Analysis of Game Cooperation in Manufacturing Industry Under the Impact of Covid-19 on Global Supply Chain Based on Dynamic Game

Xinxin Chen[1, *, †] Lingqi Yao[2, †]

[1] *Qibao Dwight High School, Shanghai, 201101, China*
[2] *Tan Kah Kee College, Xiamen University, Fujian Province, 363105, China*
[*] *Corresponding author. Email: xxchen_rachel@qibaodwight.org*
[†] *These authors contributed equally.*

ABSTRACT
The outbreak of the COVID-19 causes multifaceted disruptions and delays in the global supply chain, commodity shortages, and price increases, and may also exacerbate inflation caused by global monetary overdraft. Based on the game model, we analyze the cooperation and decision-making behaviors of suppliers and retailers, the two main business entities in the manufacturing supply chain, and the risks to the supply chain in the event of a prolonged epidemic. This paper provides suggestions to improve the efficiency of supply chain operations, layout multi-source production, and procurement, increase the transparency of supply chain information, expand the sales model, and promote digital transformation.

Keywords: *Global supply chain, COVID-19, Game theory, Manufacturing industry, Dynamic game*

1. INTRODUCTION

According to the sudden arrival of the COVID-19 that has swept the world, the trajectory of the world is gradually changing. Although countries are actively introducing corresponding policies to prevent the epidemic and actively mobilizing people to work, the economic and financial system turbulence caused by the global supply chain disruption crisis has had a significant negative impact on production and distribution, production capacity cooperation, labor mobility, and foreign investment, and the real economy and manufacturing supply chain are facing many uncertainties to return to normal. The real economy and manufacturing supply chains are facing a lot of uncertainties. Today, many countries are still facing an oversupply of some important daily commodities, even causing a scrambled panic, and with the arrival of some major holidays, the supply chain crisis has become more and more amplified, which has exposed many inherent drawbacks. Long before the global epidemic broke out in mid-to-late February 2020, global demand for medical protection supplies had increased 100-fold and prices had risen 20-fold, according to World Health Organization projections. By mid-March when the global epidemic began to enter its major outbreak phase, many countries, including Europe and Asia, banned the export of key protective items such as masks, gloves, and protective clothing, and some countries even saw the phenomenon of intercepting protective supplies from other countries, as evidenced by the shortage of epidemic prevention materials.

The impact of the COVID-19 is a stress test for the global manufacturing supply chain, bringing challenges to the supply chain and opportunities for restructuring and upgrading the global supply chain. Although the epidemic itself is a short-term impact, the impact of the epidemic on the global supply chain is long-term. The main manifestation of the long-term impact of the epidemic on the global supply chain system is closely related to maintaining the stability of the supply chain, and supply chain security has gradually become an important business requirement for U.S. and European enterprises to adjust the layout of the global industrial chain while safeguarding domestic industrial security and public health security has become an important guide for future U.S. and European government policy adjustments.

With the normal operation of global supply chains being disrupted, it is particularly important to enable both companies and customers to reduce losses,

maintain normal operation and even increase revenue and value through effective management and cooperation. Suppliers and retailers are the two main business entities and important stakeholders in the manufacturing supply chain, and the relationship between them directly affects the quality of goods distribution. Usually, the fundamental interests of suppliers and retailers should be the same to ensure the smooth sales of goods in circulation. However, the quality, quality, or status of suppliers' products fluctuates greatly under the epidemic, and changing their cooperative moves when the interests of suppliers are threatened may affect the interests of downstream retailers, and both parties will face greater risks. In this paper, we use dynamic games to study the possible cooperative behavioral decisions of suppliers and retailers under the epidemic and analyze the potential risks they face and the evolution of the results.

The research on game theory can be divided into early research stage, formation stage, growth and development stage, and maturity stage, and in the twenty-first century the game theory approach is becoming more and more the mainstream method of economic research, which has attracted the attention of scholars in modern economic theory and practice, and some results have been achieved in the study of the behavior of core members in the supply chain.

Salarpour and Nagurney constructed the first stochastic Generalized Nash Equilibrium model for the study of competition among countries for limited supplies of multicommodity medical items in the pandemic [1]. Pujawan and Bah have presented a review of literature that addresses supply chains under disruptions due to the COVID-19 pandemic. Their major findings include the rising importance of safety, digitalization, localization, the need to revisit the meaning of efficiency, and the production and some distribution of COVID-19 vaccine [2]. Vasnani et al. explored the various applications and current trends of game theory to supply chain management through an exhaustive review of the literature. Nash and Stackelberg solution concepts integrating game theory in different supply chain structures [3]. Zhu et al. researched mask output as a state variable and analyzed the differential game to study the long-term dynamic cooperation of a two-echelon supply chain composed of the supplier and the manufacturer under government subsidies [4]. Ivanov used four strategies to maintain supply chain viability when facing a pandemic and offers a model to analyze and quantify deployment and impact of adaptation. Ivanov analyzed cases such as Amazon, Johnson & Johnson, AGGO, and Ford to illustrate the practical context and supplement the literature analysis to derive relevant determinants for building a conceptual framework and construction of a formal model. [5]. Naini et al. presented guidance for practice managers in evaluating and measuring environmental supply chain management by developing a knowledge-based balanced scorecard and evolutionary game theory [6]. Aigbedo researched the significant impact on hospitality due to the COVID-19 and on the accommodation and food services which are related as well. A mixed-methods approach is used to investigate their associated supply chain [7]. Belhadi et al. indicated that the most efficient method for the automobile to overcome the pandemic is improving their localized supply sources [8]. BWM and TOPSIS are applied in Grida et al.'s research which would provide evaluation results on three topics (supply, demand, and logistics) with high accuracy [9]. Sajid researched to find the effect on the ever-emerging biomass supply chain due to the pandemic and proposed that international cooperation would help to constrain COVID-19 impacts and reinforce the world's bioeconomics [10]. By applying the twitter data, Sharma et al. researched the solutions to the pandemic. Some significant similarities revealed that firms are facing challenges of demand-supply mismatch, lack of advanced technology, and development of a resilient supply chain [11].

Therefore, the research on supply chain and game theory in different industries has been developed to a certain extent, however, the behavioral decision of stakeholders related to the global manufacturing supply chain under the COVID-19 still needs to be studied, and most of the game models choose complete information static game model or incomplete information static game model for analysis, this paper analyzes the behavior of two core members of the supply chain, suppliers and retailers, based on incomplete information dynamic game. This paper analyzes the behavior of two core members of the supply chain, suppliers and retailers, based on the dynamic game with imperfect information, considering the time sequence of the choices made by the participants, and analyzing the various risks and results that may occur in the process of cooperation.

2. METHODOLOGY

The objective of Games theory is to predict, using a set of rules the way actors will react while interacting with themselves. A complete game consists of the following elements: players, set of actions or strategies, sequence of actions, payoffs, and information. Participants are also called decision-making subjects, which can be individuals, organizations, and countries, but people who have nothing to do with the game cannot be called decision-making subjects, for example two people playing chess are decision-making subjects, while the spectators are not decision-making subjects.

2.1. Dynamic game of incomplete information

A dynamic game means that the actions are in order.

This means, one of the players takes action before the other players and may have some type of advantage. Under the condition of incomplete information, the decision-maker knows which types the opponent has and the probability of each type, that is, he knows the relationship between the different types of participants and the corresponding choices, but he does not know which type the other participants belong to. Because of the sequence of actions, the latter actor can observe the behavior of the former actor and obtain the information of the former actor, to confirm or revise his actions against the former. At the beginning of a dynamic game with incomplete information, a player establishes his preliminary judgment according to the different types of other players and the probability distribution of their types. When the game starts, the player can revise his initial judgment according to the actual actions of the other players he observes, and according to the choose your strategy based on this changing judgment.

2.2. The Harsanyi transformation

The Harsanyi Transformation is something to be discussed under the topic of game theory. In 1967, Harsanyi put forward an idea of transforming the static game of incomplete information into the dynamic game of complete but imperfect information, which is called "Harsanyi transformation". The dynamic game of incomplete information can also be transformed into the dynamic game of imperfect information by Harsanyi transformation. The specific methods are as follows: one is to introduce a virtual "natural" player, also known as "player 0", whose function is to select each actual player in a random way or to extract their respective types, before the selection of the actual players in the game, and these extracted types constitute the type vector t = (t1, …, tn), ti Ti, i= 1, …, n. The second is that this "natural" player lets each actual player know his type, but does not let (all or part of) the players know the types of the other players. The third is to carry out the original dynamic game based on the above, that is, each player chooses the action plan a1, …, an from their own behavior space according to their order.

3. SUPPLY CHAIN SUBJECT ANALYSIS

The supply chain network is an ecosystem with multiple participants, multiple objective functions, and complex internal levels. Influenced by internal and external risks in the supply chain, supply chain activities may deviate from normal expectations or plans, resulting in negative impacts on upstream and downstream enterprises in the supply chain and increasing the vulnerability of the supply chain network [12]. Supply chain disruptions caused by unexpected events or contingent factors are a direct manifestation of the vulnerability of supply chain networks. The impact of the COVID-19 on the global supply chain is manifested in three interlinked levels: first, the delay in order delivery due to the upstream shutdown and reduction in logistics carrying capacity and logistics efficiency; second, the reduction in production scale and production efficiency due to upstream supply disruption or downstream demand contraction; third, the adjustment of supply chain structure and relationship by enterprises for strategic consideration of supply chain security. This includes adding or replacing suppliers and buyers, adjusting the global investment layout, etc. The impact of the epidemic on the global supply chain is mainly manifested in the short term by the delay in order delivery and the decrease in production scale, while in the long term it is mainly manifested in the deep-seated changes in the supply chain structure and relationship.

Based on the literature analysis, this paper combines the actual situation and analysis to give the framework structure diagram (Figure 1) of the supply chain affected by the epidemic.

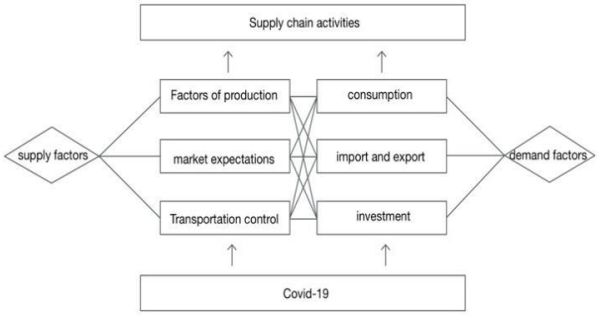

Figure 1 Supply chain affected by the pandemic.

According to the above theoretical framework, this paper analyzes the impact of the epidemic on the global manufacturing supply chain from the supply perspective, demand perspective, and industry dimensions.

3.1. Supply Shocks

First, from the perspective of products, the production of raw materials decreases during the epidemic, for example, rubber trees are left unattended and unharvested resulting in lower production of natural rubber or lower quality of products, medical necessities such as surgeon's gloves, blood transfusion tubes, and industrial production of conveyor belts and tires are not available on demand due to the lack of raw materials resulting in a delay in the production of semi-finished and finished products, which indirectly affects the recovery from the epidemic. Secondly, from the perspective of personnel, the increase in strikes, the increase in departures, the inability of manufacturing workers and various technical and managerial personnel to return to work normally, and the decrease in the number of personnel on duty lead to labor shortage,

which makes it difficult for normal technical exchanges and business activities to be carried out in an orderly manner under the non-contact prevention and control requirements, thus leading to a decrease in production and operational efficiency. For example, the UK's petrol crisis has made it impossible for existing truck drivers to meet the daily fuel needs of the nation. At the same time, employees are faced with a blurring of the boundaries between work and life, which often brings more stress and workers are exhausted, and companies cannot recruit and labor cannot find jobs. Third, from the perspective of transportation, transportation and logistics control directly affects the efficiency of the flow of raw materials, intermediate products, and finished goods, and the increase in orders, but the backlog of inventory, poor delivery, enterprise inventory management faces serious challenges, for example, during the epidemic, the number of shipping vessels decreased, transportation skyrocketed, the cost of transporting goods from Asia to the United States has increased by as much as ten times, coupled with the lack of sufficient stevedores resulting in a large number of The cost of shipping goods from Asia to the U.S. has risen tenfold.

3.2. Demand Shocks

Some countries have reduced exports during the epidemic due to production, manufacturing, and transportation, but to maintain the normal operation of domestic people's lives and protect the basic consumption of residents need to rely on a large number of imported products, which leads to a large number of empty containers piling up at the docks, making the uneven distribution of containers more and more prominent, thus exacerbating the demand gap. In addition, due to the epidemic, most people are unable to travel on vacation, and the government grants increase the purchasing power and willingness of consumers, driving people to buy more household products, such as treadmills, recreational game supplies, kitchen supplies, etc. Some enterprises do not have enough containers for export or the decrease in the number of sea shipments during the epidemic has led to a large number of products waiting to be transported piling up at the docks. The longer time to leave the port, the increase in container storage costs, and the doubling of sea freight prices during the epidemic have brought higher export costs to enterprises, and in order not to lose customers, some enterprises will choose the more expensive air freight or simply give up the export business to reduce export losses, which leads to The global import and export crisis has formed a vicious circle and intensified.

3.3. Analysis of The Impact of The Epidemic on Different Manufacturing Industries

The impact of the epidemic on the manufacturing industry includes, but is not limited to, order diversion or shrinkage, order fulfillment difficulties, trade protection, etc. From the perspective of industry chain length and supply chain complexity, the longer the industry chain and the more complex the supply chain, the greater the impact of the epidemic and the longer the cycle time to resume normal production activities, such as the automotive industry parts supply and vehicle manufacturing with the international division of labor, requiring the global industry chain to collaborate to resume work and production. However, the global manufacturing supply is too concentrated in a few countries, plus the manufacturing supply chain requires high synergy between upstream and downstream enterprises, and because of the differences in the situation of epidemic prevention and control in different places, it is difficult to coordinate the progress of resuming production and matching production capacity of upstream and downstream enterprises in the supply chain. Delayed resumption of work by individual enterprises may trigger a "domino" effect and reduce the competitive advantage of the industry chain, which is highlighted in the process of resumption of work and production by leading enterprises and core supporting enterprises.

During the COVID-19, online education, online office, online shopping, telemedicine, and other online consumer business is growing rapidly, to provide support for its software services industry has not been significantly negatively affected, while also showing an upward trend. Some digital technologies and products with high technology content, rich application scenarios, and strong industrial penetration are growing against the trend, such as 5G, big data applications, and intelligent robots. At the same time, during the recovery period of the epidemic, both Chinese and U.S. manufacturing industries have boosted their inventories, especially of raw materials, which may be influenced by the price increase of raw materials and the expectation of rising demand in the future, on the one hand, and on the other hand, to reduce uncertainty in the supply chain, such as chips, most companies have the will to increase stockpiles.

From the above analysis of the supply chain under the epidemic, the following queries can be summarized and raised. (1) Do fluctuations in product quality affect consumer purchasing behavior under an epidemic? (2) In the case of non-transparent information in the supply chain, are there any differences in the actions of the core companies, and if so, do they have different impacts on the end-users? (3) How to maximize the use of products whose nature has changed due to the epidemic without affecting the corporate image?

4. GAME MODEL ANALYSIS

4.1. Assumption of Game Model

There is a Nature N who takes action before the suppliers (player A). N can go up or down in the game tree and decide the quality of products that the suppliers are going to sell to the retailers. In addition, there is a possibility p for N to choose high-quality goods (regarded as H) and a possibility of 1-p for N to choose low-quality goods (regarded as L). The payoff of these two types of products bring is K_H and K_L respectively.

Assumption1. Linking to the setup of nature N, suppliers are assumed that could always know the type of products but retailers cannot receive the complete information, which means player B could only predict the quality of goods through player A's decisions. Player A could choose between collaborating (regarded as S) and not collaborating (regarded as F).

Assumption 2. The retailers are always willing to collaborate with the supplier (player A) and keep their relationship of being business partners. This means, if A chooses to work with them, B would not say no (the game continues).

Assumption 3. High-quality products bring B higher payoff and low-quality products bring lower payoff, which would be certain in real situations. Taking the change of selling models during the pandemic into our consideration, two actions are set for player B to take. "The Covid-19 pandemic has dramatically changed consumer purchase behavior, and the "stay-at-home order" policy has altered the operations of brick-and-mortar (B&M) retail stores. These changes have induced local B&M retailers to start online retailing with home delivery as an added option " [13]. Like the quote mentioned above, plenty of retailers prefer to have trades online or deliver them. B chooses either traditionally sell products (regarded as W), or sell innovatively (regard as Y). Recently, browsing and purchasing goods on some social media have become a common phenomenon. In our game, player B could decide to promote and sell on some shopping websites (such as Amazon or eBay) which would bring payoff of K if the quality of products is excellent, or bring payoff of αK ($0 \leq \alpha \leq 1$) due to some risks if the quality of products does not meet the standard. This is Because their customers maybe not satisfied with the commodities and the after-sale problem requires time and cost to solve.

Assumption 4. Suppliers always pay the collaboration cost (regarded as C) and the extra cost (regarded as r) if they provide L since their reputation is destroyed. The profit of selling H is K_H-C. By selling L type, suppliers could get the payoff of K_L-C-r (all through innovative way Y to sell). Profit for selling L is -C-r (with the possibility 1-p, traditional way -W) then B can avoid the welfare loss of K.

4.2. Illustration

Based on the risks brought by the epidemic to the global supply chain, this paper analyzes and discusses the game based on the core members of the supply chain, suppliers and retailers, and analyzes the possible actions taken by the core members of the supply chain under the epidemic and the possible outcomes, to provide a reference for cooperation for practitioners in related fields. As mentioned above, the game tree was proposed in Figure 2.

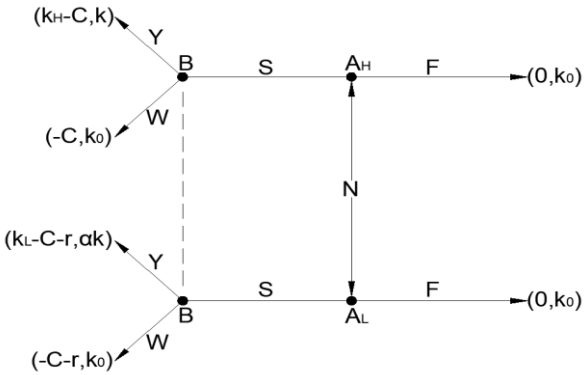

Figure 2 Game tree of supplier and retailer.

4.3. Process and Equilibrium Discussion

Perfect Bayesian Equilibrium of the game was applied in this study. Based on the above assumptions, a game tree could be designed which is shown in Figure 2. In the first stage of the game, natural N acts first and chooses the types of high-quality products (H) and low-quality products (L), which are the private information of suppliers and unknown to retailers.

In the second stage of the game, whether suppliers choose to cooperate with retailers at different levels depends on the expected benefits brought to the former by the cooperation. For a high-quality product, the expected revenue of Y is:

$$E(t \mid H) = P(K_H - C) - (1-P)\,C = PK_H - C \qquad (1)$$

The revenue from sales is significantly much greater than the cost of sales. In this case, E (t | H) >0, which means the supplier wants high-quality product A to choose Y. Therefore, the probability P (t | H) that a high-quality product chooses Y is 1.

For a low-quality product, the expected revenue of Y is:

$$E(t \mid L) = P(K_L - C - r) + (1-P)(-C-r) = PK_L - C - r \qquad (2)$$

In general, K_L is much larger than C+r, that is the cost of reputation loss is less than the revenue after innovative sales. Therefore, E (t | L) >0, and low-quality

products also hope to be sold through the Y channel, the probability is P (t | L) =1.

In the third stage of the game, B gets the probability distribution of A's H and L products in the market based on relevant experience and big data, B needs to know the probability of H and L to make decisions. According to Bayes' Theorem, the probability of H in the cooperation could be calculated and typed as:

$$\text{Prob}(H \mid t) = P(H) \times \frac{P(t|H)}{P(t)} = \frac{P(H)\times P(t|H)}{P(H)\times P(t|H)+P(L)\times P(t|L)} \quad (3)$$

Where P (t | H) = P (t| L) = 1, $P(H) + P(L) = 1$, and P (H | t) = P(H). Similarly, P (L | t) = P(L).

Also, B cannot know exactly the type of A, and its choice of Y mainly depends on expected income. B's expected income could also be calculated as follows:

$$E(B \mid t) = P(H)K + P(L) \times \alpha K$$

$$= P(H)K + [1 - P(H)] \times \alpha K$$

$$= P(H) \times (1-\alpha)K + \alpha K \quad (4)$$

Only when the expected return of B is not less than the return K_f without risk, B will choose Y, that is:

$$P(H) \times (1-\alpha)K + \alpha K \geq K_f \quad (5)$$

$$P(H) \geq \frac{Kf - \alpha K}{(1-\alpha)K} = Q \quad (6)$$

When P (H) is greater than or equal to Q, pooling equilibrium occurs in the game, all A will cooperate, and B will select Y with probability Q. At this time, although B's expected income meets the profit requirement, it may still choose L and suffer losses, has failing to meet the principle of utility maximization.

When the world suffers from the pandemic, the number of goods on the market drop, supply falls short of demand, the quality of goods in the market fluctuates widely, high-quality products in demand and scarce, and the distribution probability P (H) is reduced so that the P (H) is greater than or equal to Q, B will not choose a high-quality product for the sake of risk in a multi-channel mode for sale, thus the utility of B can't be maximized.

The above analysis can reflect the risks in the game process between retailers and suppliers: in the case of information asymmetry, retailers still can cooperate with low quality or sell at the same time, and consumers who are not satisfied with low-quality products will affect the sales behavior of high-quality products in the market. Retailers cannot determine the probability distribution of high and low-level products, and with their expected revenue as the goal, they may still choose low-quality products in the case of shortage of epidemic goods. Retailers who choose low-quality products will bear huge public opinion risk and economic risk, which will hurt the long-term development of enterprises. Companies developing new sales models for channel innovation will bring more customer base based on also bring more topics and challenges.

5. CONCLUSION

In the era of economic globalization and high division of labor in the industrial chain, suffering from the impact of the COVID-19 is a management revolution for any node in the global supply chain. Good cooperation among enterprises can bring about brand value improvement, revenue increase, and market share enhancement, but at the same time, it also puts forward higher requirements for enterprises' infrastructure, technical support, and operational innovation. In the face of trade protection and global supply chain restructuring under the epidemic, attention should be paid to the following aspects. Laying out multi-source procurement and developing multi-point production networks, attaching importance to the construction of stable global supply chain networks, expanding the scope of international production capacity cooperation, forming supply chain security statements with major trading partners, establishing long-term cooperation mechanisms with various important customs and maritime organizations or alliance members, formulating industry-recognized standards, regulations, and policies, stabilizing the structure of global supply chains, improving the bearing capacity of global supply chains, and jointly building cross-regional and resilient global supply chains. In addition, transparency of supply chain information and timely synchronization of upstream and downstream orders during the epidemic are important measures to reduce losses for all parties in the supply chain. Old infrastructure needs to be upgraded to avoid system paralysis due to increased demand and to improve operational efficiency. Also, it needs to enhance the flexibility of workers' work, cultivate multi-dimensional talents, provide multi-faceted office conditions, and effectively protect workers' legal rights and social welfare. Finally, it should adopt a multi-channel sales model, provide online ordering, contactless in-store pickup or commissioner delivery, etc., adjust selling prices and methods promptly according to commodity conditions, establish partnerships with mobile, and use media, apps, and bloggers to increase audience groups to maximize product value.

This paper believes that digital interaction factory or enterprise is the future big development trend, during the epidemic with face-to-face communication opportunities to reduce, through the webcast video and other forms of a factory to monitor the process, check the key parameters, product quality, etc., to improve the production efficiency caused by the inability to reach the scene, delivery delays, and other problems. Leading enterprises must strengthen their own digital, intelligent and automated system construction, accelerate the

establishment of a standardized digital office and training management system, and accelerate the digital transformation of the industry, which is an indispensable element for the future survival and development of manufacturing and related supply chains. The analysis and the conclusions obtained in this paper also lay the theoretical foundation for supply chain management and risk management in different industries.

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