Simulation on the effects of Pfizer vaccine on the spreading of the pandemic

Who should receive it first and what proportion of the population should take it in order to optimally reducing the virus' strength

Alessandro Fedel and Vittorio Costa

November 2020

Abstract

This research project has the objective of analyzing the possible outcomes of a vaccine on a virus spread among the world, i.e. a pandemic. In particular, we will focus our efforts in optimizing two main factors: the percentage of people to vaccinate and the age group to vaccinate first. Our strategy is to find out what is the lowest possible fraction of the population to vaccinate in order to promptly lessen the virulence of the pandemic and whether vaccinating the elderly first will result in a more positive outcome in the fight against the virus. The results will show that a percentage of 60% will be sufficient to rapidly thwart the pandemic, and that vaccinating the elderly first will hinder the spread of the virus.

Introduction

Our research follows the announcement made on the 9th of November in which Pfizer and BioNTech [1] presented evidence of success for a vaccine against SARS-CoV-2. More in detail, this candidate vaccine was found to be more than 90% effective in preventing COVID-19 in the participants of the study. In the glee of this news we would like to take a scientific approach to the matter trying to study the possible scenarios related to the distribution of this vaccine. Therefore, we will simulate the spreading of a pandemic through a software program. In order to do so we took part of the code from a simulation that has been publicly made available on GitHub [2]. This program is written on a Python library, Numpy, which exploits a fast back-end written in C for high performance calculation, and Monte Carlo procedures for approximating the spread of the pandemic. On top of that we added functionalities to test the dispensing of a vaccine inside the simulation.

Objectives

The main objective of our study is to help politicians and their task forces in taking informed decisions over the use of a vaccine in order to counteract the effects of the ingrained second wave of the COVID-19. In the following months they will have to decide how many will get the vaccine and who will receive it first and this study is aimed at "debugging" these conundrums. However, in order to be able to evaluate the different scenarios we must answer the three following questions.

- What percentage of the population needs to be vaccinated in order to lessen the strength of the pandemic significantly?
- Will vaccinating elderly people first have a positive impact on reducing the spread of the virus when compared to randomly selecting the recipients of the vaccine?
- Will an optimal distribution of the vaccine be as effective as a lockdown?

The model

The model simulates a population composed by 2000 individuals randomly distributed into a square-shaped area. Moreover, the model considers the time steps (which will be considered as hours for the purposes of the study) taken to eradicate the virus from the initial introduction in one individual of the sample.

[1] The announcement of the candidate vaccine was made on Pfizer website and can be found at the following link: https://www.pfizer.com/news/press-release/press-release-detail/pfizer-and-biontech-announce-vaccine-candidate-against

[2] The software program's author is Paul Van Gent and the code can be found at the following link: https://github.com/paulvangentcom/python_corona_simulation

According to the simulation there is a 3% chance of becoming sick when getting close to an infected person, and a 2% chance of a fatal ending. In addition, the population is normally distributed around a mean of 55 y.o. and the risk of death increases with the age of the individual, reaching 10% for individuals over 75 years old and the simulation also accounts for an healthcare capacity limited at 300, in an environment where not being cured increases the chances of death by a factor of three. Last but not least, the code enables the choice of different settings and we found it useful to experiment the "Lockdown scenario", which is defined by a limited and slowed mobility for the population, once the number of infected reaches 5%.

This model was updated in order to consider the effects of a vaccine which, just as the one announced by Pfizer and BioNTech, is effective at 90%. In other words, when the vaccine will be introduced in the population it will immunize 9 out of 10 people that take it. Moreover, we specified that the population will be vaccinated once the number of infected individuals will reach the 5%, being that also the threshold used in the lockdown scenario. Then we added the two variables that will help us to answer the research questions of this study. The first one is a floating variable that accepts values between 0 and 1 and it represents the portion of the population that will be vaccinated when the threshold of 100 actively infected people will be surpassed. The second one is a boolean variable that controls whether the elderly are prioritized or not when the vaccine is distributed.

Data Analysis

We start our assessment by modeling the spread of the virus in an environment completely free of restrictions.

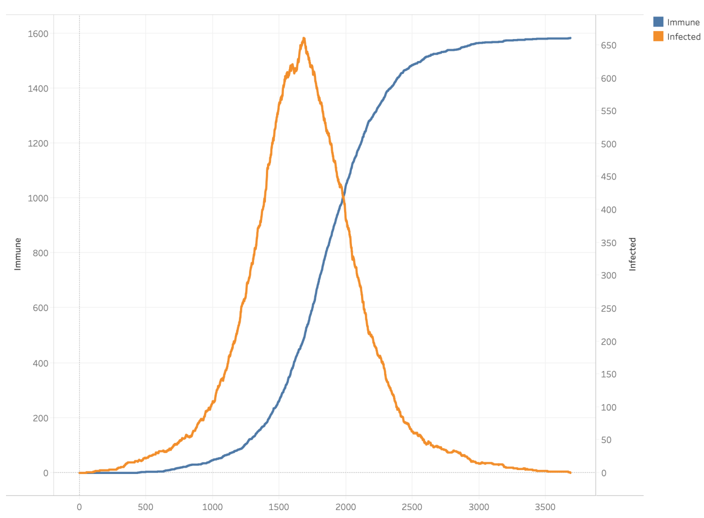

Figure 1: the orange line represents the number of infected over time, and the blue line the number of immune individuals

The first curve resembles a bell shape with a peak of 650 infected reached after roughly 1700 hours. Conversely, the second curve converges to a total number of immune individuals of 1600 following a sigmoid function. The spread of the pandemic is obviously uncontrolled in this scenario since we have a time frame of more than 1500 hours where the number of infected exceed the healthcare capacity of 300 beds.

We now consider the introduction of a vaccine having a 90% probability of success in making the patient immune and we distribute it to 30% of the healthy population as soon as the infected hit the 5% threshold.

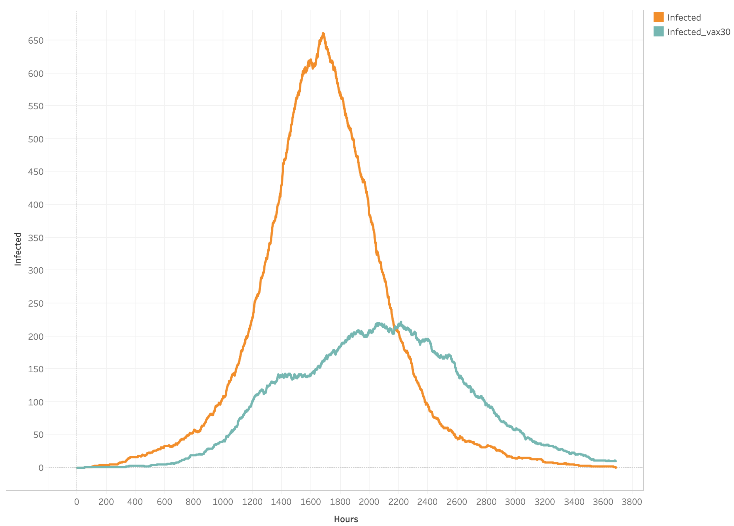

Figure 2: a comparison of the distribution over time of the infected in the case of no actions by the Government (orange Line) and in the case where the vaccine has been distributed (turquoise line)

We can observe how the second distribution doesn't reach the critical amount of infected people as the first one. In other words, in this new setting the healthcare system won't be overloaded, since the threshold of 300 hospital beds is never surpassed. Moreover, the spreading of the virus seems to be diluted over a longer interval of time. In addition, the difference in deaths (Figure 3) is very significant, we move from 61 to only 9, i.e. a reduction of 85%. This can be explained by the fact that when the pandemic reaches its peak in the orange line, the healthcare system is not able to effectively manage all the infects, and as a consequence the mortality of the virus plummets.

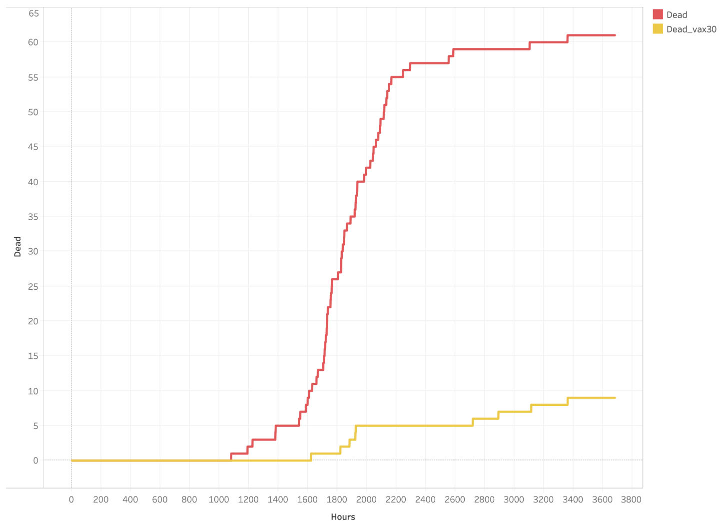

Figure 3: deaths over time in the 'free of restrictions' scenario (red line) and in the 'vaccination of 30%' scenario (yellow line)

To fully understand the effects of the vaccine distributed to 30% of the population we now move to the graph portrayed in Figure 4.

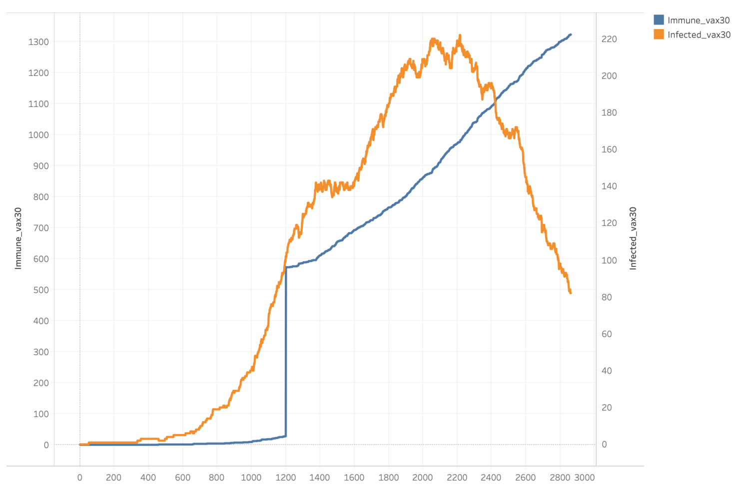

Figure 4: a comparison of the infected (orange line) and the immune people (blue line) over time in the 'vaccine to 30%' scenario

At the moment in which the number of infects reaches 100 individuals the vaccine is distributed to the population, and we can see an instant surge in the number of immune individuals reaching almost 600 individuals. Nevertheless, despite the positive effects of the vaccine that have been shown previously, we can notice that after its distribution, the number of infects still increases for a long period of time before starting to decrease. This means that a coverage of only 30% of the population might not achieve a significant decrease of cases in the short term.

The results are different when the vaccine is given to 60% of the population. From figure 5 we can see that when the vaccine is distributed, the infection is quickly hindered by the large quantity of new immune individuals and, after a brief plateau, it rapidly decreases.

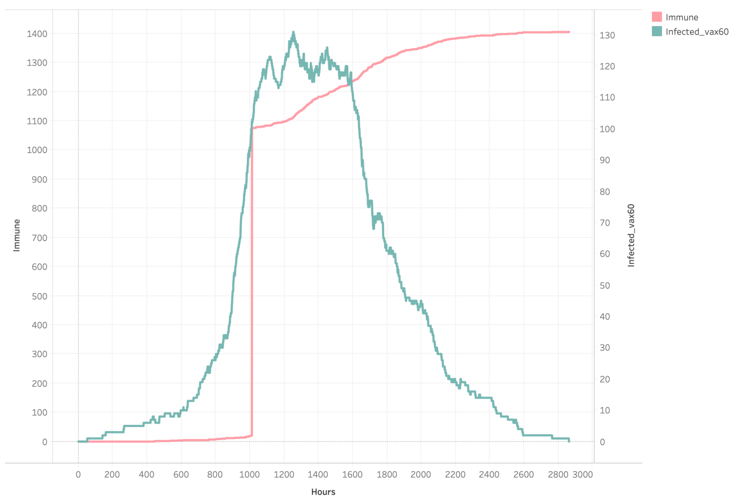

Figure 5: the number of immune individuals (pink line) and of infected (turquoise line) over time in the 'vaccine 60% scenario'

In particular we can compare the two distributions of infected in figure 6.

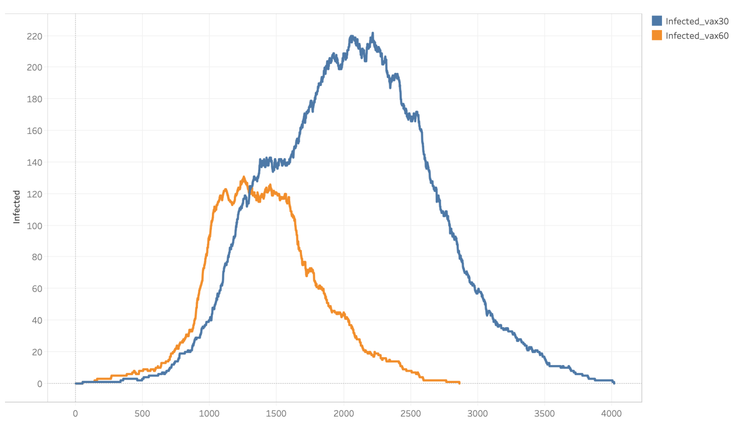

Figure 6: a comparison of infected over time in 'vaccine 30%' (blue line) and 'vaccine 60%' scenarios (orange line)

As expected when we vaccinate 60% of the population the spreading of the virus is much more limited, both in terms of peak reached and in terms of length of the spreading.

We now move to our second research question. Which is a smart way to distribute the vaccine? Will giving priority to the elderly in its distribution create a significant difference? We tried to address this matter in our simulation and the results are depicted in figure 7.

We can observe that in the orange curve, which represents the setting in which the elderly receive the vaccination first, we still have the plateau at the top, but it's for almost half of the time. Whereas the period of time of the spreading are almost identical.

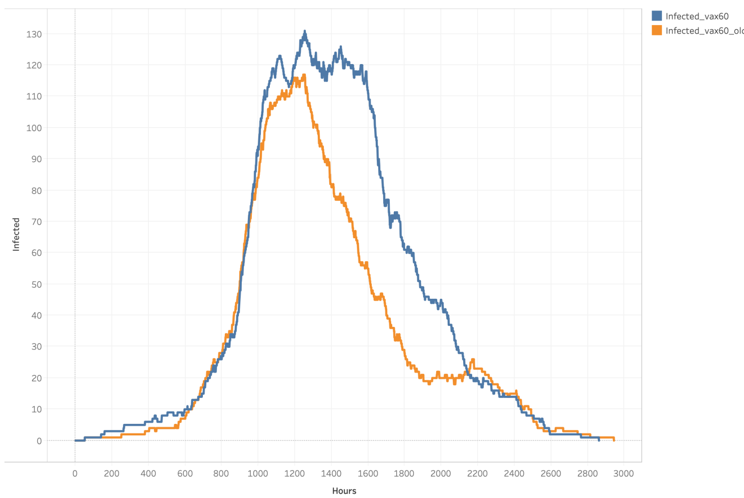

Figure 7: a comparison of infected over time in 'vaccine 60%' (blue line) and in 'vaccine 60% to elderly' (orange line) scenarios

Moreover, from figure 9 we see that in this optimized version the number of deaths further decreases from 5 to 3. Thus, distributing it to elderly people first represents a significant improvement in reducing the effect of the pandemic.

We now move to our last comparison between the vaccine to 60% of the healthy population to elderly first and a lockdown scenario. However, we want to clarify that this will be mostly a qualitative comparison analysis, as our implementation of the lockdown might fail to include some of the many variables that model such a complex scenario.

In actual fact, the results in figure 8 are quite surprising since unexpectedly in the lock-down scenario (green line) the peak reached is much higher than that in the vaccine setting. In the latter the spreading is distributed over a longer period of time, but at levels that are much more manageable. As a matter of fact from figure 9 we can also see that the number of deaths in the lockdown setting is 5 whereas with the vaccine scenario only 3 individuals day.

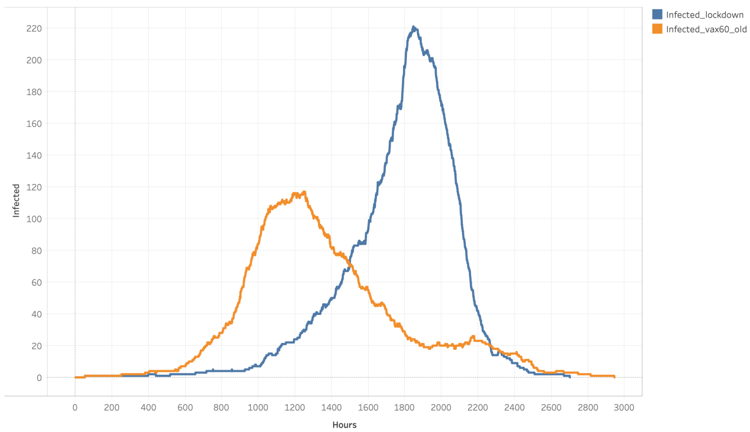

Figure 8: the number of infected over time in 'vaccine 60% (orange line) to elderly' and 'lockdown' (blue line) scenarios

Number of deaths

No restrictions	61
Vax 30%	9
Vax 60%	5
Lockdown	5
Optimized Vax 60%	3

Figure 9: the total number of deaths in all the discussed scenarios

Conclusions and further analysis

In conclusion, we can aver that in order to reach the herd immunity, with a 90% effective vaccine, national healthcare systems are required to vaccinate at least 60% of the population. Moreover, protecting the elderly and the people more at risk first will have a significant impact in both reducing the number of infected and the deaths of the pandemic. The results of these policies will be comparable, if not better, to the ones achieved with a Lockdown scenario. Thus, governments, should this candidate vaccine be made feasible for distribution in the short term, will have a viable alternative to the stringent restrictions applied in many parts of the world right now.

For further analysis the focus should be on expanding the model to better approximate the distribution of the vaccine. As a matter of fact, we have assumed that the vaccine is instantly distributed, in a specific moment in time. However, a more accurate model would account for a growth in the number of vaccines similar to the growth of infected individuals. Therefore, the future version of the model will probably account for the distribution of the vaccine over a period of time, until the required percentage of the population vaccinated is achieved.