

Analysis of Collaborative Relationship among Regional Medical Service Collaboration Based on Game Theory

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Abstract. Regional medical service collaboration is an effective way to solve the problem of uneven distribution of medical resources in China. This paper analyzes the cooperative relationship between the main bodies of the regional medical service from the point of view of game theory and uses the "prisoner's dilemma" model in game theory to analyze the cooperative game relationship between medical institutions in the region. Then it obtains the Nash equilibrium condition, and puts forward the strategy to maximize the efficiency of medical institutions according to the game results.

Key words. medical service collaboration, "prisoner's dilemma" model, cooperative relation

1 Introduction

Optimizing the allocation of medical and health resources has been the focus and difficulty of the medical and health industry in China. In recent years, the emergence of Regional Medical Association (hereinafter referred to as the Medical Union will help to promote the quality of medical resources and improve the efficiency of resource utilization in the region^[1]. And in the hospital, all levels of the hospital are supposed to cooperate with each other in order to truly play the role of the Medical Association. With the promotion of health care reform, many places actively explore the new model to improve the health care. The general office of the State Council also promulgated "the guiding opinions of the general office of the State Council on promoting the construction of the grading system of diagnosis and treatment" in 2005 to encourage the establishment of a grading system of diagnosis and treatment, and Hierarchical diagnosis and treatment is exactly the specific practice of regional medical collaborative services.

Service collaboration is a service model of multi agent cooperative interaction in modern service industry. As a special social service, medical service is the most important one to solve the relationship among different subjects, that is, the relationship between medical institutions in the region.

Constructing the collaborative service system of Medical Association under the background of new medical reform is of great significance for the establishment of an orderly and effective new medical and health service system [2]. The existing literature analysis the regional medical service collaboration model, the existing problems and platform construction extensively. Du Xin and et al. [3] divided the regional medical collaboration into 3 kinds of cooperative service mode, that is, longitudinal medical collaborative service model among multi-level medical institutions, remote medical collaboration model among different medical institutions and horizontal medical collaboration model among large medical institutions. He believes that regional medical collaboration is an effective way to solve the exchange and sharing of medical resources among medical institutions and believes it is significant to optimize the allocation of medical

resources, reduce the cost, and promote the new mode of regional medical collaborative service. Wang Shu [4] established the model of regional cooperative medical system according to the principle of CO students and identified the key order parameters. Through the analysis of the force on the regional cooperative healthcare system, he analyzed the coordination mechanism of regional medical institutions, and gives suggestions and measures to strengthen the allocation of resources to the top-level design and system planning, the establishment of regional coordination mechanism, a series of adjustment and integration of medical resources. Jiang Xianfei and et al. [5] based on the practice of regional collaborative medical service in West China Hospital of Sichuan University. He pointed out that in the western region of regional medical cooperation in promoting the lack of power, regional coordination of medical policy lag, lack of standardized medical information system platform construction standards and other issues, and put forward the corresponding improvement measures. Yu Bo [6] from the Pudong New Area Shanghai regional medical center combined the area of 11 community health service centers. He practically analyzed on the medical and health collaboration network of business closely and believed that it could solve the problem of regional medical collaboration when the hospitals achieve the same level of health care, information technology support and a reasonable cost management. Zhou Leming and et al. [7] pointed out that the factors that affect regional collaboration services are not only technical reasons but also management reasons. Sun Zhonghai[8] believed that information synergy is the most important in regional medical service collaboration, and the most important is to establish the standard of interoperability[9].

The American health care system is based on market economy and managed care or management and its regional medical service collaboration efficiency is very high. As the most important cost control mechanism, payment system and managed care led to the medical service market competition is more intense. American medical institutions began to develop collectivize and large-scale. A way of horizontal integration is that many of the poor management of the hospital were purchased, mergers, the direction of the development of the group across the region. The other way is vertical integration, that is, different levels of medical institutions to form a large-scale urban hospital as the core, community hospitals, rehabilitation hospitals, registered home care institutions as one of the hospital group. American hospital group achieve large-scale medical equipment, information, management and service sharing, management functions such as personnel, logistics, and all the implementation of social, substantial increase in service efficiency [10].

The construction of regional medical collaboration system has important theoretical and practical significance to reduce the cost of health care, improve the efficiency of medical treatment and optimize the allocation of medical resources. However, a great deal of literature has focused on the analysis of regional medical coordination model, problems, platform construction and other macro level, and they lack of relevant theoretical research how to obtain the maximum benefit and how to analyze the main body of the system from the perspective of game theory. This paper based on this starting point, through analysis of the game relationship between the main regional service cooperative medical systems, and draw conclusion on how to make full use of the game system between the main interests of regional medical institutions.

2 Analysis of the competition and cooperation among medical institutions

According to the synergy theory, if the regional medical institutions form collaborative services, the whole region will be the quality of medical services to improve the quality of production. It cannot be achieved for a single medical institution and it plays an important role in improving the social cooperative medical service system. The goal of collaborative service implementation has not only exceeded the level of the participating parties, but also a higher social level [11].

Hospitals will compete with each other in China. In the process of cooperation of regional medical institutions, the relationship between medical institutions is a kind of cooperative competition, not a purely competitive competition any more. It is mainly manifested in the following aspects. First of all, for the superior medical institutions, too many patients mean to occupy more medical resources. There are not so many superior hospitals and their accommodation for patients is limited, while the superior hospitals' high quality medical resources should be given to severe patients. It will lead to a decline in the quality of hospital service if mild patients crowded high-quality medical resources. For the primary medical institutions, there are many primary hospitals and they have high accommodation. It can improve the benefit of the

hospital with patients increasing and it can improve the level of primary medical services. Therefore, superior hospital in the region can be guided by the government to allow mild patients to diagnose in the primary hospital or to use telemedicine to make high-quality medical resources benefit the primary hospitals. Their sharing resources and complementary advantages like these can overcome the problems that difficult and expensive to see a doctor in China for a long time. It also makes the original competition in the medical institutions to achieve a win-win situation. Therefore, it embodies a kind of cooperative competition in the process of service collaboration of medical institutions in the region.

3 Analysis of the cooperative relationship based on game theory

3.1 The basic nature of the game model among medical institutions

There are a lot of medical institutions in the medical association, and medical service collaboration can occur between two or more medical institutions. In order to facilitate the model, this paper simplifies the relationship between medical institutions and medical institutions to a superior hospital and a primary hospital. The whole collaborative service is a dynamic process, and it is also a process of continuous selection. In the whole process, there exist two kinds of state——cooperation and betrayal.

According to the basic theory of game theory, there are characteristics in the process of cooperative game between the superior hospital and the basic level hospital as follows:

(1) Hospital has the right to choose independently, without government intervention. That is hospitals can trust each other, to take cooperative action; but also can take the betrayal.

(2) Every hospital is rational. The starting point of the hospital selection is to obtain the maximum benefit with the minimum investment. In the process of the game, when the expected benefits of cooperation are greater than the betrayal of the hospital, the hospital will choose to cooperate, and vice versa, will choose to betray.

(3) Repeated game. From the first cooperative game to the termination, the whole process of the game is a dynamic process, which is the result of many times.

3.2 Game model construction

This paper uses the classic prisoner's dilemma model in game theory to analyze. The prisoner's dilemma model was proposed by Tucker Albert. It mainly describes the contradiction between individual rationality and collective rationality, namely, the behavior of individual interests as the starting point of a lot of times and cannot realize the maximum benefit of the group. And it also explains the inherent contradictions of individual rationality, namely, the behavior of individual interests as the starting point is not necessarily guaranteed to achieve the maximum benefit of the individual [12].

In order to build the model expediently, this paper makes the assumptions as follows:

Hypothesis 1, Participant input. On the assumption that the input of each cooperative need in the game process is expressed by I (Including manpower, material resources, financial resources, information, technology and other resources in the input, in the form of a unified currency translation). Let I_H represent the investment of the superior hospital and let I_L represent the investment of the basic level hospital.

Hypothesis 2, Cooperation benefit. It assumes that if the superior hospital and the primary hospital trust each other and cooperate with each other, the output benefit is related to the investment of each other. And it is a kind of linear output, that is to say, the size of the cooperative benefit is positively correlated with the cooperative effect coefficient k ($k > 1$).

Hypothesis 3, Betrayal punishment. It assumes that the superior hospital and the basic level hospital, one side to take the trust behavior, one side to take the betrayal. As a result, who takes the trust of one party's income is 0, and who betrayals can get the trust of the investment, but it will get the corresponding punishment b (Including the credibility of the hospital and other non-quantitative indicators in the form of currency conversion).

Hypothesis 4, Trust incentive. The cooperation between the superior hospital and the basic level hospital makes the investment cost of the cooperation be affected by the negative feedback. Let $1-\mu(0<\mu<1)$ represent it. The more times of the number of collaboration and cooperation are, the lower of the cost of the corresponding cooperation is.

Hypothesis 5, Collaborative process. The whole process is dynamic. It assumes that before the superior hospital and the primary hospital collaborate for n times, the hospitals have been mutual trust and cooperated all the time. As the result, the hospitals will continue to maintain the choice of collaborative. Once a hospital chooses betrayal for the n stage, then the superior hospital and the basic level of hospital cooperation will no longer be carried out [13].

Let p represent the probability of superior hospital to take cooperative action, and its probability of choosing betrayal is $1-p$. Let q represent the probability of cooperation behavior of the primary hospital, and its probability of choosing betrayal is $1-q$. According to the above assumptions, this paper constructs the payment matrix on the time node of the cooperation between the superior and the basic level hospitals in the n times. Table 1 is the collaborative service payment matrix of superior hospital and primary hospital.

Strategic combination 1. According to the assumptions, when the superior hospital and the primary hospitals are selected to cooperate, the payment matrix of superior hospital is the benefits of superior hospital excepting its investment cost.

$$U_{1H} = I_H k p q - I_H (1 - \mu)^{n-1} p q = I_H p q [k - (1 - \mu)^{n-1}] \tag{1}$$

$$U_{1L} = I_L p q [k - (1 - \mu)^{n-1}] \tag{2}$$

Table 1. collaborative service payment matrix of superior hospital and primary hospital

The probability of superior hospital	The probability of primary hospital	
	cooperation (q)	betrayal ($1-q$)
cooperation (p)	U_{1H}, U_{1L}	U_{2H}, U_{2L}
betrayal ($1-p$)	U_{3H}, U_{3L}	U_{4H}, U_{4L}

Strategic combination 2. When the superior hospital selects cooperation, and the primary hospital select betrayal, the superior hospital will not have the benefits, but it will pay the cost; the primary hospital will get the cost of superior hospital, but it will be punished out of betrayal.

$$U_{2H} = -I_H p (1 - q) (1 - \mu)^{n-1} \tag{3}$$

$$U_{2L} = I_H p (1 - q) (1 - \mu)^{n-1} - b \tag{4}$$

Strategic combination 3. When the superior hospital selects betrayal, and primary hospital select cooperation, its situation is the same as strategic combination 2.

$$U_{3H} = I_L (1 - p) q (1 - \mu)^{n-1} - b \tag{5}$$

$$U_{3L} = -I_L (1 - p) q (1 - \mu)^{n-1} \tag{6}$$

Strategic combination 4. When the superior hospital and the primary hospital are both select to betray, the superior hospital and the primary hospital will not have benefits, and they will be punished out of betrayal.

$$U_{4H} = -b \tag{7}$$

$$U_{4L} = -b \tag{8}$$

3.3 Analyzing game process

This paper uses the prisoner's dilemma game model. In order to make the model be able to get the solution, and make the superior hospital and the primary hospital get a win-win strategy s^* , that is the superior hospital and primary hospital both selecting cooperation, the model must be made to achieve the Nash equilibrium condition. According to the Nash equilibrium theory, for all the participants, when the other participants choose the strategic combination of s^* given in the given strategy, the choice of s^* in the corresponding strategy to obtain the payment will be not less than the choice of other strategies [14]. That is the following conditions:

From the point of view of the superior hospital, when the primary hospital selects to cooperate, the payment of superior hospital to select cooperation should not less than the payment of selecting betrayal. And when the primary hospital selects betrayal, the payment of superior hospital to select cooperation should not less than the payment of selecting betrayal as well.

$$\begin{cases} U_{1H} \geq U_{3H} & p = 1, q = 1 \\ U_{2H} \geq U_{4H} & p = 0, q = 1 \end{cases} \quad (9)$$

Put the payment result into it.

$$\Rightarrow \begin{cases} I_H p q [k - (1 - \mu)^{n-1}] \geq I_L (1 - p) q (1 - \mu)^{n-1} - b & p = 1, q = 1 \\ - I_H p (1 - q) (1 - \mu)^{n-1} \geq -b & p = 0, q = 1 \end{cases} \Rightarrow \begin{cases} I_H [k - (1 - \mu)^{n-1}] \geq I_L (1 - \mu)^{n-1} - b \\ - I_H (1 - \mu)^{n-1} \geq -b \end{cases} \quad (10)$$

$$\Rightarrow \begin{cases} I_H k \geq (I_H + I_L)(1 - \mu)^{n-1} - b \\ I_H (1 - \mu)^{n-1} \leq b \end{cases} \quad (10)$$

From the point of view of the primary hospital, similarly, when the superior hospital selects to cooperate, the payment of primary hospital to select cooperation should not less than the payment of selecting betrayal. And when the superior hospital selects betrayal, the payment of primary hospital to select cooperation should not less than the payment of selecting betrayal as well.

$$\begin{cases} U_{1L} \geq U_{2L} & p = 1, q = 1 \\ U_{3L} \geq U_{4L} & p = 1, q = 0 \end{cases} \quad (11)$$

$$\Rightarrow \begin{cases} I_L p q [k - (1 - \mu)^{n-1}] \geq I_H p (1 - q) (1 - \mu)^{n-1} - b & p = 1, q = 1 \\ - I_L (1 - p) q (1 - \mu)^{n-1} \geq -b & p = 1, q = 0 \end{cases} \Rightarrow \begin{cases} I_L k \geq (I_H + I_L)(1 - \mu)^{n-1} - b \\ I_L (1 - \mu)^{n-1} \leq b \end{cases} \quad (12)$$

It can achieve the conditions of Nash equilibrium of superior hospitals and primary hospitals to combine formula (10) and formula (12):

$$\Rightarrow \begin{cases} I_L k, I_H k \geq (I_H + I_L)(1 - \mu)^{n-1} - b \\ I_L (1 - \mu)^{n-1}, I_H (1 - \mu)^{n-1} \leq b \end{cases} \quad (13)$$

$(k > 1, 0 < \mu < 1, n = 1, 2, 3 \dots)$

It assumes that the investment of superior hospital is more than primary hospital. Let $I_H = I_L + \alpha, \alpha > 0$ represent the investment of superior hospital.

$$\begin{cases} b \geq (2I_L + \alpha) (1 - \mu)^{n-1} - I_L k \\ b \geq (I_L + \alpha) (1 - \mu)^{n-1} \end{cases} \quad (14)$$

Let

$$\begin{cases} B_1(n) = (2I_L + \alpha) (1 - \mu)^{n-1} - I_L k \\ B_2(n) = (I_L + \alpha) (1 - \mu)^{n-1} \end{cases} \quad (15)$$

$$\begin{aligned}
 B(n) &= B_2(n) - B_1(n) \\
 &= I_L k - I_L(1 - \mu)^{n-1} \\
 &= [k - (1 - \mu)^{n-1}]I_L > 0
 \end{aligned}
 \tag{16}$$

$$\Rightarrow b \geq I_H(1 - \mu)^{n-1}
 \tag{17}$$

From the above, the condition of Nash equilibrium of superior hospital and primary hospital to collaboration is formula 17. That is to say, there must be enough punishment to constrain their selection in the initial cooperation. Even in the first time to cooperate, the punishment of betrayal should be more than the investment of superior hospital. When cooperation is carried out step by step, the punishment will be quickly reduced. Even when the number of cooperation is enough for a long time, it will also make the game to be Nash equilibrium without punishment of betrayal.

3.4 Analyzing the result of game

When the game can reach the Nash equilibrium, and superior hospital and primary hospital take the choice of cooperation all the time before the cooperation for the n times, the total benefit for the n times is:

$$\begin{aligned}
 W(n) &= U_{IH} + U_{IL} \\
 &= I_H p q [k - (1 - \mu)^{n-1}] + I_L p q [k - (1 - \mu)^{n-1}] \\
 &\qquad\qquad\qquad p = 1, q = 1 \\
 &= (I_H + I_L) [k - (1 - \mu)^{n-1}]
 \end{aligned}
 \tag{18}$$

the total benefit is:

$$\begin{aligned}
 W &= \sum_{n=1}^n W(n) \\
 &= (I_H + I_L) \left[nk - \frac{1 - \mu - (1 - \mu)^n}{\mu} \right]
 \end{aligned}
 \tag{19}$$

It can obtain the following results according to the formula 18 and 19:

(1) When k and μ are invariant, if let the superior hospital and the primary hospital to achieve more income, it will need to increase the I_H and I_L , and they should keep cooperating. It can be seen from the formula 18, with the increase of n , that is, the increase in the number of cooperation, the single cooperation benefit will increase. That means it will enhance the trust of both parties with each cooperative selection. And it will reduce the possibility of betrayal in the next collaborative selection. This is conducive to format a long-term stable cooperative form of cooperation.

(2) When I_H , I_L and μ are invariant, if they want to get more benefit, it needs to increase the value of k . That is to increase the cooperation effects.

(3) When I_H , I_L and k are invariant, if they want to get more benefit, it needs to increase the value of μ , and let the value of μ close to 1. That is to reduce more the cost of each collaborative selection than ever.

3.5 Analyzing the conclusion of game

According to Nash equilibrium theory, if s^* is not Nash equilibrium, then there is at least one participant will deviate from the strategy that the agreement s^* provided. And it makes the agreement s^* cannot be implemented. Therefore, if the agreement can be implemented automatically, it is necessary to make the agreement be Nash equilibrium [14]. Therefore, first of all, it should make the hospital consciously reach the intention of cooperation, and it should have enough betrayal punishment to constrain. If it can conform a long-term stable cooperation and win-win situation between hospitals or not, it to a large extent depends on the position and attitude to cooperation between the two sides of hospitals [15]. This punishment can be signed by the hospital agreement between the two parties to bear the additional loss of betrayal. After the game can reach the Nash equilibrium, it will be beneficial to both sides and achieve the goal of win-win.

According to the analysis of 3.4, this paper believes it should be taken to improve the synergy between medical institutions as the following aspects:

(1) The hospital itself needs to increase the investment of collaborative cooperation. Initially, it can be guided by the government. When the hospitals get the benefits of cooperation and identify the cooperation model, they will increase the cooperative investment consciously.

(2) Improving the effect coefficient of collaborative service cooperation among hospitals. The greater the effect of hospital collaboration is, the more willing to continue to cooperate with the hospitals. And hospitals are increasingly willing to continue cooperation. It can improve the effect of hospital collaboration through optimizing cooperation mode, strengthening hospital contact, upgrading hospital hardware facilities and so on.

(3) Increase the range of cost reduction to multi-collaborative. When the hospital formed a stable form of cooperation, the investment cost of each cooperative selection will be reduced exponentially. For example, it can achieve the superior hospital and primary hospital cooperative cooperation through the way of remote consultation. In the initial collaboration, they need to pay a lot of hardware costs, labor costs, learning costs, etc. When cooperation is getting more and more mature, the cost of cooperation will be reduced quickly. In order to improve the scope of the cost reduction, the cooperation mode can be realized through regulating the cooperation mode and strengthening the information exchange.

4 Conclusion

This paper analyzes the synergy relationship between medical service collaboration based on the theory of game theory and research methods. And put forward some corresponding suggestions according to the model. It aims to stimulate the enthusiasm of each hospital in the system, and to maximize the benefits of cooperation among the subjects in the system. And then it promotes the Medical Union to realize the service collaboration through the classified diagnosis and treatment; realizes the reasonable allocation of medical resources effectively; makes all-level hospitals function reasonably, distinctly, practically and efficiently.

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