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COVID-19 from Game Theory's Perspective: Lockdown and Vaccine Rollouts

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Abstract

The novel Covid-19 pandemic has wreaked havoc across the world. It has infected almost 195 million people globally, and 4 million people have succumbed to its deadly effects (WHO Coronavirus Dashboard). This paper tries to analyse the responses of variables of different scenarios to prevent the spread of the virus, based on game theory. The three games formulated in this paper talk about the different aspects of the lockdown. The first one is a payoff between countries that wish to opt for a lockdown and those that don't. The second game is a modern take on the original "Battle of the Sexes", reflecting a couple's choices on going out during the pandemic. The last one illustrates the vaccinated and unvaccinated people along with their utilities. While these games look at different variables individually, on a whole, they look at various aspects of the pandemic in relation to the lockdown. Equilibriums like Mixed Strategy, Nash Equilibrium, and Game Tree have been reflected in these three games. The way forward to tackling the pandemic is through the means of lockdown, vaccines, as well as social distancing.

The paper tries to highlight and analyse measures to prevent the spread of the virus. The decision to incorporate changes is a big toll on countries, communities, as well as individuals. It also takes control of spread as an important area of focus. While for the lockdown, we analyse the different utilities based on the economy and saving lives. For vaccines, we analyse the responses of different groups involved. Furthermore, the paper also maps the response of individual and joint choices of couples to the Covid-19 lockdown and their strategies in case of going out.
Keywords: *Covid - 19, Battle of the Sexes, Mixed Strategy, Nash Equilibrium, Game Tree*

1.0 Introduction

The world is facing the worst pandemic in a century due to the new form of Coronavirus. To address the current global human tragedy and economic devastation, efforts need to be coordinated as an outbreak anywhere in the world puts all other countries at risk. If one country decides to relax its control measures and provokes an outbreak, all other countries will be adversely affected. In addition, even higher-income economies have seen that individual efforts may not suffice to control an outbreak. The situation will be even worse if serious outbreaks occur in developing countries or transition economies like India. Hence, cooperation and not only coordination is needed to address this pandemic. According to the reports of the World Health Organisation and Johns Hopkins University, Covid-19 has affected more than 19,40,80,019 people and the total deaths were 41,62,304 worldwide. Countries including the USA, Spain, Italy, France, the UK, China and India have been exposed to this virus intensely. The lockdown protocol used, usually allows essential supplies such as pharmacies, hospitals, banks and grocery shops to operate and shut down all nonessential activities throughout the extent of the lockdown. Around the world, most countries had implemented the lockdown protocol to control the spread of Covid-19. Likewise, India also adopted a complete nationwide lockdown policy which assisted in curbing the rise in confirmed cases initially in the country. According to the Ministry of Health and Family Welfare (MoHFW), by imposing the largest and continuous lockdown, a total of 24,530 positive cases were witnessed among 1.3 billion population by 25th April 2020, which is almost 4 times more population than the US, thus a number of positive cases reported in India were less as compared to other countries (MoHFW, 2020).

Now, India has entered its decisive phase of vaccination in the battle against Covid-19. The world's largest vaccination drive was launched in the country on 16th January 2021 by rolling out two approved vaccines namely Covishield by Serum Institute of India and Covaxin by Bharat Biotech. To begin its journey on the road of recovery from the global crisis, the Ministry of Health and Family Welfare has planned a three-phased approach for the allocation of the vaccine. The healthcare and front-line workers were given utmost priority, followed by people above 60 years of age. The roll-out of vaccines in the month of April focused on people above 45 years of age, especially those with some serious illness. By the start of May, people above the age of 18 were eligible to get a dose of vaccination as well. Many individuals till now are scared to get a vaccination dose because the side effects of the vaccine are unknown to all. A total number of 44,61,56,659 people have been vaccinated in India as of 28th July 2021. After months of preparation and numerous dry runs, optimism and energy are restored in the country. As warned by the WHO Chief, Tedros Adhanon Ghebreyeses, the Covid-19 pandemic is in the early stages of its third wave. The delta variant of the virus, anticipated to be more easily transmissible and deadly, is now in 111 countries. Due to increased vaccination drive, there was a considerable decline in Covid-19 deaths but now rising again mainly due to increased social mobility. A shocking disparity has also been noted in the provision of vaccines worldwide. From Canada, Poland, Germany, the US and half the nations of Africa have already fallen prey to the third wave. WHO has also suggested that the most efficient manner to combat the virus would be to get at least 20% of the population of every nation vaccinated by September and 40% by the end of 2021. The number of Covid-19 cases and the death toll will only continue to rise in counties without comprehensive vaccination campaigns. Partners in Health (PIH) continue to campaign for equitable distribution of vaccines worldwide, especially when 0.9% of the population in low-income countries have received at least one dose in comparison to 45% of the population of higher-income nations. (WHO, Vaccine Equity, 2021)

Thereby, this paper analyses the game-theoretical aspect of Covid-19 and vaccine roll-out in one of the leading transitioning countries, India. The vaccination doses administered worldwide is of 3,69,61,35,440 as of July 2021 and hence the number of cases in India since June 2021 has fallen considerably. (MoHFW, 2021)

A game is an abstract model of a strategic situation in which players make strategic decisions, implying that the players take each other's actions, reactions and counter-actions into consideration. A game consists of three essential elements: -

- Players- A player is a participant in the game with respect to choosing a particular course of action. It is assumed that each player has the necessary skills and knowledge required to choose the best course of action, given the constraint.
- Strategies- A strategy is an action plan for playing the game. A strategy may be a simple action or a complex action plan that may be dependent on earlier actions or reactions of the players. Each player believes that rivals being rational, shall take decisions to maximise their payoffs. This fact shall be taken into consideration while choosing a strategy.
- Payoffs- An action plan when implemented results in a particular payoff. Thus, a payoff is a gain or loss that a participant experiences, this can be monetary or non-monetary.

(Game Theory, Investopedia, 2021)

This paper analyses Two-Cross-Two game models. The 2*2 model is where two players play two different actions and both try to get more benefit out of their decision.

The Nash equilibrium is a decision-making theory which states that a player can achieve the required consequence by not drifting from their initial strategy. It can be found when each player has only a few actions by examining each action profile, in turn, to see if it satisfies the equilibrium conditions. The strategy for each player is optimal when considering the decisions of other players. It is an action profile with the property that no player can do better by changing their action, given the other player's actions. A Nash equilibrium can be thought of as an action profile for which every player's action is the best response to the other player's actions.

A dominant strategy is a strategy s* for player i that is the best response to all strategy profiles of other players, that is to say, s* BR(s) for all s. It is a strategy that is the best response to any strategy other players might choose. Players do not always have a dominant strategy but if they do then they will not prefer any deviation from playing that strategy. When this happens, what is best for the player is irrespective of the decisions of other players. Solving for the equilibrium in a sequential game to find all the Nash equilibria using the normal form and then to look for the subgame perfect equilibrium, a shortcut method can be put to use.

Backward Induction is the shortcut to find subgame perfect equilibrium directly. It is particularly beneficial in games that feature multiple rounds of sequential play. As rounds are added, it becomes difficult to solve for all Nash Equilibria and then to sort out which are perfect subgames. But with Backward induction, an additional round is simply adjusted by adding another iteration of the procedure.
(Game Theory, Investopedia, 2021)

A Player's strategy can often be more complicated than simply choosing an action with certainty. A player can also choose from several possible actions randomly. This corresponds to the case of having a mixed strategy which includes a special case of a pure strategy game. A pure strategy is a special case wherein only one action is played with positive probability but a game where two or more actions being played with positive probability involves a strictly mixed strategy. This paper operates on the above-stated definition and principles to solve several games.

2.0 Literature Review

This section deals with the review of a number of research papers, studying game theory and its real-life implications. The concept of decision making in which various players must make choices that potentially affect the interest of other players is known as Game Theory. It addresses the dilemma in conflict and cooperation and the concepts of this theory apply whenever the actions of various agents are interdependent within a competitive situation. Covid-19 has been considered the first serious and life-altering pandemic in a truly interconnected world. The whole world has been deeply affected by the unknown virus and the long-term impact of the virus remains a mystery. Given below are three relevant game structures which focus on the impact of Covid-19 on several individuals in real life. There have been different papers available in the literature that focus on the trend analysis and forecasting of Covid-19 in various parts of India.

The paper **"A Noncooperative Game Analysis for Controlling Covid-19 Outbreak"** focuses on the analytical model for controlling the outbreak of the pandemic by augmenting isolation and social distancing norms of individuals;

The article - **"The Indian Covid Response: A Lesson in Game theory with Dynamic Strategy"** also discusses the real-world India-specific data national and state-level data since January 2020 to understand which of the several possible trajectories the nation is on in different states/districts of India. Increased Random Testing and identification of asymptomatic spreaders can curb the virus once and for all. By building a rigorous mathematical framework for reasoning about the human mind and behaviour in various complex situations, researchers can gain new insights into how to modify design systems that hold accountability for biases and imperfections in individual decision-making;

A paper by Bellal Ahmed Bhuiyan on **"An Overview of Game Theory and its Application"** concludes game theory as the formal study of conflict and cooperation between intelligent and logical decision-makers. It has been an impressive analytical tool to help us understand the phenomena that can be observed when decision-makers interact. Game-theoretic models have become sophisticated and in consequence, much more potent. It has been successfully applied to a wide variety of disciplines including economics, sociology, psychology, philosophy. Game theory has helped sharpen our intuitions, allowing 'reasonable reconstructions' of fresh ideas, norms, values among agents (players) for significant philosophical expositions. The application of game theory in the field of politics was discussed with an interesting example.

The two players in the game were Bangladesh and India. Both countries face a common threat of terrorist attacks, and both must agree on whether or not to jointly apply an active counter-terrorism policy. The matrix for the game is drawn below:

Bangladesh→ **India ↓**	Active	Reactive
Active	(-4, -4)	(-2, 6)
Reactive	(6, -2)	(0, 0)

In this game, it is assumed that active policy for individual countries gains benefits of 6 and costs of 8 for countries that applied active policy. If India is applying active policy and Bangladesh is the state that will only get benefits associated with it, then Bangladesh will have the advantages of the 6. India gets a -2 (6-8), a deduction of the cost of 8 from the benefits of 6. Otherwise, if India is a free-rider, the benefits are reversed. If both countries play 'active' as the strategy, then everyone gets the benefit of -4 (8- 2×6). The result is a prisoner's dilemma game, in which no country wants to apply an active counter-terrorism policy. The above-stated game was one of the real-life applications of game theory in politics; many such games in different fields like business, psychology, etc. were discussed.

The paper- **"Game theory, Strategies and the convoluted triangle- India, Pakistan, Kashmir"** by Siddhartha Pradeep aims to understand the ways in which international relations and real-world events constitute in the lens of game theory. The inherent instability in the game of Kashmir is because of the contrasting approaches towards the game by India and Pakistan. The paper concludes that from a game-theoretic perspective, in the long-run stability can be achieved by complementing table talks with strict policies against Pakistan-sponsored cross bordered terrorism. These games have been found to fit the observed story of relations between India and Pakistan, with the recent involvement of China.

The paper- **"Optimal Governance and Implementation of Vaccination Programs to contain the Covid-19 Pandemic."** articulated the perspective that vaccination uptake will have the most prominent influence in the control of the pandemic, and effective modelling of uptake using appropriate measures is of paramount importance. The paper presented the case for game theory, coupled with simulation techniques and social network analysis that highlighted the efficacy of the vaccines developed, as well as the efficiency of testing, contact tracing, and isolation procedures shall remain primary factors in containing the Covid-19. The Non-Cooperative game theory in the paper is ideally suited for modelling human decision-making behaviour regarding vaccination, while the Cooperative game theory can be considered to inform the government decisions about prioritisation.

3.0 Research Methodology

This paper has been written on the basis of secondary data collection. It has been formulated keeping in mind the behaviour as mentioned in the assumptions. The basis for our research is also through the means of data that has been collected through secondary means i.e. non-primary in nature.

Assumptions**:**

- All players involved in the game act rationally and intelligently.
- Hence, it is assumed that players within the game will strive to maximise their payoffs.
- Each player has the necessary skills to choose the best course of action, given the constraints.
- Each player has a definite course of action.
- There is a conflict of interest between the players i.e. they can choose either of the choices available to them.
- The rules of play are available to all the players.

4.0 Game 1: 'Lockdown and Normal Life during Covid - 19: Life across the Globe

On the last day of 2019, a case was reported of the novel coronavirus- COVID-19, which originated in Wuhan, China. The virus can be transmitted directly through contact like shaking hands, touch, and even being in close contact with the infected person. To battle this, countries across the globe have been using various techniques such as social distancing and lockdowns. The spread of the virus needs to be stopped. Therefore, many countries across the world adopted a strategy to start a "lockdown" in which they stopped all forms of travel and going out. Citizens had to stay within their premises, and could only go out for emergencies. This lockdown significantly impacted the economy of the country, as well as the livelihood of the people. However, it was also essential to spread the infection rate, since this virus spreads through direct communication. India was one of the few countries to adopt a lockdown, even before it hit its peak. On 24th March 2020, it announced this world's "largest" lockdown. However, some countries like Sweden have not adopted a lockdown. Some of the reasons for such countries not going for a lockdown may be herd immunity and to keep the economy running. These may have a better impact on the finances of the country, but they will not be good for the population's health as a whole. Hence, we can observe types of countries in the present situation- with and without lockdown. Both countries impact one another in different ways.

Model: This is a matrix 2*2 Game
The game focuses on two countries- A and B which may be in Lockdown and no Lockdown (Country). Both the countries are similar in their background for their medical resources, cultural, political and policy system, scale and size of the economies, and both do not have a serious community outbreak of COVID-19.
Each one of them has two strategies - either to be in 'Lockdown' or 'Not to be in Lockdown'. If one goes into lockdown, it will act as a positive externality for the other. The best course of action for these countries is to go into "lockdown".
Players: The two players are Country A and Country B
Strategies: {Lockdown, No Lockdown}
Payoffs: The payoffs are non-monetary in nature.

- (Lockdown, Lockdown)

This payoff is for both the countries which choose to opt for lockdown. According to the assumptions, if country A decides to opt for a lockdown, it would be better off and thus would reflect a greater utility. Similarly, if country B also opts for a lockdown, it would help it too. Since this virus spreads by direct contact, it would be helpful for citizens of both countries. It will reduce the chance of getting infected by the virus and thus would also indicate a better utility. If both of them opt for a lockdown, the risk of catching the virus would be reduced. Considering them as practical and rational, their utility would be maximum if this bundle is chosen. Thus, a value of (20,20) has been assigned to this payoff.

- (Lockdown, No Lockdown)

This payoff depicts that country A chooses to opt for a lockdown, whereas country B does not go for one. According to the assumptions, if country A opts for a lockdown, it will be better off and thus would reflect a positive utility. In this case, country B does not opt for a lockdown, it is thus at risk of getting infected with the virus. The utility, thus, designed for this payoff is (10,5). This smaller payoff is chosen for country B as it will keep the economy running, but the virus will still spread in the country. However, in-country A, the lockdown will save more lives than in country B.

- (No Lockdown, Lockdown)

This payoff represents country A not opting for a lockdown, whereas country B chooses to opt for one. As country A does not opt for one, it may result in higher cases of infection, and more problems. Whereas country B has opted for one, and according to the assumptions, is in a better state. It is better suited to control the virus, as opposed to country A. Country B will also save lives, but the economy of country A is still running. Thus, the utility given to this payoff is (5,10).

- (No Lockdown, No Lockdown)

This payoff shows both of them playing the No Lockdown strategy. This would highly affect both the countries since they are similar in all forms and resources. The cases of the virus will shoot up if the people are not careful, as assumed. Thus, their utility would be less and at its least. Therefore, the utility given to this particular payoff is (2,2).

Utility Preferences:

Country A: The utility preferences for country A has been ranked below:

U(Lockdown, Lockdown) > U(Lockdown, No Lockdown) > U(No Lockdown, Lockdown) > U(No Lockdown, No Lockdown)

Country B: The utility preferences for the player B has been ranked below:

U(Lockdown, Lockdown) > U(No Lockdown, Lockdown) > U(Lockdown, No Lockdown) > U(No Lockdown, No Lockdown)

The 2*2 model game designed is presented in its normal form -

Country A → **Country B ↓**	No Lockdown	Lockdown
No Lockdown	2,2	5,10
Lockdown	10,5	20,20

The above game matrix shows the normal form of a simultaneous game which can be solved using a dominant strategy. The best response for all strategy profiles can be obtained using this kind of strategy.

Country A has a dominant strategy to go for lockdown. This can be explained as follows-

If Country B → No Lockdown; Country A→ Lockdown

If Country B→ Lockdown; Country A→ Lockdown

Hence, we can see that Country A tends to maximise its utility regardless of the decision made by Country B.

Likewise, Country B also has a dominant strategy to go for lockdown. The conditional statement to prove this is -

If Country A → No-Lockdown; Country B → Lockdown

If Country A→ Lockdown; Country B→ Lockdown

So going for a lockdown, irrespective of the strategy of Country A is the best strategy for Country B.

Nash Equilibrium

Country A → **Country B↓**	No Lockdown	Lockdown
No Lockdown	2,2	5,10
Lockdown	10,5	20,20

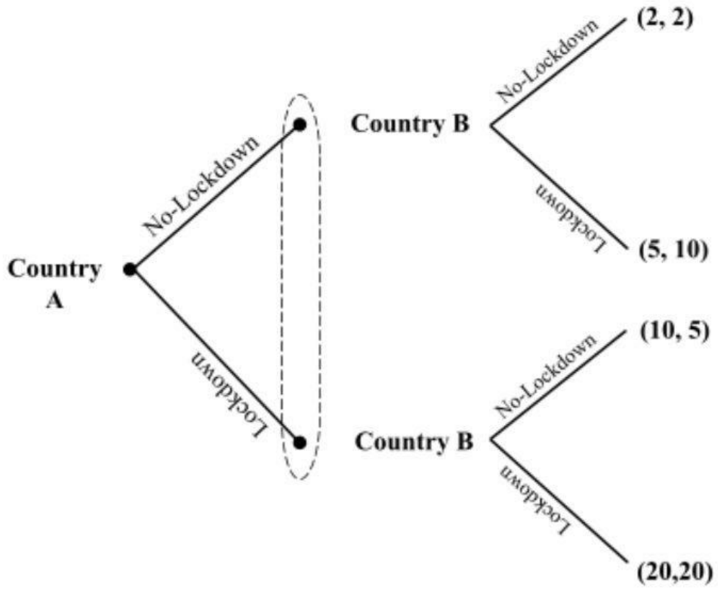
From the above game, it can be noticed that the unique Nash Equilibrium is at (20,20). Each player prefers to stick to his Nash strategy because the payoff at this equilibrium is the highest for both. To understand the Nash equilibrium, consider the following statements:

For Country A, Column 2 dominates Column 1

For Country B, Row 2 dominates Row 1.

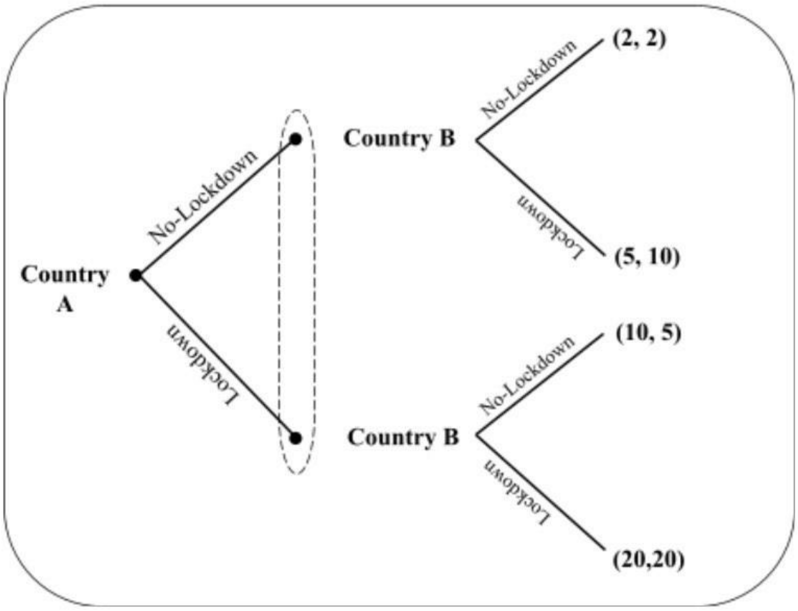
Hence, it is evident that by choosing lockdown both the countries receive the highest payoffs.

Figure 1: Extensive Form or Game Tree of Simultaneous Game



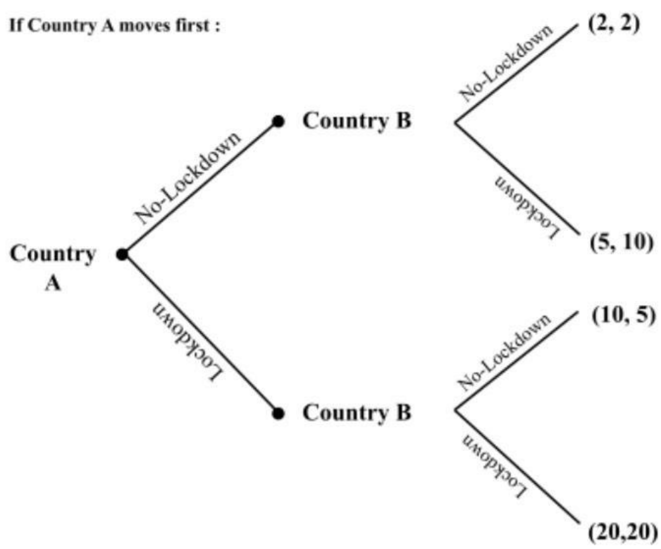
The above tree diagram denotes the extensive form of the game. Country A makes its move at the top-most node following which Country B makes its move at the nodes around which a dotted oval has been drawn. This indicates that the two nodes are in the same information set, that is to say, the second player - Country B, is ignorant about the decision of the first player- Country A. In other words, whatever move Country B decides to make is independent of the move made by Country A.

Figure 2: Subgame of Simultaneous Game



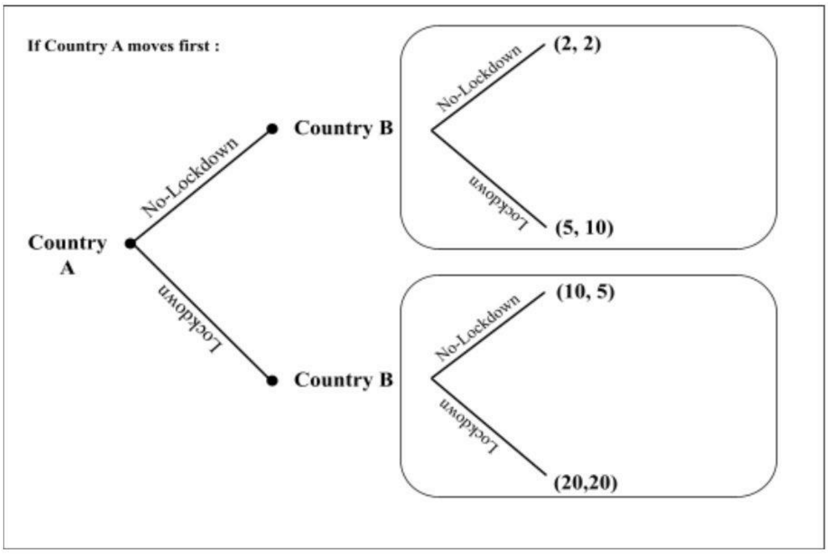
A subgame is a subset of any game that includes an initial node that is independent of any information set at all its successor nodes. In the simultaneous game shown above, the decision node at the top is not connected to any other node in the same information set. Hence, the only proper subgame here is the game itself.

Figure 3: Extensive Form or Game Tree of Sequential Game



The above diagram shows the extensive form of a sequential game wherein the payoffs and actions are the same as before, but now, the two countries are not simultaneously making any individual choice. Here, Country A makes the first move followed by Country B. The catch is that in this game Country B's decision depends on what move Country A makes. In other words, Country A gets to move first and Country B gets to react seeing what Country A chose.

Figure 4: Backward Induction Strategy for finding Subgame Perfect Nash Equilibrium



The game shown above has three proper subgames, the original game itself and the two other lower subgames with decision nodes at which Country B makes its move. Country A executes its decision at the first decision node. A, B and C as indicated in the diagram are the subgames. Country B receives the highest utility at 20 utils. In subgame B, Country B would receive maximum utility when it would opt for a lockdown as it will help in reducing the transmission of the virus among the masses ensuring better safety of the netizens. Likewise, in subgame C, Country B would again opt for lockdown for the same reason. After solving both the subgames, it can be seen that the best option is to go for a lockdown. Therefore, by applying backward induction, two of the utility bundles with lower payoffs - (Lockdown, No Lockdown) and (No Lockdown, No Lockdown) will be eliminated. Now, Country A has a choice between (Lockdown, Lockdown) and (No Lockdown, Lockdown). Country A is likely to go for a lockdown as its strategy since opting for a lockdown will definitely ensure better containment of the virus by cutting off human contact in public spaces, thus maximising its utility. Thus, from the above game, it can be inferred that the Subgame Perfect Nash Equilibrium lies at (Lockdown, Lockdown) with a payoff of (20,20).

Contingent Strategy for Country B where Country A moves first

Contingent Strategy for Country B	**Written in conditional format**
Always go with the Lockdown	(L|L, L|NL)
Follow Country A	(L|L, NL|NL)
Do the opposite	(NL|L, L|NL)
Always go with Non - Lockdown	NL|L, NL|NL)

In a sequential game, the second mover has the benefit of knowing about the actions taken by the player who acted first. Hence, the second mover's strategy can act as a contingent plan, depending on the decision of the first mover.

Normal Form of Sequential Game

The normal form of the sequential game has been shown in the matrix given below:

Country A→ **Country B** ↓		No Lockdown (NL)	Lockdown (L)
L|L	L|NL	20,20	10,5
L|L	NL|NL	20,20	2,2
NL| L	L|NL	5,10	10,5
NL|L	NL|NL	5,10	2,2

Note -

- L stands for Lockdown
- NL stands for No-Lockdown

Example - L|L means that Country B chose lockdown conditional on Country A choosing lockdown.

Conclusion of the game

The Covid-19 pandemic has affected countries all across the world. However, it can be controlled with preventative measures like lockdowns. Through the means of this game, we have defined how the best strategies for both countries are to opt for a lockdown. It is advised that both countries will get maximum utility by opting for a lockdown. Of course, if a country does not opt for a lockdown, their economy is still running and thus, indicates a positive utility. However, it is still at major risk by not opting for a lockdown, as the spread of the virus will increase. To battle this virus, it is best advised, as seen by the aforementioned game, to opt for a lockdown which includes social distancing and other preventative measures to control the spread of the virus.

5.0 Game 2: Battle of the Sexes during Coronavirus

The Covid-19 has reshaped and changed many personal relationships in ways which had forced individuals to live closer together with some people and further apart from others. Lockdown at times has necessitated close and constant contact with our families and partners. Various families and couples have found themselves navigating new problems, which perhaps aggravate existing tensions. Married couples have been hit hard by the pandemic that has tanked the economy and has thrown millions of men and women out of work. In the month of January 2021, the number of cases was comparatively low and herd immunity was developed against the strain. The restrictions were less in the early 2021 months and people could go out of their houses easily. During this pandemic, four types of situations can be formed in the life of a married couple - both of them stay in, the wife goes out and the husband stays in, the husband goes out and the wife stays in, both of them go out.

This is another two crosses two-game model where the predicament of a married couple is taken into consideration. This is a classic example of a 'battle of the sexes' game where the preferences of one of the players affect the other's utility. The players chosen to represent the game are Husband and Wife who have to choose from the two options or strategies namely "Stay In" and "Go Out". Both prefer to spend time together rather than apart, that's why they argue about how to handle the pandemic.

Players: The two players are the wife and the husband

Strategies: {Stay In, Go Out}

Payoffs: The payoffs here are non-monetary in nature.

- (Stay In, Stay In)

This payoff illustrates the couple planning to stay in. The wife always prefers to stay in owing to her fear of catching the virus if she does the opposite. Thus, her utility is maximum when she goes with her instincts. The husband prefers to go out but he also likes to spend time with his wife. Therefore, his utility is comparatively lower than his utility if he goes out. The utility bundle thus decided is (2,1).

- (Stay In, Go Out)

As mentioned above, both of them prefer to spend time together rather than being apart. This payoff displays the wife planning to go out, unlike her husband who plans to stay in. Thus, if they decide on the opposite strategy, they will not be able to enjoy it at all. Hence, the utility bundle provided to this particular payoff is (0,0).

- (Go Out, Stay In)

This payoff shows the conflicting behaviour of the wife and the husband where the husband plans to go out and the wife decides to stay in. Since the couple wants to spend time together, if they go separate ways, they will receive no utility. Thus, the available set of payoffs will be (0,0).

- (Go Out, Go Out)

Here, the couple decides to go out. Because they are going out together, it is clearly perceptible that they will not be at their worst. However, one of them will be experiencing greater satisfaction than the other. In this case, the husband experiences greater utility as he always preferred to go out, he is thus acquiring maximum utils of 2 utils. Consequently, the required bundle is (1,2).

Utility Preferences:

Husband (Player 1): The utility preferences for Player 1 i.e. the husband have been ranked below:

U(Go Out, Go Out) > U(Stay In, Stay In) > U(Stay In, Go Out) = U(Go Out, Stay In)

Wife (Player 2): The utility preferences for Player 2 i.e. the wife have been ranked below:

U(Stay In, Stay In) > U(Go Out, Go Out) > U(Go out, Stay In) = U(Stay In, Go Out)

The description of the game in its normal form is -

Matrix Form of Simultaneous Game

Wife → **Husband ↓**	Stay In	Go Out
Stay In	2,1	0,0
Go Out	0,0	1,2

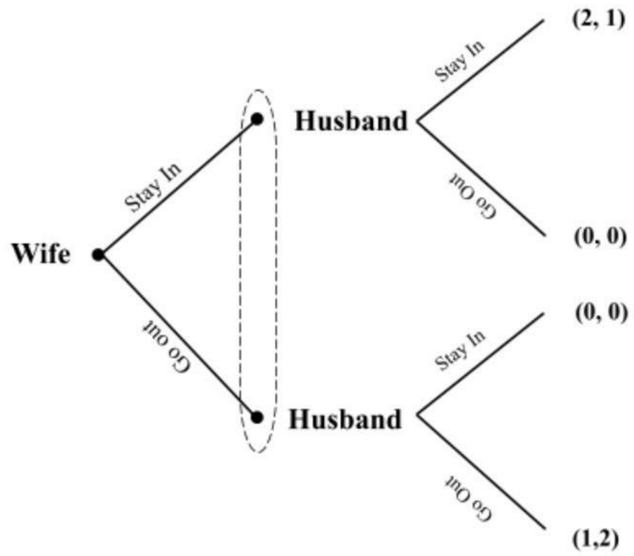
The normal form of a simultaneous game is shown above. Here, the two players i.e. the husband and the wife have to resolve the payoff that would maximise their utility, keeping in mind that the couple likes to spend time together rather than apart. The battle of sexes is an example of a game with no dominant strategies.

Nash Equilibrium

Wife → **Husband** ↓	Stay In	Go Out
Stay In	<u>2</u>, <u>1</u>	0,0
Go Out	0,0	<u>1</u>, <u>2</u>

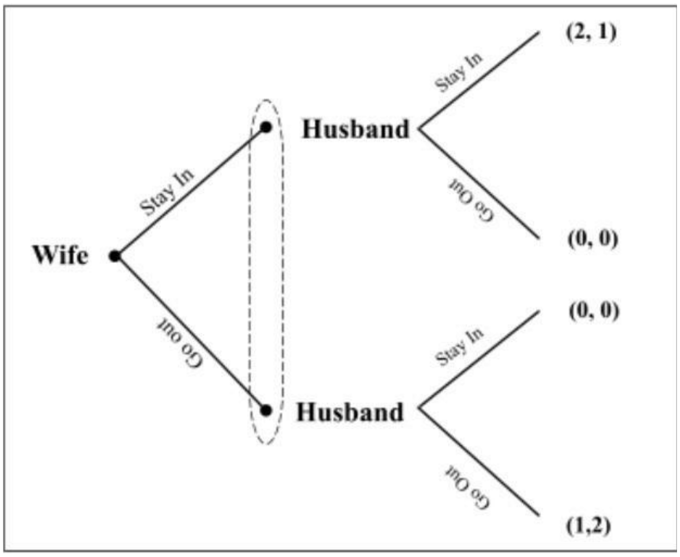
Both the players strive to maximise their utility while choosing their course of action. This game consists of multiple Nash equilibriums at (2,1) and (1,2). At (2,1), the husband is doing his best given what the wife is doing. At (1,2), the wife is doing her best given what the husband is doing. Here, a player prefers to stay in if the other chooses to stay in and go out if the other chooses the same.

Figure: 5 Extensive Form or Game Tree of Simultaneous Game



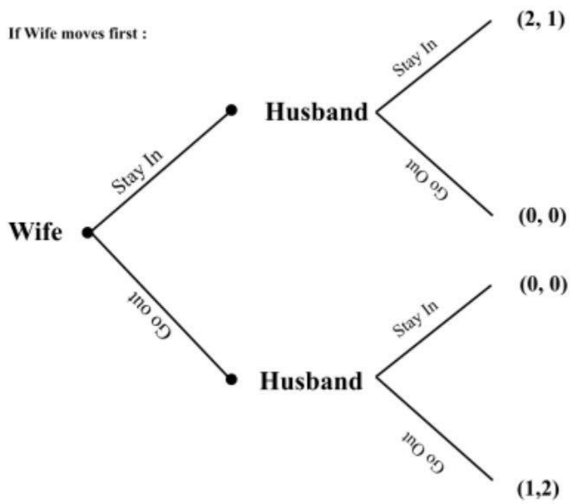
The extensive version of the simultaneous game has been shown in the tree diagram above. The wife moves first at the topmost node following which the husband moves at the lower nodes. The dotted oval that has been drawn implies that the two players share no knowledge about the strategies selected by one another.

Figure: 6 Subgame of Simultaneous Game



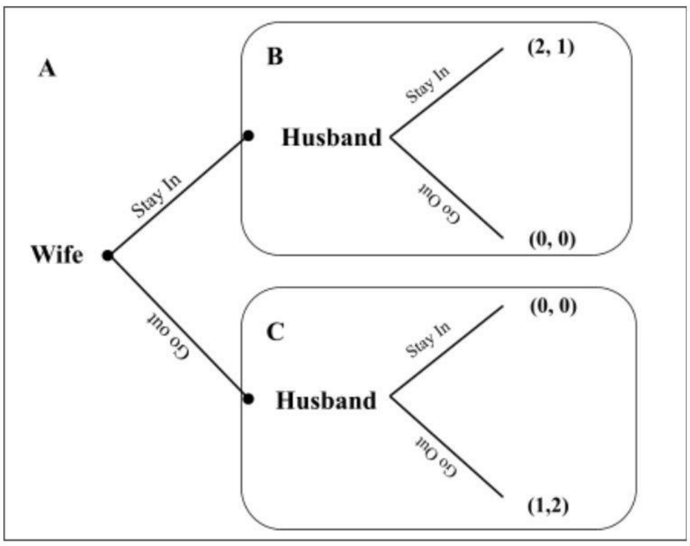
As seen earlier, it can be noticed that the simultaneous game shown above, has only one proper subgame as the top-most node is not connected to any other node in the same information set. The two players are devoid of any information about the decision made by one another, that is to say, they don't know what individual move the other person would choose to make at his/her respective node.

Figure: 7 Extensive Form or Game Tree of Sequential Game



The above diagram game explains the extensive form of the sequential game where there are no changes in the payoffs and actions but with a change in the timings of the moves that have been altered. Now, the husband and the wife are not making any individual choice simultaneously. The decision taken by the husband depends on what the wife chooses to do as and when she makes the first move.

Figure: 8 Backward Induction Strategy for finding Subgame Perfect Nash Equilibrium



As seen in the figure above, the sequential game has three proper subgames:

Subgame A is the game itself where the wife, the first player, makes her move at the topmost node. This is followed by two lower subgames B and C starting at the decision node where the husband, the second player, makes his move. In subgame B, the husband would like to stay in because he likes to spend time with his wife and the wife would always prefer staying in to avoid catching the virus. In subgame C, the husband would want to go out since he experiences greater utility as he had always preferred to go out, thus acquiring a maximum utility of 2 units. It is clearly evident by solving both the subgames, that the husband would choose to stay in; ruling out two of the utility bundles - (Stay In, Go out) and (Go out, Stay In). Applying the backward induction technique, the husband now has to choose between (Stay In, Stay In) and (Go Out, Go out). Choosing to stay in or going out together implies that the couples get to spend time with each other. Hence, through backward induction, we obtain two Subgame Perfect Nash Equilibriums here which are (Stay In, Stray In) and (Go Out, Go Out) with the respective payoffs being (2,1) and (1,2). Neither of the players will be at their worst at these equilibriums but in each case, one of them will be maximising his/her utility.

Contingent Strategy for the Non-Infected where the wife moves first

Contingent strategy for the husband	**Written in conditional format**
Always Stay In	S|S, S|G
Follow Wife's decision	S|S, G|G
Do opposite	G|S, S|G
Always Go Out	G|S, G|G

Normal Form of Sequential Game

Wife → **Husband ↓**	Stay In	Go Out
S|S S|G	2,1	0,0

S|S G|G	2,1	1,2
G|S S|G	0,0	0,0
G|S G|G	0,0	1,2

Note -

- S stands for Stay In
- G stands for Going Out

Example - S|G means "the wife decides to stay in conditional on the fact that the husband decides to go out".

Mixed Strategy:

In a mixed strategy, players will make random choices between two or more possible actions based on a set of probabilities.

Wife → **Husband ↓**	Stay In (w)	Go Out(1-w)
Stay In (h)	2,1	0,0
Go Out (1- h)	0,0	1,2

In the above game, the husband plays "Stay In" with the probability 'h' implying the strategy to go out to be chosen has a probability of '1-h'. Similarly, the wife plays "Stay In" with the probability 'w' and "Go Out" with the probability '1-w'.

General expression for the expected payoff of the wife is written below:

U_w (w,1 - w), (h, 1- h)) = 1hw + 0(h)(1 - w) + 0(1 - h)w + 2(1 - h)(1 - w)

U_w (w,1 - w), (h, 1- h)) = 2 - 2h - 2w + 3hw

By differentiating the above equation with respect to w, we get:

$\frac{d}{dw}(U_w) = 3w - 1$

Equating the above equation to zero gives us, w = ⅓

Thus, the probability that the wife plays "Stay In" as her strategy is ⅓. To analyse, when the wife chooses to stay in with a probability of ⅓; expected the payoff of the husband is maximised.

Now, the expected payoff of the husband is:

U_h (h,1-h), (w, 1-w)) = 2hw + 0(1-h)(w) + 0(h)(1-w) + 1(1-h)(1-w)

U_h (h,1-h), (w, 1-w)) = 1 - h - w + 3hw

By differentiating the above equation with respect to h, we get:

$$\frac{d}{dh}(U_h) = 3h - 2$$

Equating the above equation to zero gives us, h = ⅔.

Thus, the probability that the husband chooses to "Stay Home" is ⅔. To analyse, when the husband plays to stay in as the strategy with a probability of ⅔, the expected payoff of the wife is maximised.

Hence, the Nash equilibrium in strictly mixed strategy is (⅔, ⅓).

Best Response Curve

As U_w (w, 1-w), (h, 1-h)) = 2 - 2h - 2w + 3hw shows, the best response of the wife depends on h.

If h < ⅔ , she wants to keep w as low as possible, in essence, w=0.

If h > ⅔ , she would want to set w as high as possible i.e. w=1.

When h = ⅔, her expected payoff would be ⅔ regardless of the value of w she chooses.

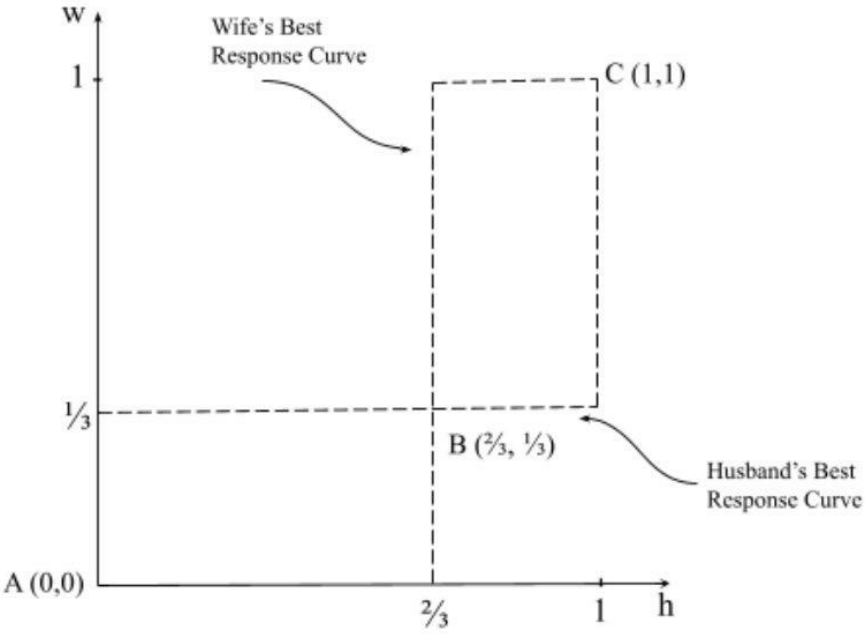
As U_h (h, 1-h), (w, 1-w)) = 1 - h - w + 3hw shows, the best response of the husband depends on w.

If w < ⅓, he would want to keep h as low as possible, h=0.

If w > ⅓, he would set h as high as possible, in essence, h =1.

When w = ⅓, he would be indifferent among all values of h, obtaining a payoff of ⅓ regardless.

With reference to the above cases, the best response curves of the couple have been graphed below.



Conclusion of the game

When the wife chooses to stay in with a probability of ⅓; the expected payoff of the husband is maximised.

When the husband plays to stay in as the strategy with a probability of ⅔ , the expected payoff of the wife is maximised.

6.0 Game 3 - 'Vaccination and Risk Factor during Covid - 19: The Indian Overview'

India launched its vaccine drive, the world's largest inoculation effort in early January. More than 30 million people have been vaccinated so far- healthcare and frontline workers were given a priority in the first phase. The current phase of vaccination focuses on people above 60 years of age and those between the age group of 45 - 59, who have other serious illnesses. Access to the vaccine in the country is given by the priority group, listed by the government.

There are a large number of people in the country who are eligible to get vaccinated but are choosing not to get the vaccine; majorly because there hasn't been enough research on the long-term side effects of the vaccine. Moreover, a lot of uncertainty is linked to the concept as a huge number of confirmed cases include people who have already been vaccinated. This conundrum has been considered while framing this game. We can observe four types of individuals in the present situation - people who are infected with the virus and have access to the vaccination, people who are infected with the virus but do not have access to the vaccination, individuals who are not infected with the virus yet have been vaccinated and the last group of individuals who are not infected with the virus and are not vaccinated as well. All four groups of individuals impact one another in different ways. There is no clarity on the timeline of the third wave but the wave is inevitable and the increase in covid cases will be observed during that time. The second wave of coronavirus had severe effects on the people which caught our country's attention. The spike in cases made sure that hospitals have enough medical supplies and vaccination doses are administered properly to ensure that the next wave doesn't become as severe as the one preceding it.

The 2*2 models represent the two players - Infected and Non-Infected. Each one of them has two strategies- Vaccination and No Vaccination. Each player has to make an informed decision of whether getting vaccinated would maximise its utility or not. If one gets vaccinated, it will act as a positive externality for the other. But if one of them decides to opt for "No Vaccination", it will act as a negative externality for the player being vaccinated.

Players: The two players are infected people and non-infected people
Strategies: {Vaccination, Non- Vaccination}
Payoffs: The payoffs here are non-monetary in nature.

- (Vaccination, Vaccination)

This payoff defines both the infected and the non-infected opting for vaccination. According to the assumptions, if the infected person decides to get vaccinated, they would be better off and thus would reflect a positive utility. Similarly, if the non-infected plays "Vaccination", they would reduce the chances of getting infected with the virus and thus would also indicate a positive utility. If both of them get vaccinated, the risk of catching the virus would be minimal. Considering them as rational, their utility would be maximum if this bundle is chosen. Thus, a value of (20,20) has been assigned to this payoff.

- (Vaccination, No Vaccination)

This payoff depicts that the infected opts for Vaccination unlike the non-infected, who chooses No Vaccination. According to the assumptions, if the infected person plays Vaccination, they will be better off and thus would reflect a positive utility. In this case, the non-infected plays No Vaccination, they are thus at risk of getting infected with the virus. They would also act as a negative externality for the infected and thus their utility will be lower than the aforementioned case. However, since the infected are getting vaccinated, the chances of the non-infected catching the virus become low but are not equal to zero. The utility bundle, therefore, designed for this payoff is (10,10).

- (No Vaccination, Vaccination)

This payoff represents the infected not getting vaccinated and the non-infected getting vaccinated. No Vaccination, as played by the infected cannot affect him as he is already infected with the virus but he could transmit the virus to the other player i.e. non-infected. The non-infected opts for Vaccination, which should be good for him. When examined together, the risk factor remains high as the infected plays No Vaccination; thus negative utility is depicted for the non-infected. But on account of the non-infected choosing Vaccination, there is a possibility that the non-infected fights the virus and remains healthy throughout. Accordingly, the utility bundle allocated to this payoff is (0,-10).

- (No Vaccination, No Vaccination)

This payoff illustrates both of them playing the No Vaccination strategy. This would merely affect the infected as he is already infected with the virus but will adversely affect the non-infected as he has a higher probability of getting infected with Covid-19. Consequently, his utility would be negative and at its minimum. Hence, the bundle allotted to this particular payoff is (0,-20).

Utility Preferences:

Infected People (Player 1): The utility preferences for Player 1 i.e. infected people have been ranked below:

U(Vaccination, Vaccination) > U(Vaccination, Non Vaccination) > U(Non Vaccination, Vaccination) = U(Non-Vaccination, Non-Vaccination)

Non- Infected People (Player 2): The utility preferences for Player 2 i.e. non-infected people have been ranked below:

U(Vaccination, Vaccination) > U(Vaccination, Non Vaccination) > U(Non-Vaccination, Vaccination) > U(Non-Vaccination, Non- Vaccination)

The 2*2 model game designed is presented in its normal form -

Matrix Form of Simultaneous Game

Non - Infected → **Infected ↓**	Vaccination	Non - Vaccination
Vaccination	20,20	10,10
Non - Vaccination	0,-10	0,-20

The normal form of a simultaneous game is shown above. The game can be solved using the dominance strategy which suggests the best response to all strategy profiles of other players. The infected have a dominance strategy to opt for vaccination. This can be understood by the following conditional statement -

If Non – Infected → Vaccination; Infected → Vaccination

If Non – Infected → No Vaccination; Infected → Vaccination

Thus, Player 1 (the infected) is maximising his utility, irrespective of the decision of Player 2 (the non-infected).

Similarly, the non-infected also have a dominant strategy to opt for vaccination. The conditional statement to prove this is -

If Infected → Vaccination; Non – Infected → Vaccination

If Infected → No Vaccination; Non – Infected → Vaccination

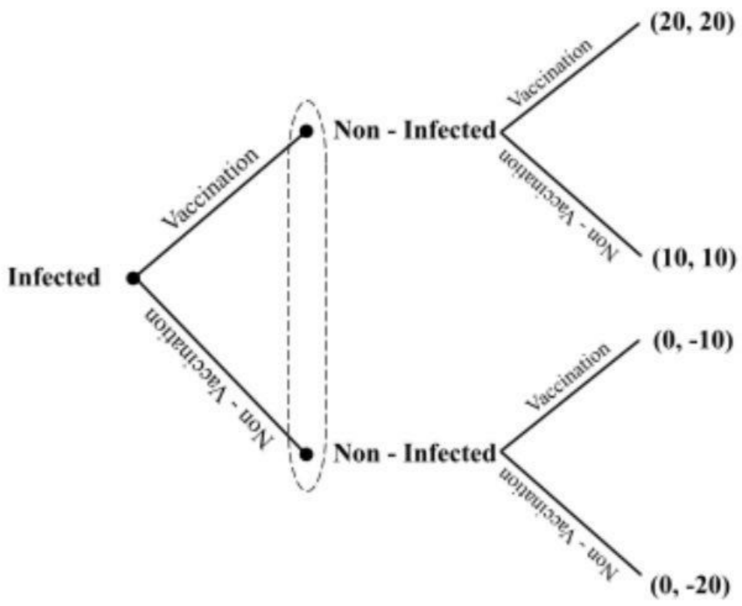
Therefore, opting for vaccination, independent of the strategy played by Player 1(the infected) is the best strategy for Player 2 (the non-infected).

Nash Equilibrium

Non - Infected → **Infected ↓**	Vaccination	Non - Vaccination
Vaccination	20,20	10,10
Non - Vaccination	0,-10	0,-20

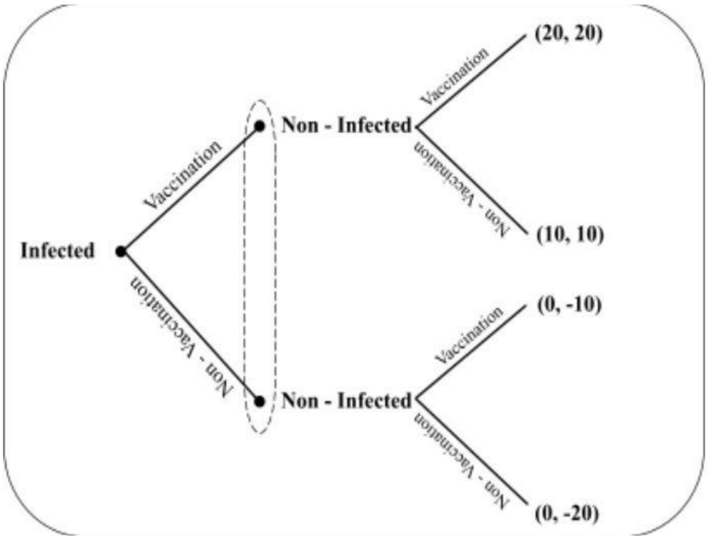
The unique Nash equilibrium for the above game is (20,20). There is no incentive for any player to deviate from his Nash strategy. The Nash equilibrium has been attained as follows - Row 1 dominates Row 2 which implies that all payoffs for the infected in Row 1 are better than all corresponding entries in Row 2. Therefore, the infected people are always better off if they choose vaccination. Similarly, Column 1 dominates Column 2 which implies that it is always better for the non-infected to choose No Vaccination. (Vaccination, Vaccination) is thus, a Nash equilibrium and a Pareto-efficient outcome.

Figure: 9 Extensive Form or Game Tree of Simultaneous Game



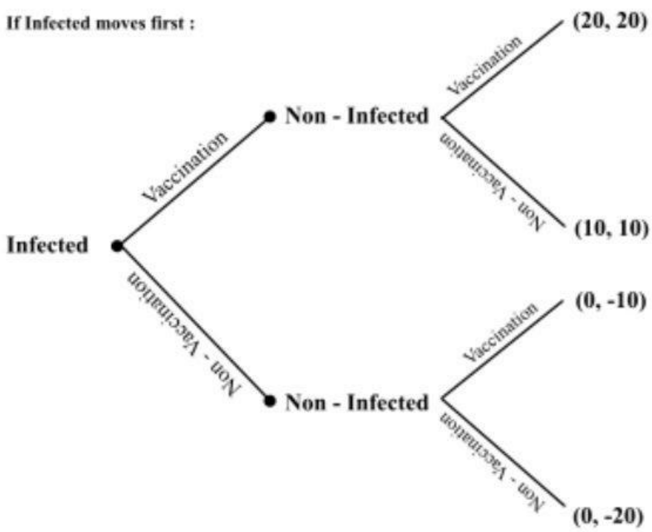
The extensive form of the game has been demonstrated in the above diagram. The dotted oval is drawn around the nodes at which infected people (Player 1) move, indicating that the two nodes are in the same information set. In other words, Player 2 i.e. the non-infected are unaware of the decision of Player 1 i.e. the infected people have chosen.

Figure: 10 Subgame of Simultaneous Game



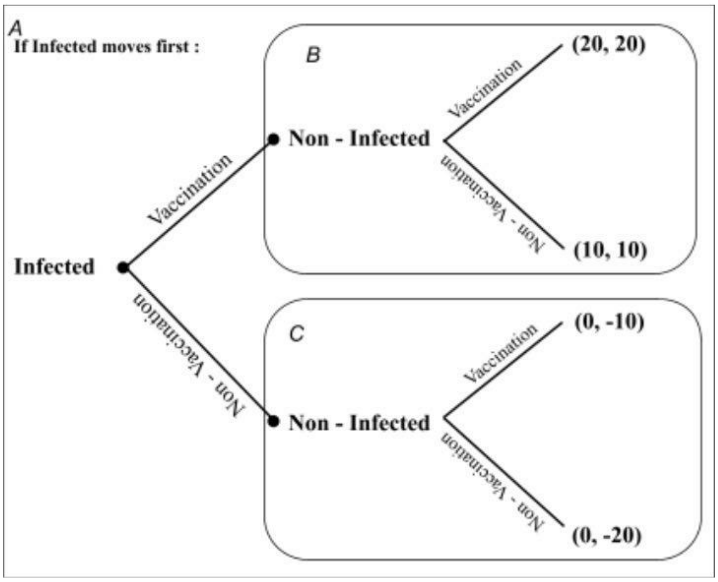
In the above simultaneous game, there is only one decision node - the topmost node - that is not connected to another in the same information set; hence, there is only one proper subgame viz the game itself.

Figure: 11 Extensive Form or Game Tree of Sequential Game



The payoffs and actions remain the same as mentioned previously, but now the timings of the moves have been changed. Now, both the players do not make their individual choices simultaneously, rather the infected person acts as the first mover, followed by the non - infected. This explains the sequential game; the extensive form for which has been shown above.

Figure: 12 Backward Induction Strategy for finding Subgame Perfect Nash Equilibrium



The above sequential game has three proper subgames, the game itself and the two other lower subgames starting with the decision node where Player 2- non-infected people execute their decision. The subgames have been named A, B, and C as shown in the figure. The highest utility for the non-infected can be noticed at 20 utils. Thus, in subgame B, the non-infected would like to opt for Vaccination which provides them with maximum utility because it guarantees a higher chance of remaining healthy. In subgame C, the non-infected would want to opt for vaccination as there is a relatively higher probability of them being healthier. It is clearly evident by solving both the subgames, that the non-infected would choose to be vaccinated; ruling out two of the utility bundles - (Vaccination, No Vaccination) and (No Vaccination, No Vaccination). Applying the backward induction technique, the infected people now have to choose between (Vaccination, Vaccination) and (Non-Vaccination, Vaccination). As choosing for vaccination will guarantee them less risk of being diagnosed with the virus, they would likely choose Vaccination as their play strategy. Hence, through backward induction, the Subgame Perfect Nash Equilibrium emerges as (Vaccination, Vaccination) that has a payoff of (20,20).

Contingent Strategy for the Non-Infected where Infected moves first

Contingent Strategy for the non-infected	Written in conditional format
Always go with the Vaccination	(V|V, V|NV)
Follow infected people	(V|V, NV|NV)
Do the opposite	(NV|V, V|NV)
Always go with Non - Vaccination	(NV|V, NV|NV)

In a sequential game, the second mover has the benefit of knowing about the actions taken by the player who acted first. Hence, the second mover's strategy can act as a contingent plan, depending on the decision of the first mover.

Normal Form of Sequential Game

The normal form of the sequential game has been shown in the matrix given below:

Non – Infected → **Infected ↓**	V|V V|NV	V|V NV|NV	NV|V V|NV	NV|V NV|NV
Vaccination (V)	20,20	20,20	10,10	10,10
Non - Vaccination (NV)	0,-10	0,-20	0,-10	0,-20

Note -

- V stands for Vaccination
- NV stands for Non - Vaccination

Example - V|NV means "the non-infected people choose vaccination conditional on the fact that the infected people choose non-vaccination".

Conclusion of the game

The current situation of this pandemic has made people observe that even after getting vaccinated, the chances of being diagnosed with COVID do not reduce. But the risk of harmful side effects of coronavirus has been reduced in those individuals who have got themselves vaccinated. There is no risk of death or any other major serious health condition if a person decides to get themselves vaccinated. If the individuals get diagnosed with the virus after getting the vaccine shot then the impact of the virus is very mild and the severity of harmful side effects is less. If the individual does not get themselves vaccinated then they are putting themselves at risk as well as those individuals who have taken the vaccination. Hence, both the individuals getting vaccination works in the best-case scenario in the above game as the chances of being diagnosed with the virus are very less.

7.0 Conclusion

COVID-19 pandemic has affected the lives of countless individuals on many levels- economic, social, psychological and physiological. Game theory provides a model for analysis and understanding of how the virus has made an impact on every individual of this country. We can observe how the vaccination drive can help in combating the virus and secure most individuals from the risk of contamination. Lockdowns and other preventative measures too can enable in stopping the spread of the corona strain and keep individuals safe. There is no expiration date for the virus and hence the vaccination drives, preventative measures (such as staying inside the home) and lockdowns have the ability to keep millions of people away from the risk of contamination from this unexpected virus.

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