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Analysis of the Advantages and Disadvantages of People Wearing Masks in COVID-19 Pandemic: A Game-theoretic Approach

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Abstract: In recent years, a global health shock, Covid-19, has exerted a huge negative impact. Exhibited a high rate of infection and mortality, this pandemic caused tremendous losses in various fields. After studying how virus spread, people find that wearing masks can effectively reduce the probability of infection. However, there are still number of people struggling whether to wear masks or not. In the current paper, based on the probability of infection we construct two matrix models, one for standard players and one for players who have been recovered form Covid-19, to analysis the expected payoff of to being a mask wearer or non-mask wearer. Comparing the expected payoff as number of people increasing in the model, we find a critical point that people are indifferent of wearing masks and not wearing masks and name it as indifferent ratio. According to the results of the model and corresponding analysis, governments are suggested to enforce policies such as wearing masks in public and enable certain social distance. For people who have been recovered from Covid-19, they can choose not to masks in places where few people around them.

Keywords: Covid-19, wearing masks, game theory

1. Introduction

In 2019, a burst of Coronavirus was firstly reported from China. Soon, this pandemic swept over 200 countries and territories, and millions of people were infected [4]. Due to the susceptibility to infection and high mortality of this disease, lots of industries such as tourism, manufacture, and various types of services were forced to shut down [6]. It is not only a global health shock, but it also a global economics crisis [9]. So far till 2022, the most severe pandemic period has been come through, and people find that wearing masks can greatly prevent getting infected in pandemic [8]. Most countries have already cancelled the order of lockdown, and people are allowed to work or socialize with mask on.

However, it is common to find number of people refuse to wear masks in public, even though they are awarded of those policies can reduce the probability of infection and the fact that the pandemic has not fully ended [10]. Taking the perspective of evolutionary game theory and public goods game, we categorize this group of people as free riders [2], since they enjoy the relative virus-free environment without contributing any commitment to maintain common safety [3 & 7].

In the current paper, we interpret this non-compliance behavior through the matrix model. In addition, we take the probability of getting infected on condition of wearing masks or not into account when we compute the expected payoff of players. In doing so, we hope to provide the intuition of non-compliance behavior in a different point of view and help to find more possible insights and mechanism for Covid-19 pandemic regulation management.

2. Model

2.1. Introduction and Assumptions

In the current paper, we construct simple game theory model and calculate each player's expected payoff in the game as the number of players increasing. To establish the model, relevant statistics and assumptions are necessary to clarify.

1. If player has a positive Covid-19 test result, he or she receives (-a) payoff, and if player has a negative Covid-19 test result, he or she receives zero payoff.
2. Mask wearers will receive (-b) payoff due to the uncomfortable experience of wearing masks, and non-mask wearers will receive the payoff of (+b) multiplied by the probability of stay healthy.
3. According to the research conducted by Alihsan et al. on July 31, 2022 [1], the results concluded that in general cases, mask wearers infected by Covid-19 with a probability of 7% and non-mask wearers infected by Covid-19 with probability of 52%.
4. According to the statistical analysis conducted by Ghorbani et al. on June 28 [5], 2021, the result suggested that the probability for people who have been infected by Covid-19 before to get reinfection is about 21%. Therefore, we assume that for them, the probability for them to reinfect by the virus is 0.21 if they do not wear masks. If they wear mask, the probability to reinfect will be 0.01, due to the double protection from masks and antibiotics.
5. We assume that the infection between individuals is independent.
6. We will save three decimal places for statistics.

2.2. Multi-player Infection Model

To derive our multi-player infection model, we start from the simple 2*2 payoff matrix. Based on statistics and assumptions that we established above, we can calculate the expect payoffs of player's different choices.

$$\mathrm{E(wear\ masks)} = [1 - (1 - 0.07)] * (-a) - b = -0.07a - b \quad (1)$$

$$\mathrm{E(not\ wear\ masks)} = [1 - (1 - 0.52)] * (-a) + b(1 - 0.52) = -\ 0.52a + 0.48 \quad (2)$$

Table 1: 2*2 payoff matrix.

Choice	Wear masks	Not wear masks
Wear masks	(-0.07a – b), (-0.07a – b)	(-0.07a – b), (-0.52a + 0.48b)
Not wear masks	(-0.52a + 0.48b), (-0.07a – b)	(-0.52a + 0.48b), (-0.52a + 0.48b)

The 2*2 payoff matrix exhibits the interaction of two players and the payoff each choice. According to our last assumption that the infection between individuals is independent, in the model of n players, an individual will repeat n times this payoff matrix when he or she interact with other players. Therefore, we can derive the expected payoff of different choices in multi-player infection model.

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$$E(\text{wear mask}) = [1 - (1 - 0.07)^{n-1}] * (-a) - b \tag{3}$$

$$E(\text{not wear mask}) = [1 - (1 - 0.52)^{n-1}] * (-a) + b(1 - 0.52)^{n-1} \tag{4}$$

Intuitively, when the expected payoff of not wearing masks exceeds that of wearing masks, players will choose not to wear masks. Based on this basic rule, we can set an inequality to obtain the relationship between the ratio of a and b and players' decision-making.

$$E(wear\ mask) < E(not\ wear\ mask)$$

$$[1 - (1 - 0.07)^{n-1}] * (-a) - b < [1 - (1 - 0.52)^{n-1}] * (-a) + b(1 - 0.52)^{n-1} \tag{5}$$

let $(1 - 0.07)^{n-1} = x$; $(1- 0.52)^{n-1} = y$

$$(1 - x) * (-a) - b < (1 - y) * (-a) + b * y \tag{6}$$

$$a / b < (1 + y) / (x - y) \tag{7}$$

$$a / b < [1 + (0.48)^{n-1}] / [(0.93)^{n-1} - (0.48)^{n-1}] \tag{8}$$

Therefore, once a/b ratio is smaller than $[1 + (0.48)^{n-1}] / [(0.93)^{n-1} - (0.48)^{n-1}]$, players will choose to not wear masks. We denote a/b ratio that is equal to $[1 + (0.48)^{n-1}] / [(0.93)^{n-1} - (0.48)^{n-1}]$ as indifference ratio, because at that time, players are indifferent of acting different choices. The following table present the indifference ratio of a/b as n increasing from 2 to 7.

Table 2: Value of a/b as n increasing from 2 to 7.

n	2	3	4	5	6	7
a/b	3.289	1.930	1.601	1.515	1.530	1.595

2.3. Multi-player Infection Model of Reinfection

In the study conducted by Ghorbani et al. and assumption, we have established that the probability for them to reinfect by the virus is 0.21 if they do not wear masks. If they wear mask, the probability to reinfect will be 0.01. Then, repeating the previous calculation, we can obtain:

$$E(wear\ mask) = [1 - (1 - 0.01)^{n-1}] * (-a) - b \tag{9}$$

$$E(not\ wear\ mask) = [1 - (1 - 0.52)^{n-1}] * (-a) + b(1 - 0.52)^{n-1} \tag{10}$$

Let $E(wear\ mask) < E(not\ wear\ mask)$

$$a / b < [1 + (0.79)^{n-1}] / [(0.99)^{n-1} - (0.79)^{n-1}] \tag{11}$$

Similarly, we can create a table of the change of a/b indifference ratio of as n increasing.

Table 3: New value of a/b as n increasing from 2 to 7.

n	2	3	4	5	6	7
a/b	8.95	4.562	3.128	2.433	2.033	1.780

3. Discussion

As we presented in assumptions, a is the payoff of people who do not wear masks and get infected by Covid-19. To be more specific, a can be considered as the risk of being non-mask wearers. b stands

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for the payoff of wearing masks. a/b represents the ratio of the risk of not wearing masks and the payoff of wearing masks. Typically, we expect the value of this ratio to be small: lower risk of not wearing on numerator and (or) higher payoff of wearing masks on denominator.

In the Multi-player Infection Model, connecting the ratio of a and b with the decision-making of people in the game, we find a critical point which we denote as the indifferent ratio of a and b. When a/b is equal to this indifferent ratio, players will be indifferent between wearing masks and not wearing masks. Accordingly, when the actual a/b is smaller than the indifferent ratio, people will choose not to wear masks, vice versa.

From the further analysis in Multi-player Infection Model, we know that the indifference ratio of a/b is determined by a function of n, where n is the number of players in the game. As we represented in the model with a table of n increasing from 2 to 7, we observe that the value of indifferent ratio of a/b decreases first and then increases. If we illustrate the deviation of indifferent ratio as n increasing on a graph, we can see a concave-up shape of curve. The intuition behind this shape is that theoretically, the higher population density, the higher risk of Covid-19 infection [11]. As the number of people in the model increases, the probability and risk of an individual to infection increases as well. When n achieve certain amount, the increment rate of risk on numerator will exceed the increment rate of wearing masks on denominator. Then, the curve will exhibit an upward-sloping trend.

We also derive the Multi-player Infection Model for people who have been recovered from Covid-19. Since this group of people have lower probability of reinfection if they do not wear masks and nearly zero probability of reinfection if they wear masks, with all else set equal, they will have a higher indifference ratio compared with standard players. This means that the chance that their indifference ratio higher than the actual a/b will be greater than that of standard players, leading them to choose not to wear masks with higher probability.

4. Conclusion

To sum up, the effectiveness and importance of wearing masks to prevent Covid-19 infection have been proved. Consequently, it is beneficial for governments to strengthen policies in epidemic management. They can issue policies and public announcements to reduce the number of people gathering as much as possible, to avoid the increase in the risk of infection caused by the large number of people. At the same time, people are still advised to wear masks. In the Multi-player Infection Model, it presents that for people who have been recovered from Covid-19, their infection probability is small even though they choose not to wear masks. So, for these group of people, they are not necessary to wear masks in where the number of people around them are relatively small and enjoy the comfortability of not wearing masks. However, it is still recommended for them to wear masks when they are surrounded by large number of people.

Several countries around the world have well shown how to contain the outbreak and reduce the risk. Take China as an example. China's Covid-19 regulation managements, for example people are compulsory to wear masks in public, are effective. Therefore, if human want to reduce the new cases or eliminate Covid-19 pandemic, more effective policies and the cooperation of masses are needed. The current paper is not only helpful for governments to establish effective pandemic regulation management, but it also provides suggestions to people's decision-making of wearing masks under Covid-19 pandemic.

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