# The Applications of Game Theory in Natural Disaster Management: a Case Study of COVID-19 Pandemic

Zhenbei Guo[1, *]

[1]RDFZ Chaoyang Branch School, Beijing, China

*Corresponding author: guozhenbei@rdfzcygj.cn

**Abstract.** As of 2022, mankind has been struggling with the COVID-19 pandemic for three years. This paper is based on the application of game theory in natural disaster prevention and control. Using a case study approach, the paper specifically examines the game process between policy makers (states), policy transmitters (hospitals) and policy implementers (individuals) in the prevention and control of the pandemic, as well as the answers to three questions: why governments have coercive measures, how hospital decisions at the beginning of the pandemic caused the spread of the coronavirus, and the impact of uneven control efforts between countries. It is found that from the individual perspective, which can include individuals in the pandemic prevention and control or a particular hospital in the healthcare system, the rational choice of interest of the individual is inconsistent with the rational choice of interest of the whole and a Nash equilibrium is thus reached. From a national perspective, in a world of countries experiencing progressively globalized and integrated, the unevenness of control efforts has led to the fact that no country can be left alone, thereby imported COVID-19 cases are always present. This is also reflected in whether or not to collaborate on vaccine development.

**Keywords:** game theory; COVID-19; pandemic; natural disaster management.

## 1. Introduction

A disaster is a social situation in which serious damage, either natural or man-made, brings about significant harm to life. Disasters can therefore be divided into natural disasters and disasters caused by human beings. Natural disasters are caused by geophysical, hydrological, meteorological, biological, extraterrestrial or climatic hazards[1], such as earthquakes, floods, epidemic diseases, etc. Natural disasters often occur with forces that are irresistible to humans or to any species on the planet, which reflects their uncertainty and uncontrollability. Catastrophic events that erupt under the long-term influence of some cause may occur locally, as in the case of some countries in earthquake zones facing earthquakes, floods, or on a large scale, as in the case of the global outbreak of the COVID-19 pandemic. Disaster management is a multi-sectoral process that involves planning, implementation, early warning, emergency response and relief measures to reduce or mitigate the impact of natural or man-made disasters on society. Disaster management can be divided into four stages: pre-disaster mitigation and preparedness, disaster response, and post-disaster recovery[2]. The following discussion will focus on the stage of response in times of disaster.

The Prisoner's Dilemma is one of the most famous examples of game theory, and as a matrix game it is similar to what will be discussed following. It is about two criminals who are caught by the police and whoever confesses first will receive a lenient sentence of 3 months, while the person who confesses will be sentenced to 10 years[3]; if both sides insist on not confessing, both will eventually be acquitted, but if both confess the crime, each will be sentenced to 5 years in prison. In this scenario, as the two have no way of knowing the other's options, each is acting in his own interest. Obviously, this is the best strategy for the two individual offenders to confess, as they can expect a short sentence: three months in prison, but only if the other person does not confess, which is clearly better than the 10 years that would be served if the other person chose to confess and they did not. So in the end, both men choose to confess. Such an outcome is known as a Nash equilibrium, and represents a situation where no one participant can increase their gains by acting alone. The non-cooperative game represented by the prisoner's dilemma can be divided into a static game with perfect information, a dynamic game with perfect information, a static game with incomplete information and a dynamic game with incomplete information. The equilibrium concepts corresponding to these four games are: Nash equilibrium, subgame refined Nash equilibrium, Bayesian Nash equilibrium and refined Bayesian Nash equilibrium.

## 2. Background

The COVID-19 pandemic first began on December 2019 in the city of Wuhan, People's Republic of China, and soon after in January 2020 the World Health Organization announced that pneumonia caused by this new coronavirus constituted a public health emergency of international concern and declared a new pandemic on 12 March[4]. As of September 4, 2022, there have been more than 600 million cases of the new COVID-19 and it has caused approximately 6.5 million deaths[5]. Worldwide, people have been battling COVID-19 for almost three years.

In the early stages of the development of the coronavirus, the lack of scientific understanding of this new coronavirus failed to attract the attention of the hospital where Patient 0 was first identified. The words of Li Wenliang, a doctor working at Wuhan Central Hospital, who was the first person to come into contact with the coronavirus and realise the seriousness of the situation, were not taken seriously by the hospital, but were instead considered to be spreading rumours and punished[5]. Such examples are common in the early stages of natural disasters and they indirectly contribute to the deterioration of the situation. It is therefore necessary to understand the occurrence of such dilemmas in order to reduce the occurrence of similar situations and to contribute to the prevention and control of natural disasters. Following the outbreak, governments took decisive measures to prevent and control the pandemic, including quarantining infected and exposed populations, urging citizens to wear masks outside, and even closing cities and other mandatory measures. Individual decisions resulting from individual lack of understanding and cooperation have led to significant resistance to the implementation of measures in some countries and have not achieved the desired results. It is therefore particularly important to understand and cooperate with government measures at the individual level in natural disaster prevention and control. As the battle lines against the COVID-19 pandemic continue to lengthen, some countries have opted for lax policies and epidemic prevention and control has gradually become uneven between countries. But with continued globalisation, the close ties between countries led to a constant movement of people and the pandemic was never brought under control on a global scale. Is this another manifestation of game theory in the COVID-19 pandemic, and can governments reach a win-win situation in terms of game play, i.e. a full control of the epidemic on a global scale.

## 3. Game model analysis of individual’s behaviour

Individual decisions and actions play a critical and absolute role in the development of an epidemic. If governments and coordinating agencies are the ones who make the decisions in a natural disaster like this, individuals are the real practitioners of policy in the collective. When the epidemic broke out, the World Health Organisation and governments issued warnings about personal protection and avoiding crowds[6]. People were also encouraged to get vaccinated as soon as possible after the subsequent introduction of the vaccine**错误!未找到引用源。**. The application of game theory will be illustrated below, using vaccination and personal protection as examples. In vaccination, suppose that c and d are citizens of a country who are considering whether or not to be vaccinated, and that they are players in the game. The cost of vaccination is assumed to be x. This may include the risk of adverse reactions, the pain associated with vaccination, etc., while the cost of not being vaccinated will be the risk of being infected followed by the widespread of the pandemic, will be represented by y.

**Table 1.** payoff matrix between citizens assumed citizen D is healthy

| | | Citizen D | |
|---|---|---|---|
| | | vaccinate | not |
| Citizen C | vaccinate | x,x | x,0 |
| | not | 0,x | 0,0 |

**Table 2.** payoff matrix between citizens assumed citizen D is infected

| | | Citizen D | |
|---|---|---|---|
| | | vaccinate | not |
| Citizen C | vaccinate | x,x | x,y |
| | not | y,x | y,y |

Assuming citizen D is healthy, in Table 1, if citizen c is vaccinated, neither party under citizen D's vaccination will be infected, but both parties will need to bear the costs associated with vaccination at the same time. Any of the other three combinations of decisions, while able to have cost avoidance potential whether for citizen C or citizen D or both together, is the most rational choice because citizen D's health status is assumed, citizen C has no way of knowing whether citizen D is infected, and the spread and severity of the coronavirus can be reduced for citizens with the vaccine, so both are vaccinated. On the other hand, in Table 2, assuming citizen D is infected, citizen C needs to be vaccinated to ensure that he is not infected by citizen D. However, for citizen D, it does not matter whether he is vaccinated or not, so it is likely that he will choose not to be vaccinated and refuse to bear the cost of vaccination, thus accelerating the spread of the pandemic.

## 4. Hospitals and the Prisoner's Dilemma

The Prisoner's Dilemma in game theory can be used well to explain how, in the early stages of the COVID-19 outbreak, hospitals, as individuals in the healthcare system, appear to have made the most rational choice for themselves, i.e. refusing to believe the word of doctors, forgoing accepting infected patients to avoid risk, etc. But from a group, or societal, perspective, such decisions are irrational. Suppose there are two hospitals in the health care system, Hospital A and Hospital B. If the hospital chooses to treat the infected population, the cost to be borne by the hospital is c, including but not limited to occupational exposure, the risk of nosocomial infection, the financial cost and the possible reputational impact. If the hospital chooses to reject the infected population, then the cost incurred is zero. Simplifying the influencing factors at the time, the following game matrix was able to be produced.

**Table 3.** payoff matrix between hospitals

| | | Hospital B | |
|---|---|---|---|
| | | accept | not |
| Hospital A | accept | c,c | c,0 |
| | not | 0,c | 0,0 |

Table 3 shows the two possible choices made by hospital A and the two possible choices made by hospital B form four combinations. Firstly, when both hospitals A and B choose to accept the infected population, the costs mentioned above will be spread out, thus reducing the risk to hospitals A and B respectively. In addition, because the patient has the choice of two hospitals, which prevents the spread of pandemic in a greater extent. This is considered to be the most rational choice for the group as a whole. However, the situation faced by the hospitals is a static game of incomplete information, and neither hospital A nor B has any way of knowing the other's choice, so from the perspective of individual hospitals A and B, they are both afraid of being the only hospital to bear all the costs and risks, so the most rational choice for hospital as individual is to avoid the risks and choose not to accept infected people. In practical terms, in the early stages of the pandemic, hospitals did choose not to accept patients for reasons of self-interest and risk aversion due to a lack of scientific knowledge and a rigorous regulatory system. When patients are rejected and have nowhere else to go for treatment, the risk of transmission is maximised at this point, ultimately leading to widespread outbreaks.

## 5. Country-level game theory analysis

### 5.1 The prevention and control differences between countries

In these three years of battle with the pandemic, some countries are choosing to move straight into the post-pandemic era and 'live with the COVID', while in stark contrast others are choosing to stick to strict prevention of the emergence of COVID-19 infections错误!未找到引用源。. Country E and country D are hypothetically two countries that are closely linked and who have an unbreakable trade chain in terms of imports and exports. However, as they face a lengthening of the pandemic timeline, their decisions are being played out. As shown in the diagram below, when a country chooses to defend itself against COVID-19, the costs incurred are set to m. This includes high protection costs, disruption of import and export trade, a stagnant economy and so on, but when choosing to live with the epidemic, there appears to be no cost in these terms.

**Table 4.** payoff matrix between countries

| | | Country E | |
|---|---|---|---|
| | | defence | not |
| Country D | defence | m,m | m,0 |
| | not | 0,m | 0,0 |

In Table 4, when both countries E and D are protected against the COVID-19, it can be seen that although the economic situation of both countries will be impaired, i.e. a cost m emerges, at the same time neither country's citizens will therefore be infected with the COVID. However, when only countries D and E either insist on preventing and controlling the COVID-19 pandemic, although the other country appears to make the best choice for its economy, however lead by the uncontrollable or very difficult to control nature of the movement of people as imports and exports pass, neither the preventing nor the non-controlling country can control the spread of the COIVD-19 between countries, thus leading to the continued emergence of the pandemic. In the last scenario, when both D and E countries choose to live with the pandemic and minimise prevention and control, the global economy can grow together, but the health of the world's people will become another challenge.

From a practical point of view, today China is still contributing to the prevention and control of the pandemic, while at the same time the US and other Western countries tend to ignore the pandemic in favour of economic recovery[7], which leads to the emergence of imported cases causing national alarm even though China spends a lot of resources every day to prevent the spread of the epidemic, and so on and so forth. It is easy to see that in a globalised world, countries are inextricably linked and therefore no country can be left alone in the face of an epidemic. It is only when the choices of individual countries converge that the overall welfare can be optimised.

### 5.2 The vaccine development around world

The process of vaccine production has been described as long and expensive[10], and only a few countries in the world have the capacity to develop and produce vaccines and make them widely available to the general public, making collaborative vaccine development incredibly important. In the famous example of the prisoner's dilemma, it is in the best interests of both parties that neither criminal A nor B confesses. Similarly, in the case of pandemic research and development as a non-zero-sum game, any country that chooses not to cooperate but to develop on its own in its own interests, whether based on distrust of other countries or a rational desire to maximise its benefits, results in a collective irrationality and is not the best choice in the group, i.e. in the world. The economic and time costs of vaccine development are greatly reduced when countries cooperate in a clear and transparent manner, which on the other hand prevents opportunity costs from arising. The Nash equilibrium can therefore be broken and an optimal situation reached.

## 6. Conclusion

At the individual level, it is not known whether others in the group represented by citizen d are healthy in real life and whether they have been vaccinated and have avoided the risk of transmission from them, so citizens of countries in the context of a raging new crown epidemic should respond to policies to vaccinate themselves to prevent infection and amplify the risk of transmission, and should consider the collective interest and risk of infection to themselves before considering the cost of vaccination. Similarly, in natural disaster prevention and control, individuals should have full confidence in the government and the policies enacted and implemented.

The prisoner's dilemma can be used well to explain why hospitals indirectly contributed to the spread of the pandemic from the hospital level, i.e. the individual in the healthcare system, at the beginning of the pandemic. Hospital A and Hospital B in the hypothesis, choose for themselves the most rational approach, i.e. not accepting infected people, in order to avoid risk and reduce costs. However, in the case of the group, such an approach contributes to the spread and spread of the epidemic. The rational choice of the individual is often not the best choice for the collective, a reflection of the Nash equilibrium. Therefore, in the prevention and control of natural disasters, institutions that act as policy transmitters, such as hospitals in the prevention and control of new crown epidemics, should do so by looking at the bigger picture and avoiding a preoccupation with individual interests. The government should also enact more timely policies to regulate some of the institutions that tend to avoid cost and risk, and therefore maximise the effectiveness of disaster prevention and control.

At the national level, close communication and cooperation are inevitable in this era of progressive globalisation. No single country can win the fight against the epidemic, whether it is the prevention and control of the epidemic or the development of a vaccine. In the case of epidemic prevention and control, the inconsistency of policies between countries means that some countries choose not to prevent and control the epidemic and thus repair their economies, while others guard against it. The result is that the number of imported cases continues to increase and the countries that are defending themselves are unable to achieve a complete zero of new coronavirus cases, so the epidemic continues and the end is not in sight. The development of a vaccine is very similar and there are no countries in the world with independent research and development capabilities, but they are also affected by the New Coronavirus epidemic, so cooperation and help is needed between countries to achieve a complete global victory for humanity against the virus.

## References

[1] Seaberg, D., Devine, L., & Zhuang, J. (2017). A review of game theory applications in Natural Disaster Management Research. Natural Hazards, 89(3), 1461–1483. https://doi.org/10.1007/s11069-017-3033-x

[2] Asghar, S., Alahakoon, D., & Churilov, L. (2006). A comprehensive conceptual model for disaster management. Journal of Humanitarian Assistance, 1360(0222), 1-15.

[3] Shubik, M. (1970). Game theory, behavior, and the paradox of the Prisoner's Dilemma: three solutions. Journal of Conflict Resolution, 14(2), 181–193. https://doi.org/10.1177/002200277001400204

[4] Who declares public health emergency on novel coronavirus. PAHO/WHO | Pan American Health Organization. (2020, January 30). Retrieved September 16, 2022, from https://www.paho.org/en/news/30-1-2020-who-declares-public-health-emergency-novel-coronavirus

[5] Coronavirus cases: Worldometer. (n.d.). Retrieved September 11, 2022, from https://www.worldometers.info/coronavirus/

[6] BBC. (2020, February 7). Li Wenliang: Coronavirus kills Chinese whistleblower doctor. BBC News. Retrieved September 11, 2022, from https://www.bbc.com/news/world-asia-china-51403795

[7] World Health Organization. (n.d.). Advice for the public on covid-19. World Health Organization. Retrieved September 11, 2022, from https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

[8] World Health Organization. (n.d.). Covid-19 vaccines advice. World Health Organization. Retrieved September 11, 2022, from https://www.who.int/emergencies/diseases/novel-coronavirus-2019/covid-19-vaccines/advice

[9] Pearce, N., Lawlor, D. A., & Brickley, E. B. (2020). Comparisons between countries are essential for the control of covid-19. International Journal of Epidemiology, 49(4), 1059–1062. https://doi.org/10.1093/ije/dyaa108

[10] Shahcheraghi, S. H., Ayatollahi, J., Aljabali, A. A. A., Shastri, M. D., Shukla, S. D., Chellappan, D. K., Jha, N. K., Anand, K., Katari, N. K., Mehta, M., Satija, S., Dureja, H., Mishra, V., Almutary, A. G., Alnuqaydan, A. M., Charbe, N., Prasher, P., Gupta, G., Dua, K., … Tambuwala, M. M. (2021). An overview of vaccine development for covid-19. Therapeutic Delivery, 12(3), 235–244. https://doi.org/10.4155/tde-2020-0129