PROPOSAL

STUDIES OF HUMAN BEHAVIOURAL PATTERNS DURING THE COVID-19 PANDEMIC USING EVOLUTIONARY GAME THEORY - PRISONER'S DILEMMA

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FORM 3

PROPOSAL MODERATION

BAMS3216 PROJECT

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Supervisor's Name: Dr Tey Siew Kian **Date:** 28 March 2021

Project Title: Studies of Human Behavioural Patterns During The COVID-19 Pandemic Using Evolutionary Game Theory - Prisoner's Dilemma.

Proposal Moderation (by Moderator) (√)

Project Requirements	Comply	Does not Comply
Math content. The project has substantial amount of Mathematics content.		
Concepts or Techniques. The project requires the students to apply various concepts or techniques learnt.		
Knowledge Expansion. The project allows the students the opportunity to expand their existing knowledge.		
Scope. The project should be of scope acceptable within the limits of resources and capability of students.		

Project Scope Moderation (by Moderator)

Changes Recommended (write 'None' if no changes are required)	**Actions Taken** (by Supervisor)

Moderator's Signature: ___________________________

Moderator Name: ________________________________

Introduction and Definitions

With the out surge of the pandemic – Coronavirus-19, it is vital for the government to make the right decisions to help ease the wide spread of the virus due to the lack of cooperation. It is known that many new standard operation procedures are being introduced due the pandemic, such as having to keep a 1-meter distance with other individuals, which requires cooperation of the population as a whole. However, the new norm has deprived many from social interactions and limits the freedom of individuals, at the same time limiting businesses to operate, causing some to find it difficult to comply. It is inevitable that some may not comply to the standard operation procedures, which makes the virus even harder to be contained. This has to be done by quick-witted decision making by the government to control the spread of the virus efficiently and effectively through identifying the human behaviours in the pandemic.

New strains of virus evolve and adapts over a fast period of time, making development of vaccines impossible to catch up with the new different strains, which causes the virus to spread like wildfire. On another hand, consumers may feel sceptical and unease in receiving the vaccine as it is developed over a limited period of time. Some of which may have compromised stages of the development cycle of a vaccine due to the time constraints not to mention the urgent needs of the vaccine, by carrying out research of different development stages simultaneously. Thus, not all potential risks and side effects can be evaluated on time as the reactions towards the vaccine varies on different individuals. (WHO Team, 2020)

With that said, it is rather a difficult task to ensure the whole population will accept and receive the coronavirus vaccine considering it is a subsidized expense made by the Malaysian Government. According to an interview conducted by (Roberts, 2020), a mathematical biologist, Chris Bauch said that some people may play a 'wait-and-see' game due to uncertainties and concerns towards the vaccine. Thus, individuals who opt out of the vaccine gets benefited effectively as the transmission of virus greatly reduces as others receive the vaccine, generating a collective threat while opted- out individuals reap the fruit equally. This reinforces that the pandemic is a type of game in game theory – The Prisoner's Dilemma. (Bauch & Earn, 2004)

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. 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 and etc. One of the most used games in game theory is the Prisoner's Dilemma Game.

Literature Review

Game theory is 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) The most famous game in game theory is known as The Prisoner's Dilemma Game. The Prisoner's Dilemma 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, and was then ratified and named by a Princeton mathematician, Albert William Tucker. The Prisoner's Dilemma was named after the prison's sentence rewards. However, it is now more widely used to investigate other situations such as vaccinations strategies.

The investigation of evolutionary game theory gave some rather gripping results on vaccination strategies of infectious diseases to interpret the vaccination dilemma. 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.

According to (Chapman, et al., 2012), individuals with age are more susceptible to transmission of a 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 a disease. The study targets 2 groups: younger groups and older groups, pay-out incentives were offered in the game individually and by group. 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 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.

For good measure, (Wu, et al., 2011) conducted a study using 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 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.

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.

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 causes a rather insignificant coverage within the society collectively. Hence it shows that human behavioural patterns show significant impact on vaccine decisions made.

Objectives

Since vaccination strategies are considered as governmental investment decisions, social costs are to be incurred to ensure Malaysian populations are protected from the virus without having to incur more expenses on top of the struggles to make ends meet due to the pandemic lockdown. Hence, an appropriate strategy is to be taken in order to avoid unnecessary spending among the government. With that said, the aim of this study is to determine if the pandemic – COVID-19 is a Prisoner's Dilemma game. This makes it possible for the simulation of the real-life situation by 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 of the cooperation of the populations in the vaccination strategies. The objectives of this study are to analyse the human behavioural patterns and the role of payoff incentives in vaccination strategies 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 for the interests of the group. It is important to realise the impact various behaviours of individuals brings in a dilemma in a vaccine strategy.

Moreover, this research is done also to identify the dominant strategies in the dilemma by recognizing the important factors influencing the vaccination decision an individual make.

Methodology

This research involves the study of the relevance of game theory in vaccines strategizing. In this case, the Prisoner's Dilemma game is used to simulate the pandemic as a game. The target players of this study are individuals of a large population with two strategies known as "cooperate" and "defect".

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

The above is the payoff matrix of the evolutionary Prisoner's Dilemma game. The evolutionary Prisoner's Dilemma is usually framed in terms of benefits *b* and costs *c*, where *b* is when players choose to receive vaccination to reap the fruits 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.

Co-operators are players who choose to receive vaccination voluntarily and benefits the defectors who opts out from receiving vaccinations.

When both players co-operate and receives 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 to receive the same benefits, which is the reduced risk of coronavirus transmission between both players. On the contrary, when both players are defectors and opt-out from 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 co-operator decides to receive vaccine and the other player decides to defect, the payoff of the defector will be represented by R, where $R = b$. This is said as the defectors do not have to take risks to turn to the co-operator's advantage, the reduced transmission of coronavirus while the co-operator's payoff is rendered as Q,

where $Q = -c$, bearing the risks of receiving vaccination that dominates over the benefits received. (Turocy & Stengel, 2003)

According to (AXELROD, 1980), the defector always receives the highest payoff when the corresponding player co-operates. However, when both players choose to defect, both players receive the worst payoff which is nothing. Hence the payoff matrix satisfies the argument where R > P > S > Q and 2P > R + Q.

Replicator dynamic is the mathematical tool that can be used to apply the evolutionary game theory to our behavioural model. It can describe the evolution of frequencies of each fraction of strategies by taking into consideration their fitness and mutual influence. The replicator equations of our behavioural model are:

$$\dot{x}_i = x_i[f_i - \overline{f}],$$

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

Where:

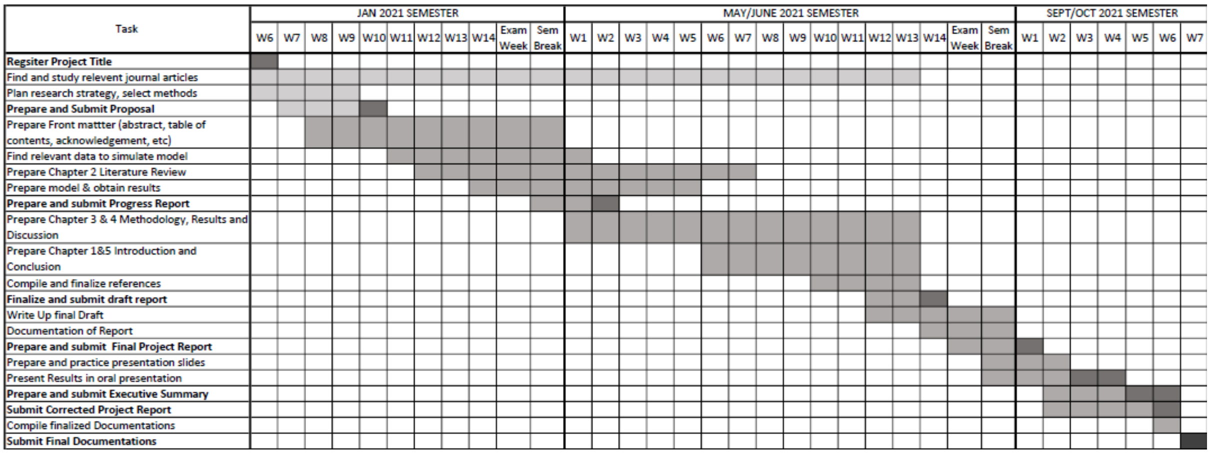
- f_D and f_C represents the average population payoff of defectors and co-operators respectively, which is also known as fitness.
- Average population payoff: $\bar{f} = X_C f_C + X_D f_D$
- Average payoff of co-operators: $f_C = X_C(b - c) + X_D(-c)$
- Average payoff of defectors: $f_D = X_C(b) + X_D(0)$

By rearranging the equation,

$f_C = X_C b - c$ and $f_D = X_C(b)$ where $X_D = 1 - X_C$

Time Framework

Gantt Chart



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