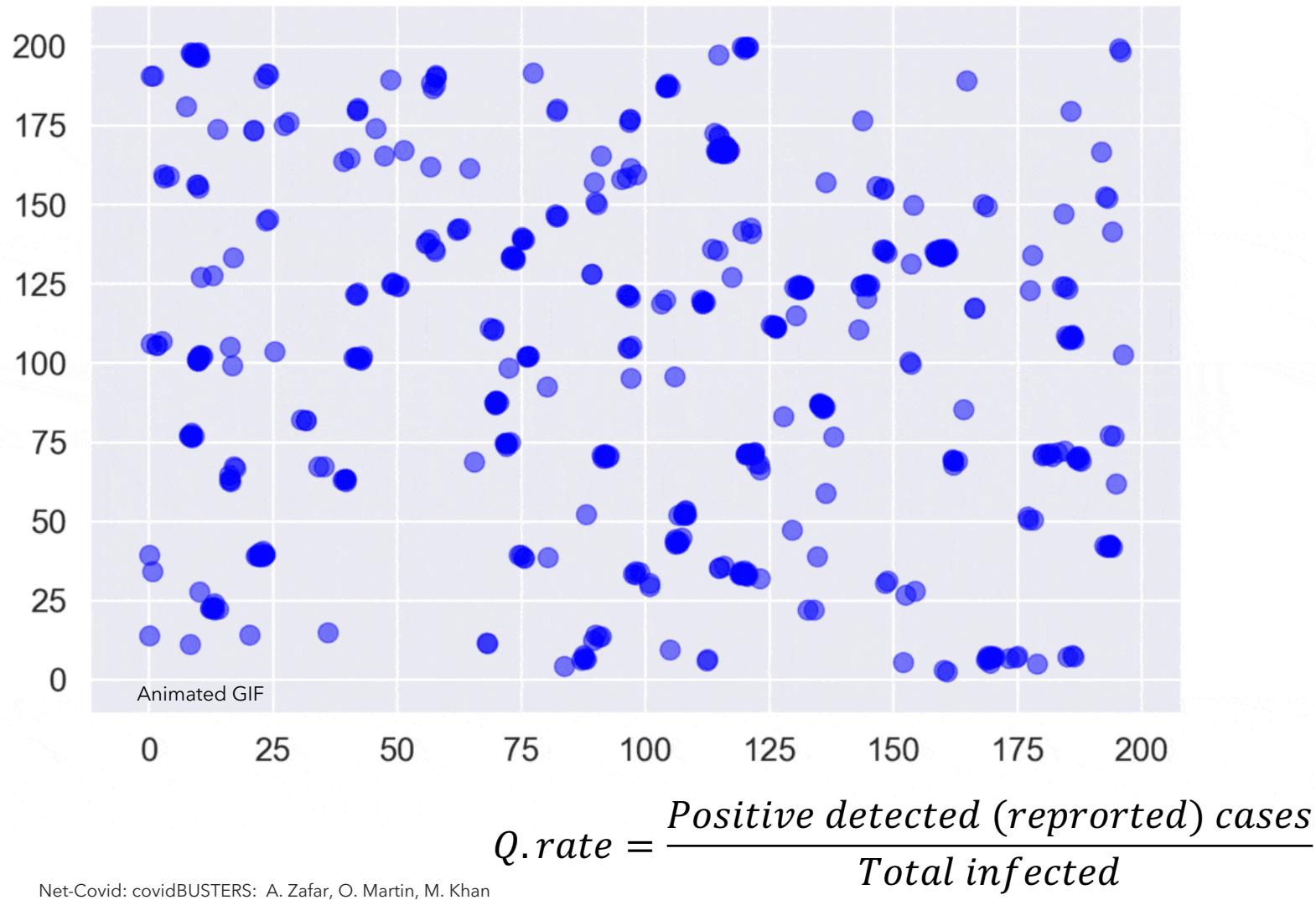
Case Study New Zealand

- They used a 4 level Alert system
- Effective from 26th March Alert level 3
- And from 28th Level 4
- We select movement policy using the mobility data provided by google to consider the change in the probabilities.
- Multi Level lockdown system is more effective in our model as well.
- Even after running the simulation multiple times we find a considerable amount of susceptible population remains susceptible.
- Peak arrives in ~10 days as seen in the data as well.



QUARANTINING INFECTED TO QUARANTINE CENTERS

We define Quarantine Center for the city that's outside the city



Quarantine

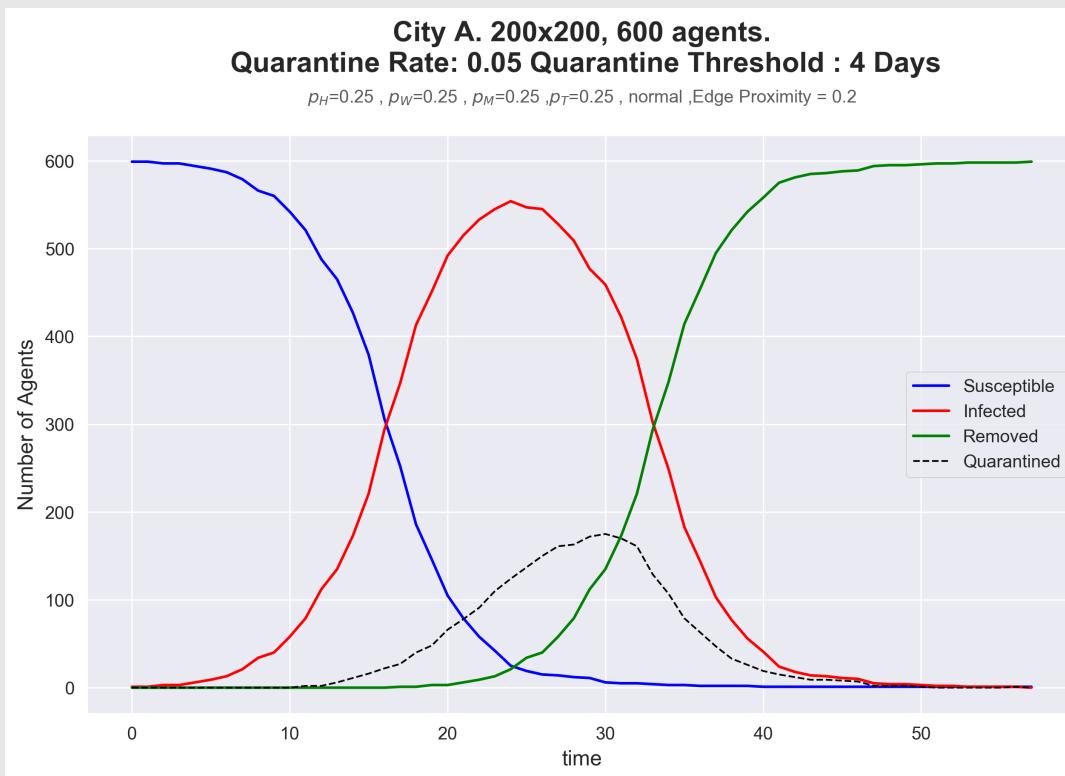
- We make a quarantine center outside the city so that we can send the infected patients that are reported to the centers.
- We define a quarantine threshold as the number of days an infected individual is reported
- Also define a quarantine Rate that is the ratio of infected individuals that are reported and thus send to quarantine.

In the following two cases we see different rates of quarantine happening. We have even movement policy, so there is no lockdown in place.

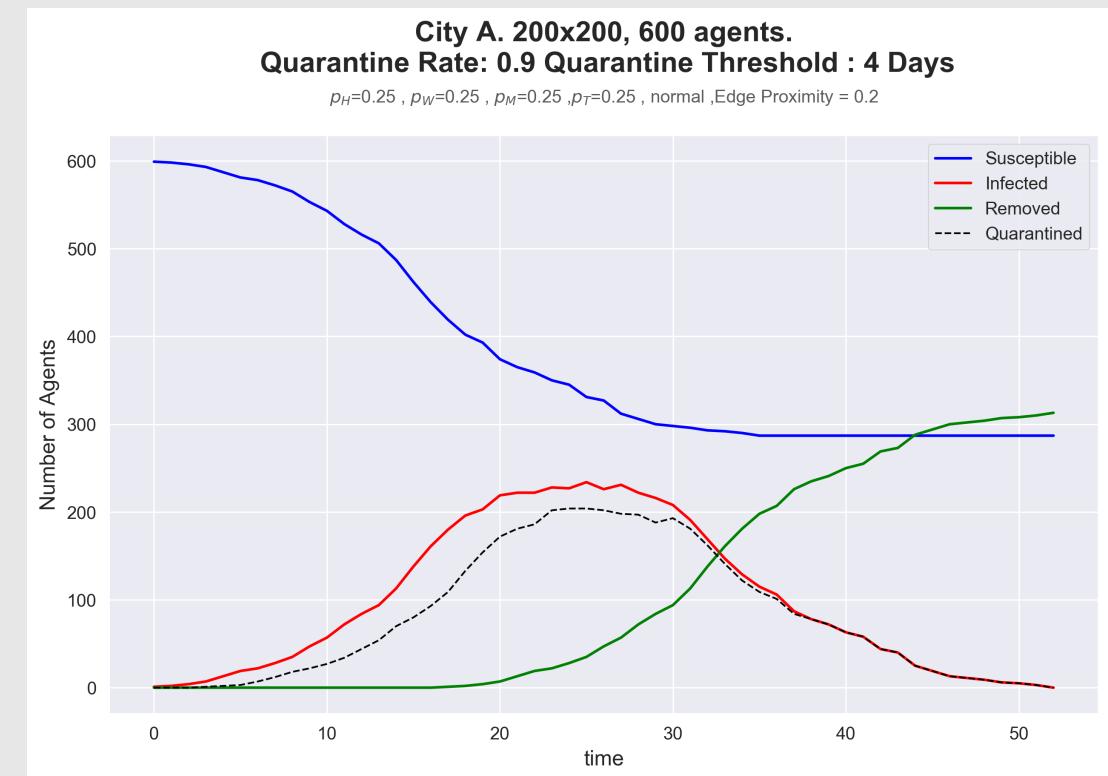
When the Q. Rate is low (left) most cases are not detected positive and thus the *infection spreads over all city*.

When the Q. Rate is large most of the infected population is quarantined after 4 days (Q. Threshold), the peak is shallower and *half of population is left Susceptible*.

Q. Rate = 0.05

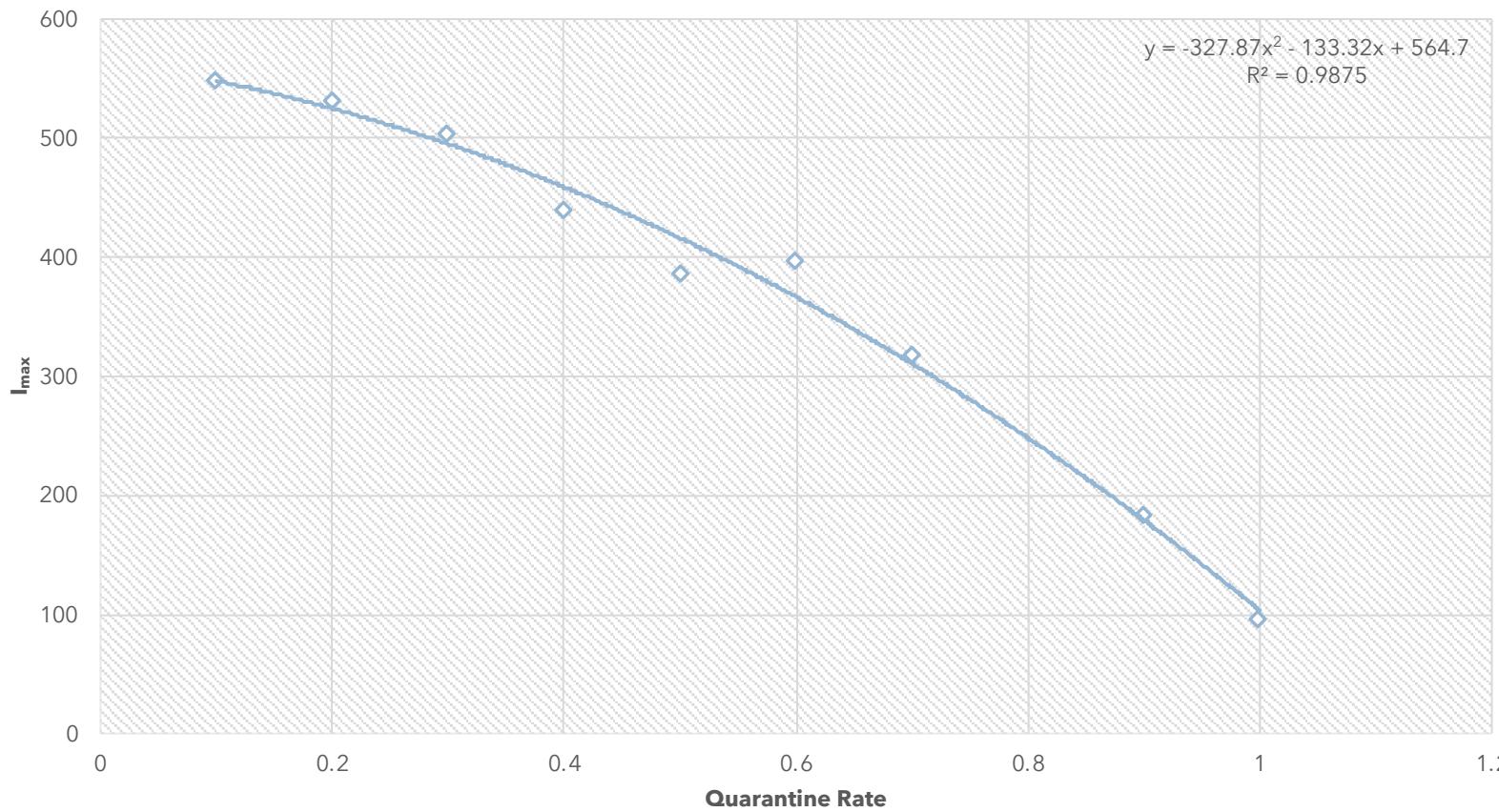


Q. Rate = 0.9



Note: Quarantining everyone quickly would lead to a very broad peak, but it leads to problem of herd immunity. If a significant part of population is left unexposed it might not lead to immunity at large scale and we then must think of better ways of achieving the same.

Different Quarantine Rates for Quarantine Threshold = 4



Because of the way we have defined our Quarantine Rate, if a test kit is not working optimally. (As we have seen in real life)¹. The Q. Rate would go down and more infected people will be allowed to move around and infect.

The drastic effect of "false negatives" comes into picture when we look at our model and real data¹.

Net-Covid: covidBUSTERS: A. Zafar, O. Martin, M. Khan

1. <https://www.healthline.com/health-news/false-negatives-covid19-tests-symptoms-assume-you-have-illness>

The peak decreases as higher ratio is quarantined

- As my quarantine rate increases the peak infected population goes down which shows the more people we quarantine the better we can control the spread of covid19.
- As WHO general director remarked on March 16th:
"Test, Test, Test"
- This graph shows the importance of testing. The more tests we do, the more positive cases we can quarantine and the better we can control the epidemic in our model.
- Testing and isolation works wonders.

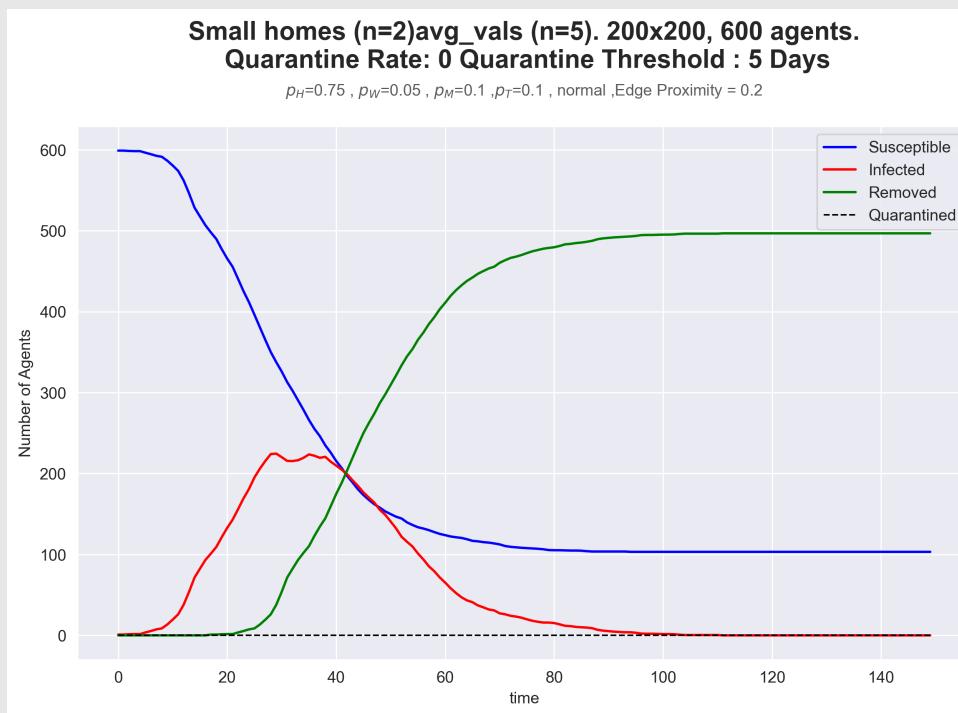


FAMILY SIZE HETEROGENEITY

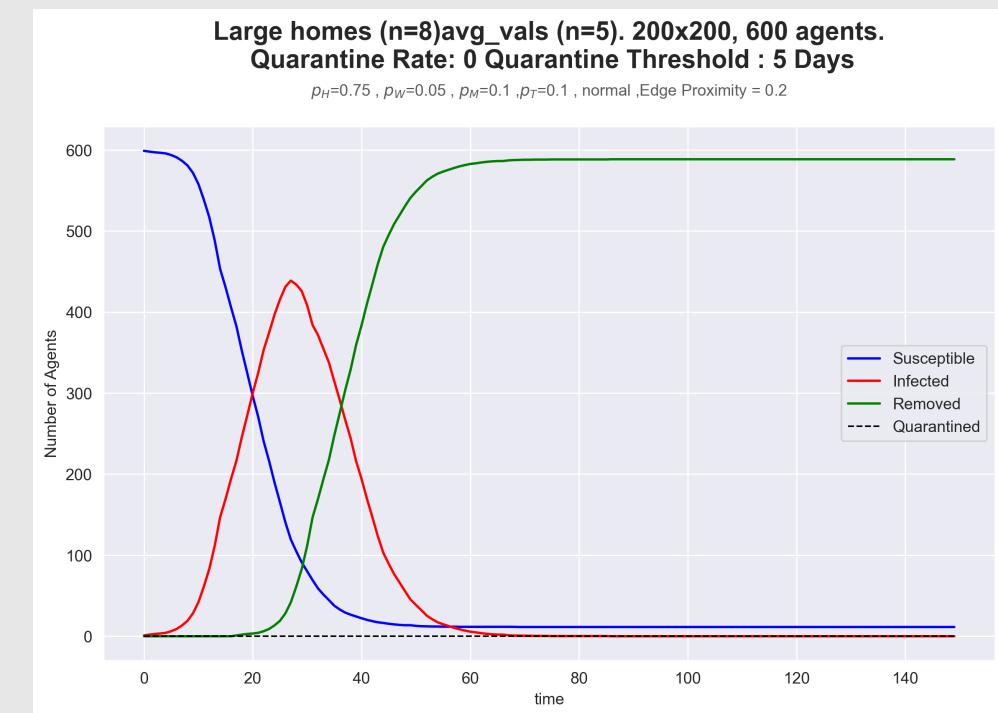
What happens when homes aren't really that isolated?

In the following two cases we do not apply quarantine, and instead rely on stay-at-home order to control infection. However, we vary the # of agents per home (on average) to simulate location effects, like what happens if many people share a residence.

agents / household = 2



agents / household = 8



Future Plans



- Figure out a way to optimize choices of which market to stay open. Location study from the apartments/housings to make sure infection is minimized
- Incorporate inter-city migration with the city lockdown rules and preferential movement.
- ~~Physical Isolation/Quarantine of Infected Population and their effect.~~
- ~~Exploring more effects of social distancing as we have defined social distancing parameter already.~~
- ~~Incorporate heterogeneous families in the cities.~~