Studies of Human Behavioural Patterns During the COVID-19 Pandemic Using Evolutionary Game Theory – Prisoner's Dilemma

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DECLARATION

The project report submitted herewith is a result of my own efforts in totality and in every aspect of the works. All information that has been obtained from other sources had been fully acknowledged. I understand that any plagiarism, cheating or collusion of any sort constitutes a breach of Tunku Abdul Rahman University College rules and regulations and would be subjected to disciplinary actions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **STUDIES OF HUMAN BEHAVIOURAL PATTERNS DURING THE COVID-19 PANDEMIC USING EVOLUTIONARY GAME THEORY – PRISONER'S DILEMMA** was prepared by **CHEW HWA ERN** and has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Hons.) Management Mathematics with Computing at Tunku Abdul Rahman U niversity College.

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Specially dedicated to

The suffering community and frontliners in Malaysia.

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ABSTRACT

This study aims to expand the knowledge put out by previous researches regarding the relationship between evolutionary game theory and a pandemic. In this study, we study the human behavioural patterns for the vaccination strategy in Malaysia during the COVID-19 Pandemic by using Evolutionary Game Theory – Prisoner's Dilemma. By simplifying the payoff matrix in Prisoners Dilemma using the cost to benefit ratio *r*, we are able to investigate whether the human behavioural patterns in the vaccination strategy meet the evolutionary stable strategy of Prisoner's Dilemma, the defective strategy. In Prisoner's Dilemma, individuals are likely to choose to defect regardless of what the opponent chooses. However, to achieve herd immunity, cooperation is vital. During the Covid-19 pandemic, individuals are likely to choose not to take the vaccine if the risk of side effects is high even though vaccination program is vital to build community immunity. The findings of the study show that human behavioural patterns in the vaccination strategy meet the evolutionary stable strategy of Prisoner's Dilemma when the risk of side effects (cost to benefit ratio) is greater than 0.2. Thus, to build community immunity through the vaccination program, the risk of side effects should be reduced.

Keywords: Prisoner's Dilemma, Evolutionary Game Theory, Vaccination Strategy, Cost to Benefits, Cooperate, Defect, Human Behavioural Patterns.

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INTRODUCTION

1.1 Background

With the outraging spread of Coronavirus-19, the Malaysian government has taken many precautions by implementing new standard operating procedures in hopes to contain the spread of the virus such as enforcing social distancing rules in public areas to reduce unnecessary interaction between individuals, limiting business hours, forbidding the crossover between states and districts, prohibition of dining in restaurants, etc. However, all efforts seemed to have gone in vain as it is difficult to ensure the cooperation of the entire population. Moreover, the new norm has deprived many of social interactions and has limited the freedom of individuals, at the same time ceasing businesses to operate, causing some to find it difficult to comply and make ends meet. Herd immunity is the ultimate goal to control the spread of an infectious disease especially one such as contagious as the Coronavirus. (Abdullah, 2021) Hence, an appropriate vaccination strategy is to be taken to ensure herd immunity is achieved. This can greatly reduce the COVID-19 cases in Malaysia not to mention reinstate the pre-COVID lifestyle in Malaysia.

As vaccines take time to be developed, the ongoing-rapid evolution of the coronavirus adds to the difficulty of vaccine development. With new variants of the virus being discovered, vaccine advancements are slow to keep up. Dr Noor Hisham Abdullah, the Director-General of Health Malaysia and Senior Consultant in Breast, Endocrine & General Surgery has also mentioned that the threshold to achieve herd immunity for Covid-19 is still being studied, unlike polio and measles which require 80% and 95% of a population to receive vaccination respectively. (Abdullah, 2021) However, the only way to keep the population protected from the virus is by providing the available vaccine to the resilient group in order to minimize the threat to the vulnerable.

Consequently, the Malaysian government bears the heavy burden to make a quick-witted decision to achieve herd immunity efficiently and effectively. In order to ensure the vast majority of the population chooses to receive vaccines concomitantly, identifying the human behavioural patterns in the pandemic through evolutionary game theory aids the planning of a deliberate vaccination strategy. As the vaccine poses risks of side effects such as fever, chills, body ache, etc, people may feel sceptical and reluctant to receive the vaccine. Furthermore, some believe that due to the urgent needs of the covid vaccine, some pharmaceutical makers may have compromised stages of the development cycle of a vaccine, (i.e., the phase 3 clinical trial which is also known as large-scale testing and researching different development stages simultaneously) due to the time constraints. (Shah, 2020) According to WHO, not all potential risks and side effects have been studied with the varying reactions towards the vaccine on different individuals, which have instilled more doubts on the benefits of the vaccine. (WHO Team, 2020)

Admittedly, it is a rather difficult task to ensure the entire population will accept and receive the coronavirus vaccine though it is a subsidized expense incurred by the Malaysian Government. However, mathematical biologist Chris Bauch stated in an interview, that the COVID-19 pandemic can be explained by a type of game in game theory - The Prisoner's Dilemma. (Roberts, 2020) He also stated that some people may play a ‘wait-and-see’ game in the face of uncertainties and concerns towards the COVID-19 vaccine. (Bhattacharyya & T. Bauch, 2011)

The portion of the community who chooses not to receive vaccinations will receive the benefits of the lowered transmission rate of the virus when a certain threshold of herd immunity is achieved. (L.Mallory, et al., 2018) However, vaccine receivers within the population are posed at a disadvantage as they not only have to expose themselves to the risk of the side effects but also compromised the rate of virus transmission as the virus can still be spread quickly within the unvaccinated community. (Oxford Vaccine Group, 2019) This situation could be related to The Prisoner's Dilemma, where defectors are benefited while the co-operator is at disadvantage. This generates a collective threat to vaccine receivers while opted-out individuals reap the fruit equally. (Bauch & Earn, 2004) Hence, displaying a general trend that the pandemic can be explained by one of the types of games in game theory - The Prisoner's Dilemma.

1.2 Game Theory

Game theory is a game that aids the strategizing of a decision-making problem among rational or irrational decision-makers by the use of a mathematical model. The Game theory is founded by John von Neumann, a mathematician, and Oskar Morgenstern, an economist back in the 1940s. They have pioneered and broken the grounds of a completely new mathematical and economic theory that revolutionized a whole new field of economics and social sciences altogether. (Neumann & Morgenstern, 1944)

Game theory is most commonly used to break down and simulate a real-world situation to analyse and strategize a solution that yields the best payoff with the use of a mathematical model. Game theory is also utilized in the analysis of a mathematical model used to strategize decision making when two or more individuals make decisions that will affect the welfare of the related parties as a whole which is also known as the payoff of the game. (Myerson, 2013)

There are several types of games in game theory that can be used based on the various natures of the problem such as Cooperative and Non-Cooperative Games, Constant Sum, Zero Sum, and Non-Zero-Sum Games, Symmetric and Asymmetric Games, etc. One of the most famous games in game theory is known as The Prisoner's Dilemma Game which is a cooperative and non-Cooperative game that was unfolded in the 1950s by employees at the Rand Corporation, an American research and development non-profit global policy institution, Merrill Flood and Melvin Dresher. It was then ratified and named by a Princeton mathematician, Albert William Tucker in the 50s as a response to the complexity in analysing different types of games in games theory. The Prisoner’s Dilemma was named after the prison’s sentence rewards. (Poundstone, 1992) However, The Prisoner’s Dilemma game is now more widely used to study human behaviours in decision making and other situations such as various vaccinations strategies. The Prisoner’s Dilemma game is a game that involves two players with different possible strategies known as Confess (“Co-operate”) and Not-confess (“Defect”). (Turocy & Stengel, 2003)

The Prisoner’s Dilemma game is a standard model used to study the short term decision making of individuals who do not have any expectations on future interactions with other individuals (Tey, 2017) The dilemma arises when two completely “rational” individuals have the freedom to co-operate yet might choose not to even though it appears to be in their best interest to do so, displaying conflicting situations in terms of societal and organizational constructs.

The evolutionary game theory used in this study is the Prisoner’s Dilemma game, which takes into consideration the population payoff in a well-mixed population where players get equal chances in pairwise interactions, interacting with each player at least once. In regards to the evolutionary Prisoner’s Dilemma used in this study - Replicator Dynamics is employed to analyse the relationship between each character change amongst a well-mixed population with the cost to benefits ratio in the COVID-19 pandemic. The evolutionary game theory is used instead of the traditional game theory as it eliminates and offsets the rationality in the decision making of an individual. The traditional game theory in Prisoner’s Dilemma only takes into account the payoff of an individual in decision making which tends to be biased and irrational, hence, evolutionary Prisoners Dilemma game theory is used to obtain the average population payoff.

The Senior Assistant Professor and Head of the Department of Economics at the Daulat Ram College, University of Delhi India, Malini Sharma states that in order to achieve the best payoff with most benefits, collective rationality is vital in ensuring the most efficient outcome. However, the most efficient outcome comes with a price as it is unstable while players have a unilateral incentive of a higher payoff for themselves when choosing to deflect. (Sharma, 2020)

Thus, when individuals choose not to receive vaccines due to their self-interests the public health is collectively jeopardized by a lower payoff. While mutual defection displays the unique dominant strategy in this case, (Pimenta & Canaan, 2021) Nash equilibrium, a state where none of the players can improve the game's payoff by any unilateral changes in strategies, is reached. (Nash, 1951) This is explained by the paradox of defecting becoming the dominant strategy due to individual decisions made based on self-interests, while cooperation, which gives the best outcome as a whole, is unmet. (Stoddard, et al., 2021) This reinforces the choice made to use evolutionary game theory instead of the traditional game theory.

Each strategy in Prisoner's Dilemma gives different payoffs. The Prisoner's Dilemma game is played by pairwise interactions within a population. When both players decide to co-operate, the payoff of the player will be represented by P; when the player defects and the opponent decides to co-operate, the payoff of the player is R, which is a higher payoff compared to when both players co-operate. When one player co-operates but the other decides to defect, the player's payoff is Q, which will give the lowest payoff, while if the opponent plays defect as well, the payoff is rendered as S which is 0. The payoff matrix is shown as:

	Co-operator	Defector
Co-operator	P	Q
Defector	R	S

Figure 1: Prisoners Dilemma Payoff Matrix

In this study, we are studying the human behavioural patterns during COVID-19 for the vaccination strategy in Malaysia. In essence, payoff P can only be obtained if both players choose to cooperate and receive vaccination, which is the ultimate goal to reduce the transmission of the Coronavirus. When the payoff is P, both players can obtain the benefits with the same amount of cost. Defection, which is to refuse vaccination, on the contrary, will end in no costs nor benefits for both parties. The payoff matrix satisfies the argument where $R > P > S > Q$ and $2P > R + Q$. (Hauert & Szabo, 2003) The payoff matrix will be explained further in detail in Chapter 3.

1.3 Aims and Objectives

Since the vaccination strategy is considered a governmental investment decision, social costs are to be incurred to ensure Malaysian populations are protected from the virus without having to incur unnecessary expenses on top of the struggles of the crippling economy due to the pandemic lockdown. Hence, an appropriate strategy is to be taken. With that said, this study aims to study the human behavioural pattern during the COVID-19 pandemic for the vaccination strategy in Malaysia using Evolutionary Game Theory. The evolutionary game theory used in this study is the Prisoner's Dilemma. By that, we want to prove that the human behavioural patterns during the COVID-19 pandemic can be modelled by the Prisoner's Dilemma game. This makes the simulation of the real-life situation possible that can be used in analysing the human behavioural pattern in a well-mixed population.

Based on past findings, it is likely that conventional models do not take into consideration the cooperation of the populations in the vaccination strategy. One of the objectives of this study is to analyse the human behavioural patterns and the role of payoff incentives in the vaccination strategy from the past using evolutionary game theory to better tackle the vaccination problems that are faced due to the pandemic. This is because people have different views and make different decisions be it for themselves or the interests of the group. Thus, this study is done to realise the impact various behaviours of individuals have in a dilemma of vaccine strategy. Moreover, this research is conducted to identify the dominant strategy in the dilemma by recognizing the important factors that influence the vaccination decision an individual makes.

The expected outcome of this study is to show that the pandemic - COVID-19 can be modelled by the Prisoner's Dilemma game using graphical analysis and with that, the effects of payoff incentives in human behaviours for the vaccination strategy of COVID-19 in Malaysia.

1.4 Project Scope

This study intends to further expand the knowledge put out by previous researches regarding the relationship between evolutionary game theory and a pandemic. To be specific, the game theory used in this study is the Prisoner's Dilemma Game in the COVID-19 pandemic. Previously, not many in-depth studies have been done on a world-scaled pandemic. Hence this research aims to contribute to the existing knowledge on vaccination strategies amongst a pandemic and develop sufficient understandings pertaining to the vaccine strategies in terms of an epidemic outbreak. Some theorems and corollaries have been studied from the aspects of the theoretical evolutionary game theory.

Books, journal articles and news articles that are relevant have been studied to expand the knowledge on evolutionary game theory. The book "Game theory Encyclopedia of Information Systems, Volume 2" written by (Turocy & Stengel, 2003), "Game Theory" written by Roger B. Myerson (Myerson, 2013), journal articles published by professionals whose areas of expertise revolve around the game theory such as "Vaccination and the theory of games" written by Dr Chris Bauch and David Earn (Bauch & Earn, 2004), etc have been read and studied.

Up to at least 20 or more journals and books have been read to develop further understanding of game theory and its correlation with different vaccination strategies and human behavioural patterns. This is to determine the most relevant and suitable game theory to be used in this case study. The Prisoner's Dilemma Game is found to be the most appropriate game to explain the human behavioural patterns in a vaccination strategy. (Axelrod, 1980)

Due to recent happenings of the COVID-19 pandemic, not much study has been made regarding the human behaviours in this epidemic. Hence, related journals were studied to get a general grasp of how the game theory applies to the trends of human behaviour patterns in a pandemic. More publications regarding the vaccination strategy in relation to game theory, specifically the Prisoner's Dilemma has also been studied in order to model the different behaviours of different individuals in decision-making during a pandemic. A model is to be built in Python to analyse the changes in proportions of strategies of a Prisoners Dilemma game with the cost to benefits ratio for the vaccination strategy in Malaysia during COVID-19. The average population fitness on the vaccination strategy among a well-mixed population is used in Replicator' Dynamics to iterate the game plays.

CHAPTER 2

LITERATURE REVIEW

2.1 Past studies on vaccination strategy during the COVID-19 pandemic

The investigation of evolutionary game theory gave some rather gripping results on the COVID-19 pandemic to interpret the human behavioural patterns in decision making among a population. In recent findings, a simulation model has been crafted by (Pimenta & Canaan, 2021) in accordance with the Prisoner's Dilemma theory to determine the effects of individual and collective behaviours during the COVID-19 pandemic in Brazil. Pimenta and Canaan state that it is crucial for individuals within a population to cooperate with the sanitary measures in order to reach a collective benefit in terms of public health security in the case of COVID-19. The decisions an individual makes to cooperate or defect with measures to social distance, mask-wearing, etc, will be externalised and shared across the population. The simulation explains that according to Prisoners' Dilemma, the Brazilian community is likely inclined to mutually defect and choose not to comply with sanitary measures as it is human nature to prioritize an individual's self-interest. This will compromise public health when the community collectively defects. Hence, they have concluded that public interventions are required to balance off the strategy by coordinating the population's behaviour towards cooperation.

According to an interview (Roberts, 2020) carried out, an epidemiologist and director of the Yale Centre for Infectious Disease Modelling and Analysis, Alison Galvani also states that self-interest-based decisions cause a rather insignificant coverage within the society collectively. Hence it shows that human behavioural patterns show a significant impact on vaccine decisions made.

In another study conducted by (Hoh & Mee , 2020), a conceptual framework is constructed to display the interdependencies between the COVID-19, social dilemmas and other negative corollaries. It is found that COVID-19 has caused social behavioural reactions among a population such as fear, anxiety, uncertainty, and greed which triggered a social dilemma, conflicting between personal and collective interests. This is further elaborated by the behaviour of opportunists' selfish acts that prioritize their own interests at the expense of others for short term benefits such as panic buying, refusing to comply with the laws and government policies. Every little makes a mickle, the self-rationality accumulates to contribute to aggravating the subsisting externalities namely longer lockdown phases, inconveniences that come with restricted movements and the surging of COVID-19 cases.

Over and above that, (Brüne & Wilson, 2020) have reviewed relevant evolutionary insights as to how people react to a pandemic and the repercussions of a pandemic in the absence of a vaccine. In this case, the Coronavirus SARS-CoV-2 is modelled on the grounds of evolutionary game theory to mock situations in which individuals decide to cooperate or defect. Public Goods Game was used in the disquisition as the researchers found it most relevant regarding the research where public health is treated as "Public Good". The game works by involving any number of players with a fixed number of tokens who will then invest their tokens in a common pool, also known as the public good, at the same time. The game host then redistributes the token in equal shares, benefiting all players equally, regardless of how many tokens were first invested by each player (Brandt, et al., 2006). Dr Brüne and Dr Wilson revised the social behavioural patterns in terms of the pandemic with the Public Good Game and predicted that cooperation (in terms of complying with sanctions such as keeping social distance and wearing face masks) will decrease over time in the absence of public health regulations. The research shows that the main adaptive responses to the pandemic are behavioural immune system (BIS) and sickness behaviour (SB).

2.2 Human behavioural patterns in other vaccination strategies

In 2011, (Wu, et al., 2011) conducted a study using a game-theoretic model with an epidemiological process to solve the significant challenge faced by The Administration and Practise of Public Health in ensuring herd immunity by voluntary vaccination, which was rendered much more complex by vaccinations sources that may not be trustworthy. It is also uncertain on the impact of vaccine effectiveness on an individual's vaccination choices. The study perceives that when vaccine efficacy improves, the percentage of people that successfully receives vaccine rises weakens the virus strains from being transmitted. When it comes to vaccination, it is discovered that when the disease is severe, all people are willing to get vaccinated for an intermediate vaccine efficacy due to their self-interests.

However, according to another study coordinated by (Bhattacharyya & T. Bauch, 2011), the Nash equilibrium model explores the results of two strategic interactions between I) the proportion of vaccination in a well-mixed population and the vaccination cost and II) the number of individuals vaccinated and the virus-infected probability of susceptible individuals. The Nash Equilibrium strategy demonstrates the "wait and see" motive whereby individuals who choose not to receive vaccination pins their hopes on the vaccine co-operators for herd immunity not to mention waiting on the vaccinated to "test the waters" on the safety of the vaccines. The study concluded that the "wait and see" behaviour contributes to the lengthened duration of the epidemic peak, and further explains that the Nash equilibrium model shows not only feedback mechanisms but also feed-forward mechanisms where the initial presumed costs of vaccination perpetuate the future perceived costs of vaccination and determines the vaccine coverage in a population for as long as the outbreak of the pandemic may last.

On top of that, an experimental study has also been orchestrated regarding the free-riding behaviour of individuals when making decisions regarding vaccinations. In 2014, (Ibuka, et al., 2014) experts interpreted that vaccination choices made of an individual are likely to affect the choices of their peers as well. The study conducted investigated the effect of the vaccination decision of an individual in a group setting for a notional disease known as "influenza" with a hypothetical vaccination for said disease with the aid of a computerized probe game. The experiment carried out had controlled conditions by certain parameters on the characteristics of both the vaccines and the disease. Descriptive statistics were used to evaluate the results gained from the experimental design on the relationship between the proportion of participants who choose to receive the vaccine and the parameters such as cost of vaccines, risk of infection and severity of influenza. On another hand, researchers used multilevel logistic regression models to study the free-riding behaviour within the group and found that when the proportion of vaccination of participants in the group increases, the less likely an individual would choose to get vaccinated in the following round. This insinuates a free-riding motive regardless of the conditions or parameters of both influenza and vaccine. The study also concluded that the chances of a participant receiving the vaccine are higher when the participant had higher exposure to influenza.

According to (Li, et al., 2017), the new prediction model and vaccination strategy proposed for infectious diseases also take into account the network properties such as clustering coefficients and degrees that affect a person's ability to influence the decisions others make and the density of a network, known as clustering coefficients. They have found that these are two important factors on a disease' widespread among a population while making allowance for instances of when the vaccine fails, i.e., vaccine infecting vaccinated individuals. The prediction model deduced in the study exhibits that vaccination strategies of infectious diseases are affected by the social network structures and the initiatives people take to receive a vaccine due to individual differences.

Another study administered by (Liu, et al., 2011) conveys that vaccination coverage motivated by self-interest (Nash vaccination) is typically smaller than group-optimal coverage, according to epidemiological game-theory research (utilitarian vaccination). A game theory model is simulated and was extended to the United States and Israel, which have different vaccine programmes, vaccination and care costs, and vaccination coverage ranges. This is to explore the impact of these externalities on the partnership between Nash and utilitarian vaccination coverages for chickenpox. In both the United States and Israel, it is found that when chickenpox severity rises with age, the conventional association between utilitarian and Nash vaccine coverages may be reversed. While vaccine costs are high, the model indicates that incentives or external control can be used to gain herd immunity from chickenpox vaccination.

For good measure, according to (Chapman, et al., 2012), individuals with age are more susceptible to transmission of disease as there is a higher mortal rate among elder individuals. With that said, they are found best protected from the transmission of diseases through the vaccination of young individuals, who are said to be the biggest contributors to the spread of disease. The study targets 2 groups: younger groups and older groups, pay-out incentives were offered in the game individually and by groups. When players are paid individual points, it shows that a higher percentage of the older group received vaccines compared to that of the younger group due to their self-interest behaviour. Whereas group benefits were prioritized when players were given points according to group point totals, more younger players received vaccines compared to the older group, achieving a higher point total. This study was conducted to learn their behavioural pattern in the vaccination strategy and concludes that the payoff in a vaccination strategy is dependent on the decisions everyone makes cumulatively as some act on self-interest and others are willing to act at a cost to benefit the group as a whole.

On another end, in a study conducted in 2014 (Capraro, et al., 2014) via one-shot Prisoner's Dilemma experiments, 308 game players were given 10 monetary units to decide how much to transfer to their partners. The transferred unit is then multiplied by a constant value of benefits to cost ratio. The benefits to cost ratio is varied within a specified range and made known to each player prior to their decision-making process. It is found that with a higher benefit to cost ratio, game players are less likely to transfer nothing and more likely to give everything. However, the benefit to cost ratio does not affect players who transfer half their ration. In sum, the study has concluded that through the decision-making process in a one-shot Prisoner's Dilemma game, individuals who cooperate are sensitive to the payoff of others and uses simple heuristics. This shows a deviation from traditional models of the self-interested decision-making process.

Over and above all, many studies have been done to study the human behavioural patterns in various vaccination strategies, it shows an overall pattern that the decisions made displays strong relations to the success or failure of a vaccination strategy, and most decisions made are often based on self-interest. This is where the importance of evolutionary game theory comes as the rationality of players is not required as the notion of a player is substituted by that of the strategy that they choose which are passed on to other players through interactions. The system is driven by the differential success of the strategies rather than the rationality of the players.

There have also been recent studies that have covered the grounds of human behavioural patterns on the cooperation or compliance of safety guidelines, behavioural dynamics on economic shutdowns and shield immunity, quarantine and isolation policies during the COVID-19 pandemic. Hence, our study aims to cover a wider area by studying the human behavioural patterns during this pandemic for its vaccination strategy using evolutionary game theory which is the Prisoner's Dilemma game.

Based on past findings, most models include collecting data by carrying out a game that requires many players to participate to find the payoff in the different games in game theory used.

CHAPTER 3

METHODOLOGY

3.1 Payoff Matrix

This research involves the study of the relevance of game theory in the human behavioural patterns in vaccine strategy during the COVID-19 pandemic. In this case, the Prisoner's Dilemma game is used to model the pandemic as a game. The target players of this study are individuals of a large well-mixed population with two strategies known as "cooperate" and "defect". The joint behaviour of the pairwise players in the game is usually expressed in the form of a payoff matrix:

	Co-operator	Defector
Co-operator	P	Q
Defector	R	S

Figure 2: Prisoners Dilemma Payoff Matrix

The evolutionary Prisoner's Dilemma is usually framed in terms of fitness benefits *b* and costs *c*, where *b* is when the player chooses to receive the vaccination to reap the benefits and *c* represents the risks players take to co-operate in receiving vaccination such as the side effects that they may face or the possibilities of their body rejecting the vaccines.

When both players co-operate and receive vaccination, the payoff is represented by P, where P = *b* – *c*. This shows that mutual co-operation produces fair results for both players as players are putting in the same amounts of effort by being exposed to the same amounts of risks in terms of costs, to receive the same benefits between both players. Conversely, when both players defect and opt-out from the vaccinations, the spread of the virus remains unruly and intractable, represented by S, where both players are not benefited at zero costs.

Nonetheless, when one player decides to co-operate and receive the vaccine and the opponent decides to defect by rejecting the vaccine, the payoff of the player will be represented by Q, where Q = -*c*. This is because the player has to bear the risks of receiving the vaccine, which dominates over the benefits received between both players. However, if a player defects and the opponent co-operates, the payoff of said player will be R = *b*. This is said as the player that defects do not have to take risks to turn to the opponent's (co-operator) advantage, the reduced transmission of coronavirus. (Turocy & Stengel, 2003) The payoff matrix satisfies the argument where R > P > S > Q and 2P > R + Q. (Hauert & Szabo, 2003)

The payoff P > S is explained by the superiority of mutual cooperation being greater than mutual defection. (Bravetti & Padilla , 2018) This is said as the best outcome is when all players co-operate and opt to take the vaccine, which will increase efficiency in attaining herd immunity in the population as fast as possible. The payoff relationship where R > P and S > Q shows that defection is always the dominant strategy and will always yield a higher payoff no matter what strategy the opponent chooses. The payoff R is said to be the highest payoff as the benefits are obtained at no costs, followed by payoff P, when each player co-operates to achieve the same amounts of benefits. Payoff S, however, yields a higher payoff than Q even when S = 0. This is because both players receive no benefits at zero costs. Q yields the lowest payoff as the defector's benefit, the lower virus transmission rate is being shared between both players at the player's own cost. The payoff matrix below is represented in terms of benefits and costs:

$$\begin{array}{cc} & \begin{array}{cc} \mathrm{C} & \mathrm{D} \end{array} \\ \begin{array}{c} \mathrm{C} \\ \mathrm{D} \end{array} & \begin{bmatrix} b-c & -c \\ b & 0 \end{bmatrix} \end{array}$$

Equation 1

Co-operators (represented by 'C') are players who choose to receive the COVID-19 vaccination voluntarily whereas Defectors (represented by 'D') are those who choose not to receive the COVID-19 vaccination. Equation 1 shows the matrix elements in terms of benefits and costs that a player obtains from playing a game.

To obtain a better analysis of the simulation model using a cost to benefits ratio, we simplify the payoff matrix where *r* represents the cost to benefits ratio. This is to see the fraction of each character's (Co-operator and Defector) change with *r*. (Doebeli & Hauert, 2005) By introducing *r*, we can also simplify and reduce the variables while analysing the relationship between the cost to benefits ratio and the frequency of defectors. The benefits in the payoff matrix are represented by *b,* whereas the cost is represented by *c.* Hence, the cost to benefits ratio is deduced by

$$r = \frac{c}{b-c}\ , where\ \ 0 \leq r \leq 1$$

Equation 2

To simplify the payoff matrix with *r*, we divide the matrix by $b - c$, with that we obtain:

$$\begin{bmatrix} 1 & \frac{-c}{b-c} \\ \frac{b}{b-c} & 0 \end{bmatrix} = \begin{bmatrix} 1 & -r \\ 1+r & 0 \end{bmatrix}$$

Equation 3

$$when\ b - c = 1\ ,$$

$$b = 1 + c$$

$$b = \frac{1+c}{b-c}$$

$$b = \frac{1}{1} + \frac{c}{b-c}$$

$$b = 1 + r$$

$$-c = 1 - b$$

$$-c = 1 - (1 + r)$$

$$-c = -r$$

When the payoff matrix is simplified in terms of *r*, the cost to benefits ratio, where $0 \leq r \leq 1$, each fraction of character change with *r* is shown.

$$\begin{array}{cc} & \begin{array}{cc} \text{C} & \text{D} \end{array} \\ \begin{array}{c} \text{C} \\ \text{D} \end{array} & \begin{bmatrix} 1 & -r \\ 1 + r & 0 \end{bmatrix} \end{array}$$

Equation 4

Equation 4 shows the simplified payoff matrix in terms of *r*, where $r \in (0, 1)$. The payoff matrix in terms of *r* shown in Equation 4 satisfies the argument where 1 + *r* > 1 > 0 > -*r*. After simplifying the payoff matrix, we are able to use replicator dynamics to iterate and to investigate the relationship between the frequency and cost to benefits ratio. By obtaining the ratio of both fraction of players and the cost to benefits, we are able to examine the vaccination choices that vary with cost and benefits by the fitness of population from pairwise interactions in a well-mixed population by eradicating the need of quantifying the cost and benefits in this study. The costs and benefits will be further deciphered in Chapter 4.

3.2 Replicator Dynamics

Replicator dynamic is the mathematical tool that can be used to apply the evolutionary game theory to our behavioural model to find the evolutionary stable strategy known as the ESS. (Hofbauer & Sigmund, 1998) A great load of studies has been conducted on the properties and applications of the replicator equation. The replicator equations have been used in many studies on behavioural models using evolutionary game theory in aspects of economical biology and social sciences. It was introduced in the late 70s by Peter D.Taylor and Leo B.Jonker (Taylor & Jonker, 1978) and was used to determine the evolutionary stable strategy to describe a stable state of a game. It is used to describe the evolution of frequencies of the change in each fraction of strategies by taking into consideration their fitness and mutual influence.

The Replicator Dynamics used in this behavioural model takes into account the fraction of co-operators and defectors in a repeated game where players from a well-mixed population interact with each other at least once. The mean fraction of co-operators and defectors is then used to calculate the fitness of the population. Based on a study conducted by (Kim, et al., 2014), the replicator dynamic motives are said to be the building blocks in understanding the behaviours of the strategies in Prisoner's Dilemma games.

According to evolutionary biology, players in the games are paired at random and strategies are chosen are genetically determined. Reproduction is asexual and individuals breed true. Each individual engages in one game per round by playing their chosen strategy. Considering a one-dimensional space as an example, players from a finite well-mixed population are arranged in a row and each player interacts with their respective neighbours. The average payoff and mutual fitness are obtained from this game. The group will eventually converge to the same periphery when we assume that similar individuals cluster and any changes of a fraction of players are dependent on the fitness of members of the groups that they interact in. Hence, the evolutionary equilibrium state is dependent on the frequency of the population and also the spatial configuration of individuals playing various strategies. (Skyrms, 1994)

Evolutionary fitness is used in determining the payoffs and the replicator equations of our behavioural model are:

$$\dot{x}_i = x_i\left[f_i - \bar{f}\right] \text{, where } i = C, D$$

Equation 5

$$\begin{matrix} \dot{x}_C \\ \dot{x}_D \end{matrix} = \begin{bmatrix} x_C \\ x_D \end{bmatrix} \cdot \begin{bmatrix} f_C - \bar{f} \\ f_D - \bar{f} \end{bmatrix}$$

Equation 6

Where:

- f_D and f_C represents the average population payoff of defectors and co-operators respectively, which is also known as fitness.
- X_C is the fraction of co-operators and X_D is the fraction of defectors
- Average population payoff (fitness):

$$\bar{f} = X_C f_C + X_D f_D$$

Equation 7

The simplified payoff matrix in Equation 4 in terms of r is used to deduce the average payoff of both co-operators and defectors (fitness):

- Average payoff of co-operators:

$$\begin{aligned} f_C &= X_C(b-c) + X_D(-c) \\ &= X_C(1) + X_D(-r) \end{aligned}$$

Equation 8

- Average payoff of defectors:

$$\begin{aligned} f_D &= X_C(b) + X_D(0) \\ &= X_C(1+r) \end{aligned}$$

Equation 9

By rearranging the equation,

$$f_C = X_C b - c \ ,$$

Equation 10

$$f_D = X_C(b) \text{ where } X_D = 1 - X_C \ ,$$

Equation 11

By comparing Equation 10 and Equation 11, we can say that f_D will always be greater than f_C. This means that co-operators are always worse off in evolutionary biology. According to the theory of survival of the fittest, co-operators will always dwindle and disappear regardless of their initial frequencies.

In this research report, the replicator dynamics is used as a framework to prove that the vaccination strategy can be modelled by the Prisoners Dilemma game. By using the replicator equation, we developed a simple framework behavioural model to illustrate the human behavioural patterns in terms of cost to benefits ratio and the fraction of strategies chosen. The fractions of co-operators and defectors are set at a 50:50 ratio to see the changes replicator dynamics brings with each varying cost to benefit ratio. The behavioural model is attached in Appendix A.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Analytical Results on PD model

A simple framework has been modelled to illustrate the relationship between the frequency of defectors and cost to benefits ratio (r) in a Prisoner's dilemma game. The fraction distribution of players is shown in Figure 3 with the fraction of each character change with r.

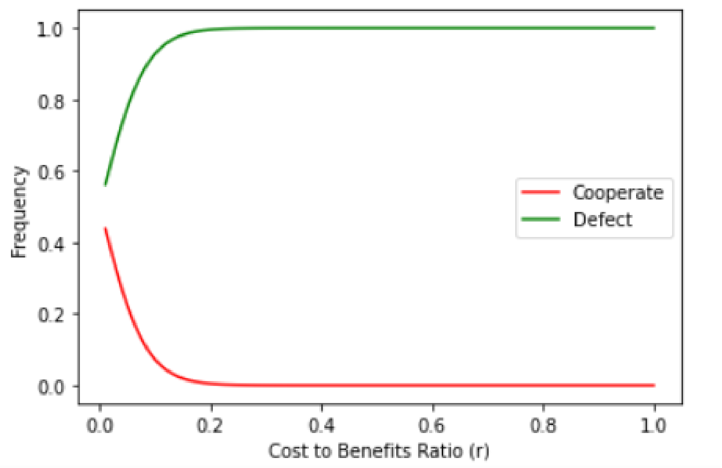

Figure 3: Analytical Results on Evolution of Strategies in Prisoners Dilemma When r is Set At 0.01 For 100 Iterations

The graph in Figure 3 shows that human behavioural patterns in choosing to cooperate or defect in the vaccination strategy are determined by the cost to benefits ratio. Based on the analytics, we can tell that players' choices in choosing whether or not to take the vaccine is dependent on the cost and benefits faced with. When the cost to benefits ratio is set initially at 0.01 for the iteration of a Prisoners Dilemma game within the range 1 to 100, the graph evolves and undergoes a rapid transition towards the stable equilibrium at the totally defective state when $r \geq 0.2$. Hence, at any value of cost to benefits ratio that is greater than 0.2, it represents a state in which all players defect and choose not to receive vaccine where the fraction of co-operators = 0 and the fraction of defectors = 1. The game is looped 100 times to simulate the fraction of change of strategies with the changes of cost to benefits ratio.

The results show that the frequency of co-operators decreases with cost to benefits ratio whereas the frequency of defectors mirrors the result of that to reach evolutionary stable strategy (ESS) in this Prisoners Dilemma game, which is the defective strategy. (Cowden, 2012) In a study conducted by (Axelrod & Hamilton, 1981), it is also mentioned that in a single shot Prisoner's Dilemma game, the ESS is to defect.

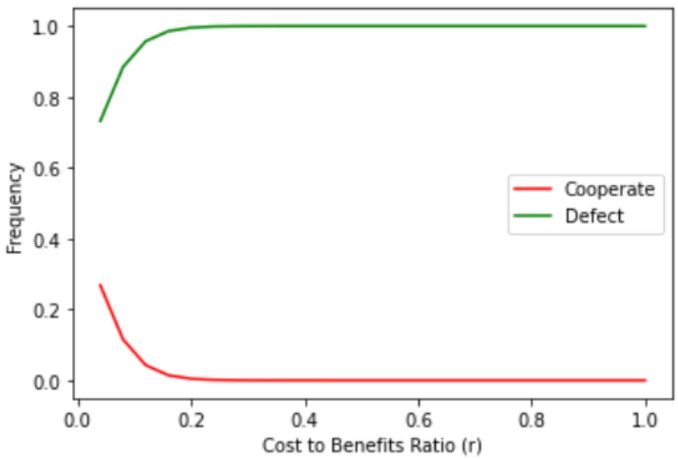

Figure 4: Analytical Results on Evolution of Strategies in Prisoners Dilemma When r is Initially Set At 0.004 For 2500 Iterations

From the graph in Figure 4, When the cost to benefit ratio is fixed at a lower value of 0.004 for iterations ranging from 1 to 2500, the fraction of both co-operators and defectors are also set equal at 0.5 initially when the cost to benefit ratio is 0. However, the agents tend to drift away from the co-operate behaviour and curve toward a totally defective state when *r* is approximately greater and equals to 0.2. This amplifies that the dominant strategy remains the defecting strategy with 2500 iterations. This is shown by the fraction of co-operators that approaches 0 at any *r* value higher than 0.2 and that of defectors approaches 1. This is because, at earlier points, there are only a few other defective strategies the agents are able to score with. Subsequently, after generations, the agents will adapt to react reciprocally to other agents and choose not to receive the vaccination.

In other words, the graphical analysis is expounded that when the defective strategy is dominated when *r* is greater than 0.2, the vaccination strategy is likely to fail with the dominating defective strategy of choosing not to receive the vaccination at a 1:5 cost to benefits ratio. To further draw light to it, if the risk of side effects to receiving the vaccination is high, whereas the benefits from receiving vaccination are such that there is unlimited freedom to go out and the freedom of choice in wearing a mask as well as being able to dine out, travel, cross-state etc, will not suffice in preventing the defect strategy to flourish.

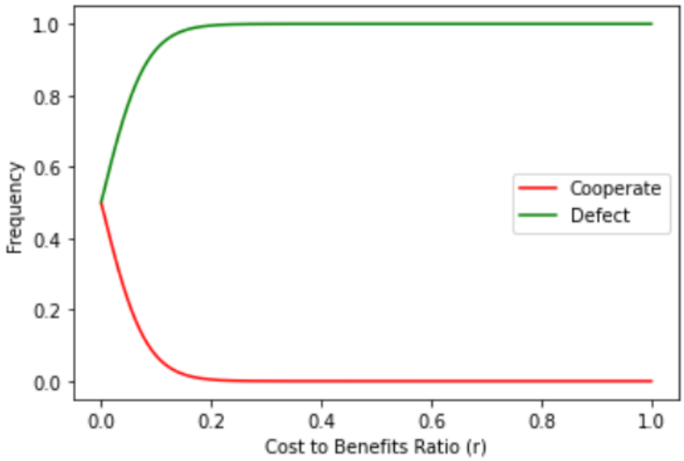

Figure 5: Analytical Results on Evolution of Strategies in Prisoners Dilemma When r is Initially Fixed At 0.04 For 25 Iterations

The analytical results in Figure 5 also show at approximately $r \geq 0.2$, the fraction of co-operations and fraction of defectors diverges towards the evolutionary stable strategy, where there are no co-operators and only defectors among the population when *r* is initially set at 0.04 for the iterations ranged from 1 to 25.

By comparing all the results from different ranges of iterations at different initial *r* values, they all show the same patterns that display the relationship between the cost to benefits ratio and the fraction of strategies. The results shown with different numbers of iterations does not deviate. At varying initial *r*, all graphs exhibit that the evolution of strategies bends to defect. This result supports the previous studies that state that the defecting strategy is the dominant strategy in the standard model of an iterated Prisoners Dilemma game that will flourish and prevail. All results obtained shows that when *r* is low, the frequency of players co-operating is higher and the chances of players defecting increase with *r*.

According to the analytics, it delineates that human behaviour in vaccination strategy can be explained by the Prisoner's Dilemma payoff matrix. The fraction of co-operators is the highest when the cost to benefits ratio is low, which means when the costs to receive the vaccination is low and benefits are high, more players would choose to co-operate. In contrast, players are more probable to choose not to receive vaccination when the cost to benefits ratio to be inoculated is high. This is analysed as when the cost is high and benefits are rare, players will not go out of their way to choose vaccination with a low payoff and be put at the risk of the side effects. In other words, comparing the risks of side effects from the COVID vaccine or contracting the COVID-19 virus, there will be a higher fraction of players choosing to defect should the risk of side effects be higher than that of contracting the COVID-19 virus.

According to the previous studies, when two players interact and know how the payoff incentives work, they will make the decision to obtain the best payoff based on the risks they are willing to take. (Wong & Hong, 2005) This can prove that upon pairwise interactions, human behaviour changes with different decisions to obtain the best payoff for themselves. With that said, players are more likely to co-operate in the next round of the game when paired with an opponent who chooses to co-operate in an iterated Prisoner's Dilemma game. This happens as players are likely to predict the choices made by their opponents in each round to obtain the best payoff.

In addition to that, human behavioural patterns in decision making are also determined by the cost and benefits analysis. (Sidarus , et al., 2019) Supported by studies, the results show that when the cost to benefits ratio is high, players are more likely to defect and influence other players to defect as well. This is said as payoff incentives for the opponents of defectors are always lower than the payoff of defectors themselves. Hence, many would rather defect and hope for their opponent to co-operate to obtain a higher payoff, or get nothing at all if the other player defects as well. In this case, individuals of the population are likely to choose not to receive the vaccination to avoid any risk of side effects at all.

True to the analytical results obtained, the frequency of defectors that increases with the cost to benefits ratio can be interpreted as such: When the costs to benefits ratio are high, the defective strategy is the dominant strategy. Consequently, there will be a higher fraction of players choosing not to receive the vaccination. When the risk of side effects is low and benefits are high, the vaccination strategy is more likely to succeed by the higher possibility of achieving community immunity within the population, which will greatly decrease the risk of any individual contracting the COVID virus, this implies that the cost to receive the vaccination is reduced. The low cost to benefits ratio, in turn, attracts other players in the population to receive vaccination as well (M.Bennis, et al., 2010)

The results shown in the graph shows strong relevance to past studies from which it states that the defect strategy is a dominant strategy that flourishes and prevails when the cost to benefits ratio r is high. (Axelrod, 1987) This can be explained by the argument in the payoff matrix mentioned in Chapter 3 in Figure 2, where R > P > S > Q and the argument derived from the simplified payoff matrix shown in Equation 4, where $1 + r > 1 > 0 > -r$. The pattern in which individuals within the population behave in the vaccination strategy leans towards defecting and choosing not to receive the vaccine shots is given that defecting always gives a higher payoff than co-operating. If the cost to benefits ratio r is high, the payoff for a player who chooses not to receive the vaccination is the highest when opposed with a co-operator, which explains why defectors increase when r is high.

The analysis satisfies the theorem where defecting and choosing not to receive the vaccination always gives the highest payoff. It is shown that players who choose not to receive the vaccination are due to the high cost to benefits ratio. Hence players will choose to defect because of self-interests when faced with a high risk of side effects from receiving inoculation. The argument from the simplified payoff matrix in Equation 4 satisfied by $1 + r > 1 > 0 > -r$ is met in this case. With the correlation between the cost to benefits ratio r and frequency of each strategy, it can be explained that when the cost to benefits ratio r is high, the payoff for defectors is the highest, represented by $1 + r$, which is when players who choose not to receive the vaccination are paired with players who choose otherwise, hence, more players defect. On the contrary, when the cost to benefits ratio is high, the payoff for co-operators is the lowest, represented by -*r*, when paired with players who choose not to receive the vaccination. Thus, fewer players will co-operate and receive the vaccination as the payoff is low. Therefore, the most optimal option to obtain the highest payoff is always to defect and not receive the vaccination.

As mentioned in Chapter 2, it is human nature to prioritise their self-benefits before others (Pimenta & Canaan, 2021), many would choose to be safe and not suffer the risk of side effects than to put themselves at risk to benefit other people. When the cost to benefits ratio is high, in other words, when the risk of getting side effects from the vaccination is higher and benefits are rare, individuals are more likely to defect and choose not to get the COVID-19 shot. The costs and benefits will be explained further in detail in Chapter 4.2.

According to the study conducted by (Chong, et al., 2007), the Replicators Dynamic explains that there are both $\frac{dX_c}{dt} < 0$ and $\frac{dX_D}{dt} > 0$ which represents the number of the strategies to Cooperate will always decline while the number of the strategies to Defect increases as the game goes on. Accumulatively, the fraction of the population choosing the strategy to cooperate will, in evolutionary biology, be eliminated and come to an extinct. This supports the results generated in this study.

4.2 Cost and benefits in Vaccination Strategy

In the case of the COVID-19 pandemic in Malaysia, monetary costs to receive the COVID-19 vaccination is covered by the government and Malaysian residents do not have to fork out money from their own pockets to receive the COVID-19 vaccines. However, the costs of receiving vaccinations in this study are said to be factors that are not quantified, such as the risks of side effects from the vaccines. Vaccine receivers are posed at the risk of their blood clots and allergies when choosing to receive inoculation. This is because studies have shown that COVID-19 vaccines namely BioNTech, CoronaVac and Oxford, AstraZeneca vaccine, triggers side effects such as soreness and swelling in the injection site (arms), fever, chills, tiredness, nausea, headache, etc. These side effects not only compromise the well-being of the individual but also affects the individual's ability to carry out daily activities due to discomfort. Besides the inconvenience in resuming normal life, the individual's immune system is also compromised and weakened a few days after inoculation though no long-term effects have been detected. (CDC, 2021)

Though clinical trials have been conducted on the COVID-19 vaccine stating that the vaccine is highly effective in preventing COVID-19 among people of diverse age, sex, race, and ethnicity categories and amongst people with underlying medical conditions, the vaccines could only reduce the possibility of death due to COVID, risk of contracting COVID-19, and severe respiratory illness among people who are fully vaccinated by 90% or more. (FDA, 2020) This still does not eliminate the risk of fully vaccinated individuals from catching the virus, hence meaning that fully vaccinated individuals are still at risk of contracting COVID even after inoculation.

By the same token, due to the vaccination strategy being a big project conducted by the government that involves the whole of the population in Malaysia, many feel sceptical to even show up at vaccination centres to get the boost with the irony of exposing themselves to crowds just to receive the vaccination. After countless days of being in lockdown, the citizens in Malaysia have already adapted to isolation by keeping a safe distance between people and that which, has made being within big crowds uncomfortable for those who have not been in close human contact with others for a long time. This also posts as one of the reasons many choose to delay choosing between receiving the vaccination or not.

Not only so, but the Malaysian government has also launched the vaccination project in phases that are broken down by different distribution strategies: The first phase is vaccinating the frontliners to ensure essential sectors can continue to operate, followed by the second phase to vaccinate senior citizens and high-risk groups, and lastly the adult population aged 18 years and above. Albeit the systematic flow planned out by the special vaccination committee in this program, the vaccination process is a large-scale project and is a tedious process that requires citizens to register themselves, be put on a queue and show up at the vaccination centre to be administered with the injection. What is more is that different types of COVID-19 vaccines require different numbers of doses with different intervals between each dose, which means vaccine receivers need to go through the process two times or more should a booster shot is needed. (The Special Committee for ensuring Access to COVID-19 Vaccine Supply (JKJAV), 2021)

As mentioned in Chapter 1, the vaccination of individuals is vital in achieving herd immunity within a population. Since the prevailing strategy is to defect and opt out of the vaccine, the vaccination strategy will fail and herd immunity will be almost impossible to attain. All things considered, the only way the vaccination strategy in Malaysia can succeed is by decreasing the cost to benefits ratio. By that, a lower cost to bear and more benefits for vaccinated individuals. Previous studies in Chapter 2 have also mentioned the vitality of external control in making a vaccination strategy thrive to succession.

Several privileges have been given to the citizens in Malaysia to boost the vaccination rate and to encourage people to receive the vaccination. Due to the movement control order, many have been deprived of their freedom. The prohibition of border crossing, state crossing and even district crossing has hindered many from meeting with their loved ones. However, after the launch of the vaccination programme, fully vaccinated individuals are permitted to dine out, cross districts and so on, given they have passed the observation period upon completion of a full course of injection and received a digital certificate. These are prerogatives that vaccine receivers are able to luxuriate on. However, strict standard operating procedures are still to be kept by wearing masks, social distancing and temperature tracking so on. Some organisations have also launched certain promotions specifically for vaccinated individuals to encourage people to get vaccinated such as giving 10% discounts on their purchases upon displaying their vaccination certificate or giving out free gifts for every purchase made. This also contributes to a lower cost to benefit ratio that will result in a lower fraction of defectors as many would be willing to receive vaccinations for the perks.

As aforementioned, one way to reduce the cost to benefits ratio in the vaccination strategy in Malaysia is to allow only vaccinated individuals to enjoy the prerogatives until herd immunity is reached. This not only protects the well-being of the high-risk groups who are not able to receive vaccination due to health reasons but also protects the co-operator’s benefits from being stripped by the group of people who chooses not to receive the vaccination in terms of public health. For instance, another way is by colour tagging each person within the community to identify fully vaccinated individuals. This can be carried out by giving vaccinated individuals a green tag upon full inoculation, which grants them access to the prerogatives to dine in or cross-state travels etc. This will also encourage other people among the community to get vaccinated as there is now transparency in the vaccination status of each individual. Individuals will no longer be able to dine out or enjoy the prerogatives unless they are green-tag holders and fully-vaccinated individuals will also get peace of mind with the knowledge that they are not in close contact with those who are not vaccinated. Thus, the spread of the virus can be contained more easily with the separation of vaccinated and unvaccinated individuals as fully-vaccinated individuals are less susceptible to contracting the COVID-19 virus.

To encourage more people to get vaccinated we must also consider the factors that influence individuals to defect and choose not to get vaccinated. Apart from the inevitable factors such as risk factors that vary by individuals, there are other factors to receive the vaccination that cannot be quantified. However, it can be improved by launching more vaccination centres in all districts and areas and improving the vaccination programme's system flow not to mention reducing clustered crowd in one single location. This can be done by making sure registered individuals are assigned to the nearest possible vaccination centre to avoid the inconvenience of needing to travel far distances. This will encourage more citizens to register for vaccination and also increase the rate of vaccination among the nationwide population.

All in all, according to CDC, fully vaccinated individuals in other countries are permitted to choose whether or not to wear masks which is often an inconvenience due to the difficulty in breathing behind a mask and the negative impacts it brings to the environment not to mention the extra cost that one has to bear despite the already existing financial downfall that has been brought forth due to the pandemic. Fully vaccinated individuals also can resume many activities that they did before the pandemic. The idea of regaining the freedom pre-COVID is vital in this context as the world-scaled pandemic has incurred a big opportunity cost.

Thus, the benefits and costs can be weighed in terms of the payoff incentives ratio in the vaccination strategy in Malaysia. Since the cost and benefits in this study are not quantified, the cost to benefits ratio is used to predict the human behavioural patterns in the vaccination strategy in Malaysia. The analytical results match the previous findings in Chapter 2 and follow the trends in the effects of human behavioural patterns in vaccination strategy.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

5.1.1 Summary

In accordance with the results obtained, we can see that defective strategy is the dominant strategy that prevails in the standard model of Prisoner's Dilemma game. In order to prevent the defective strategy to dominate, the cost to benefits ratio has to be lowered to make the vaccination strategy successful. Based on the studies done on the human behavioural patterns in decision making for the vaccination strategy during this COVID-19 pandemic using evolutionary game theory, the Prisoners Dilemma, the success of the vaccination strategy in Malaysia can be achieved by increasing the benefits and lowering the costs of getting the vaccination. Apart from what has already been done, the public officials in Malaysia can fringe the benefits granted for fully vaccinated individuals by rewarding them and penalizing the unvaccinated community by tightening the controls of their movements not to mention reducing the costs such that the community suffer from a decreased risk to get vaccinated like reducing the exposure of COVID-19 risk when going out to get vaccinated.

To summarize, this qualitative analysis from the behavioural model shows that the evolutionary stable strategy of the vaccination strategy, which is the defecting strategy to reject the COVID-19 vaccination, can be explained and modelled by the Prisoners Dilemma game using Replicators Dynamics. Based on the findings, individuals are likely to choose not to receive vaccination had there been no benefits or payoff incentives, in this case, freedom to go out and achieve herd immunity as a whole.

The human behavioural pattern in the vaccination strategy for this research also conveys that decision making is influenced by the decisions made by others. Hence, the public officials have to play a role in encouraging the community in receiving vaccination by educating the citizens regarding the pros and cons of receiving the vaccination. This will not only provide fundamental knowledge to individuals who are sceptical about the vaccine but also can help to channel the individual's instinctive tendency to be inoculated for the well-being of their own and the nation as a whole.

Co-operation in receiving vaccination should be awarded, defectors should be penalized and compromised of the prerogatives while individuals who have not made a decision on whether or not to receive vaccination should be educated with the risks and benefits that come with vaccination.

5.2 Limitations and assumptions

The behavioural model built in this study assumes that the behaviour of players is completely determined by payoff or by fitness with the use of replicator dynamics. (Martcheva, et al., 2021) This study assumes that players among the population of Malaysia have interacted at least once and that the population is well-mixed. It assumes that all players among the population either co-operate or defect, "free-riders" or individuals who do not decide whether or not to take the vaccination is not considered in this theorem. The limitation of this study is that the strategies of players are simulated by random choice and do not get the choice of whether to receive the vaccination or not. Individuals who have decided "free-ride" are assumed to be defectors. Furthermore, it is assumed that players do not make choices of whether or not to receive vaccination based on religious beliefs and instead is entirely based on the payoff of the game.

5.3 Future works

As valuable as relevant medical findings are on how to achieve herd immunity at the highest rate, studies on the social dilemma and human behavioural patterns are also vital in contributing knowledge and guidance to solve the social challenges faced with in light of a pandemic, especially one as large-scaled as COVID-19. This research has been done to analyse the human behavioural patterns of a vaccination strategy in Malaysia during the COVID-19 pandemic by using the evolutionary game theory, the Prisoners Dilemma. However, further research and studies can be done to support the findings of this research. With that said, studies on vaccination strategy using other games in the evolutionary game theory can be conducted to find out which is the best-suited game in the human behavioural patterns' predictions.

Moreover, since COVID-19 is yet to come to a halt, further studies can be done on the human behavioural patterns during the COVID-19 pandemic to be "saved for a rainy day" for when a pandemic as such happens again so that the public authorities will know how to tackle challenges faced in the future. Researches on other strategies besides the vaccination strategy to study human behavioural patterns using evolutionary game theory can be done to improve the efficiency in tackling a pandemic with a broader understanding of how individuals make decisions. For instance, the sanitary measures strategies or lockdown strategies to name a few.

Not only so, but a simulation model can also be built by looping random pairwise interactions of a Prisoners Dilemma game on the vaccination strategy by using computing languages such as Python. The simulation model can be used to determine the dominant strategy using Replicator's Dynamic based on the cost to benefits ratio.

Last but not least, a real-life study can be done by collecting data to test the hypothesis of this study by simulating the game with payoff incentives. This can be done by employing real-life participants and giving scenarios regarding the vaccination strategy in Malaysia to obtain fitness by playing the Prisoner's Dilemma game by random pairwise interactions. With that, we are able to further investigate the human behavioural patterns in decision making during the pandemic and the influences each player has on their opponents within a well-mixed population.

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APPENDICES

APPENDIX A: Analytical Graph Generated with Python

Prisoners Dilemma
Game Analytics.ipynb

Attached with python notebook consisting of codes to generate analytical graphs with Replicators Dynamics.