IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received February 18, 2020, accepted February 26, 2020, date of publication March 2, 2020, date of current version March 12, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2977385

Cooperation or Conflict in Doctor-Patient Relationship? An Analysis From the Perspective of Evolutionary Game

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This work was supported in part by the National Social Science Fund Major Project under Grant 18ZDA088, in part by the National Natural Science Foundation Project under Grant 61074134 and Grant 71871144, and in part by the Shanghai University of Finance and Economics 2019 Graduate Innovation Fund under Grant CXJJ-2019-400.

ABSTRACT The uncoordinated and conflicting relationships between doctors and patients are becoming a real dilemma faced by the medical industry and the whole society, which severely affects people's sense of well-being and health. Based on the multiple dimensions of trust, information asymmetry, and moral hazard, we use evolutionary game theory and replicating dynamic equations to construct the evolutionary game model, in the model, doctors and patients could select cooperation strategy or conflict strategy. Through an in-depth study on the model and the model's simulation, we find that the doctor-patient relationship will eventually form a zero-sum game or a win-win situation. As for which situation is stable, it is closely related to the initial parameters of the evolutionary game model and the payment matrix of the evolutionary game. Increasing the trust degree, reducing the degree of information asymmetry and moral hazard would help doctors and patients shift their strategic choices from conflict to cooperation. We also find that increasing the trust degree, reducing the degree of information asymmetry, and reducing the degree of the patients' moral hazard could promote the cooperation level effectively. The study aims to ease the contradiction between doctors and patients, solve the current doctor-patient dilemma, and provide a particular reference for building a new doctor-patient cooperation relationship.

INDEX TERMS Doctor-patient relationship, evolutionary game, information asymmetry, trust, moral hazard.

I. INTRODUCTION

In recent years, the country has frequently rectified the "medical troubles," but the phenomenon of violent medical treatment is still challenging to resolve. In 2018, the White Paper on the Practice of Chinese Physicians published by the Chinese Medical Doctor Association showed that 66% of physicians had experienced violent injuries [1]. At present, the violent attack on the relationship between doctors and patients in China has attracted the attention of scholars and has become a hot topic in academic circles [2]–[8]. The uncoordinated and conflicting relationship between doctors and patients is becoming a real dilemma faced by the medical industry and the whole society. The contradictions between doctors and patients have become increasingly prominent therefore affecting the doctor-patient relationships. As a result, people's sense of well-being and health has severely been affected. It also has hindered China from advancing the process of building a harmonious socialist society. In light of this new situation, it is of great theoretical and practical significance to explore the evolution of the relationship between doctors and patients, to construct a new model of cooperation between doctors and patients, to try and solve the problem at hand which is the poor doctor-patient relationship and promote the building of a harmonious society in China.

Considering the doctor-patient relationship from a macro perspective, due to the high complexity and specialization of medical knowledge, there is information asymmetry between patients and doctors. Generally, patients are at a disadvantage of information, and it is difficult to form an equivalence

The associate editor coordinating the review of this manuscript and approving it for publication was Xiangtao Li.

with doctors in the information. Therefore, the doctor-patient relationship often presents a static feature of the doctor's strength and patient's weakness at the macro level. However, at the micro-level, it is indeed the result of the long-term interactive evolution of doctor-patient behavior. Therefore, an in-depth study of doctor-patient behavior is inseparable from the dynamic depiction of the behavior of doctors and patients. At present, the existing researches have used qualitative analysis and case studies to research the doctor-patient relationship. For example, Wu [9] studied the relationship between doctors and patients from the perspective of discourse communication mode. The study pointed out that the continually intensifying contradictions between doctors and patients, not only needed the doctors to improve the attitude of discourse, and the patient to maintain discourse rationality, but also the doctor and patient to compete from the discourse. Polonsky *et al.* [10] and Edelman *et al.* [11] analysed a large number of patients and relevant factors in doctor-patient communication. The studies found that cooperation had a positive impact on the quality of communication and can promote harmonious relationships between doctors and patients; they also found that frustration hurt the quality of communication. Through a large number of questionnaires, Aelbrecht *et al.* [12] found that the patients' educational background and expression ability had a positive impact on doctor-patient communication. They could promote the relationship between doctors and patients. Osch *et al.* [13] used random natural experimental methods to communicate with doctors and patients. He explored the sensory-oriented communication mechanism and found that empathy and positive attitude had apparent effects on improving the relationship between doctors and patients. The above scholars use qualitative and case study methods to study the relationship between doctors and patients. They can obtain some information and the characteristics of the doctor-patient relationship. However, from the above studies, it is difficult to find the interaction and evolution features of the behaviors of doctors and patients from a dynamic perspective.

As everyone knows, the cooperation behavior between doctors and patients is a kind of human behavior. Now, the evolutionary game is gradually being adopted by the academic community to explain the dynamic evolution of human behaviors. As a dynamic selection method of studying group strategy, evolutionary game theory believes that both sides of the game can learn and evolve. It can guide the next strategy choice by imitating the last strategy choice based on past experience. Therefore, through the long-term imitation and improvement, all players will choose a strategy that is conducive to self-development. Since the evolution theory has been put forward by Charles Darwin, people find that the competition between individuals can promote social evolution and individual development, as time goes on, people also find that social development and human progress are inseparable from another phenomenon which is the cooperation. When people understand this, they begin to explore the development, evolution and function between cooperation and competition using the evolutionary game theory. At first, scholars explore the two-player game models, which constitute the most important archetype among evolutionary games. In the two-player game models, each player has two choices and can select either of them to mitigate or cancel current dilemmas according to five fundamental protocols. The five fundamental protocols are as follows: Direct Reciprocity; Indirect Reciprocity; Kin Selection; Group Selection; Network Reciprocity [14], [15]. Furthermore, If each player has two choices, so two players' choices can construct a $2 * 2$ symmetric or asymmetric game matrix. Depend on the relative magnitudes of the matrix elements, the game can be divided into 4 classes: The Trivial game with no dilemma; the Prisoner's Dilemma (sometimes abbreviated PD) [16], [17]; Chicken (also known as the Snow Drift or Hawk–Dove Game) [18], [19]; and Stag Hunt (sometimes abbreviated SH). At present, $2 * 2$ symmetric or asymmetric game has been applied in many fields, such as Sociology [20], Economics [21], Computer Science [22], Environmental Science [23], and other fields. Later, with the development of research, three-party games [24]–[26] and multiplayer games [27], [28] have been applied in many fields [29]–[31].

Currently, plenty of scholars have used the game theory and other methods to explore human complex behavior, they use different theories and methods from various disciplines including statistical physics, social physics, and mathematics to explore some related fields about human and society, such as human cooperation, social evolution and human's moral behavior. Specifically speaking, Dirk Helbing *et al.* [32] used the methods of complex science to study the macro-level collective dynamic behavior, such as terrorism, crowd disasters, and disease spreading; Matjaž Perc [33] explored the phenomenon of phase transitions in models of human cooperation, he also researched the public goods game with punishment, positive and negative reciprocity; Valerio and Matjaž [34] used the method of statistical physics to research the moral behavior in social dilemmas. In addition, some scholars research the human cooperation from the reputation mechanism. Dong *et al.* [35] did some research about the second-order reputation evaluation model, and considered that the second-order reputation evolution model can reflect the cooperation process in human societies well; Xia *et al.* [36] also found that the reputation effect can favor the evolution of cooperation and reduce the risk of cooperation; Chen *et al.* [37] found that the cooperation behavior would be obviously influenced by the reputation threshold (RC) based on the a new spatial public goods game model, meanwhile, the fraction of cooperators will be higher with the greater threshold. From the above research results, we can know that scholars have made some achievements in the field of evolutionary game and human behavior, and these studies can provide some insights for the follow-up scholars.

At present, some scholars have used the evolutionary game method to research the relationship between doctors and patients. Huang *et al.* [38] used the three-party games model to explore the feasibility and equilibrium conditions of the implementation of the doctor-patient system, and propose long-term and short-term recommendations for reconstructing the trust of doctors and patients. Zhang and Li [39] used the evolutionary game and carried out related research on the rights game in medical disputes. The research found that the outcome of medical disputes was often a zero-sum game or harmonious win-win. Guo and Wu [40] formed a complicated relationship between collusion and game coexisting around patients, doctors and the government concerning the financing and use of medical expenses. They thought that the taking doctor-patient relationship as an example, the evolutionary three-group asymmetric evolutionary game model was used to explain the positive effects of consumer empowerment and cooperative governance on the moral hazard of the medical service market and even the control of medical expenses. Jaegher and Kris [41] explored the evolution of the doctor-patient relationship which took patient information part in the model based on the conflict of interest between doctors and patients. Zhu [42] discussed the inevitable violation of doctors in the treatment of doctors and patients from the perspective of game theory in the case of information asymmetry. Tian *et al.* [43] explained the inefficiency of the experts in the medical service market from the perspective of social preference and empty talk game and found that no search cost competition can solve the problem of inefficiency in the expert services market.

The above scholars have studied the relationship between doctors and patients from the trust of doctors and patients, the competition of power, information asymmetry, etc., which provide some inspirations to follow-up scholars for studying the relationship between doctors and patients. However, the above studies don't consider the moral hazard. The moral hazard exists in both doctors and patients, and it refers to the fact that in the performance of a contract, one party uses its information superiority to do an act that is beneficial to oneself and disadvantageous to the other party. The literature [44] pointed out that in the process of doctor-patient activities, we must pay attention to prevent two types of moral hazard. Firstly, the moral hazard caused by patients. It happens when the patient does not have to bear the most cost of drug and instrument examination. During the consultation, the patient tends to exaggerate his/her symptoms in an aim to influence the doctor's diagnosis, and this will result in the doctor runs more tests than necessary on them and even prescribes unnecessary medicine. Secondly, excessive service is the moral hazard of the doctor. Generally, doctors have more medical knowledge than patients. They are often on the side of information superiority. They know more about the tests and what medicines are better for patients. When the medicines are profitable, doctors will prescribe more medicines than needed thereby forcing patients to overspend. In addition to that, the literature [45], [46] pointed out that the asymmetric information between doctors and patients can cause moral hazard between doctors and patients, but the existing research does not integrate information asymmetry, trust and moral hazard between doctors and patients in a unified framework, and it is different to clarify the microscopic mechanism of the doctor-patient relationship from the existing research.

This article intends to comprehensively consider the degree of information asymmetry between doctors and patients, the degree of trust between doctors and patients, and the moral hazard of doctors and patients. On top of that, from the perspective of dynamic evolution, the evolution of cooperation between doctors and patients is established by constructing a game model of doctor-patient relationship evolution. The relevant analysis is carried out to provide some new ideas for revealing the contradiction between doctors and patients, promoting the harmonious development of doctor-patient relationships, and building a new type of doctor-patient relationship.

II. BASIC ASSUMPTIONS AND MODEL CONSTRUCTION

A. BASIC ASSUMPTIONS AND PAYMENT MATRIX CONSTRUCTION

In the process of developing the relationship between doctors and patients, today, the occurrence of doctor-patient disputes is a direct manifestation of the existing tension between doctors and patients in China. We know that a lack of trust, information asymmetry, and moral hazard between doctors and patients can cause disharmony between doctors and patients. Therefore, based on the careful consideration of the problematic factors mentioned above, the relationship between doctors and patients is discussed through the construction of the evolutionary game model of the doctor-patient relationship. In order to clarify the problem, the following assumptions are made:

(1) Information asymmetry assumption. It is assumed that the information is asymmetrical, and the doctor's information about the patient's medical treatment is unclear. The patient's diagnosis and treatment information and the medication information are not clear, so the doctor and patient have certain asymmetry in the degree of information mastery.

(2) In the process of doctor-patient cooperation, it is assumed that there are two strategic choices for doctors and patients: Cooperation and conflict. If both parties choose a cooperation strategy, it means that there will be a cooperative consensus and a cooperative activity between the doctors and patients. If both parties choose a conflict strategy, indicating that there will be contradictions between doctors and patients, which will lead to the breakdown of the partnership. The proportion of doctors who choose a cooperation strategy is x, the ratio of doctors who choose a conflict strategy is $1-x$. The proportion of patients who choose a cooperation strategy is y, the ratio of patients who choose a conflict strategy is $1-y$. If both parties choose a conflict strategy, they will obtain the benefit Π_i and Π_j.

(3) In the process of cooperation, it is assumed that the partners will invest a certain amount of time, energy and money, and other cooperative resources. Assuming that the cooperation resources invested by doctors and patients are Λ_i and Λ_j. In the process of cooperation, there is information

TABLE 1. Evolutionary Game Payment Matrix between doctor and patient.

		patient	
		cooperation(y)	conflict ($1-y$)
doctor	cooperation (x)	($\Pi_i - \beta_i\Lambda_i + \delta_i\Lambda_i, \Pi_j - \beta_j\Lambda_j + \delta_j\Lambda_j$)	($\Pi_i - \beta_i\Lambda_i, \Pi_j + \alpha_j\Lambda_i$)
	conflit ($1-x$)	($\Pi_i + \alpha_i\Lambda_j, \Pi_j - \beta_j\Lambda_j$)	(Π_i, Π_j)

asymmetry between the doctor and the patient. Doctors have a comprehensive understanding of the patient's pathology and medication information, and the degree of asymmetry is low. The patient has less information about the hospital and the doctor, so the degree of asymmetry is higher [47]. Suppose the doctor's information asymmetry coefficient is β_i, the patient's information asymmetry coefficient is β_j, and $\beta_i < \beta_j$, besides, the information asymmetry between doctors and patients will cause a specific cooperation cost. Therefore, it can be assumed that the doctor's cooperation cost is C_i, the cost of cooperation for patients is C_j, $C_i = \beta_i\Lambda_i$, $C_j = \beta_j\Lambda_j$.

(4) We suppose the doctor's moral hazard coefficient is α_i, and the patient's moral hazard coefficient is α_j. If one party chooses the cooperation strategy and the other party chooses the conflict strategy, the moral hazard will happen [44]. The party choosing conflict strategy will obtain an additional return from the information and resource provided by the party choosing cooperation strategy. For example, if a doctor chooses the cooperation strategy, but the patient chooses the conflict strategy, then the patient will obtain additional return R_j from the doctor, $R_j = \alpha_j\Lambda_i$. Vice versa, the doctor will obtain additional return R_i from the patient, $R_i = \alpha_i\Lambda_j$.

(5) In the process of cooperation between doctors and patients, the trust can promote the harmony between doctors and patients, and generate additional synergistic benefits. In addition to the specific benefits such as material benefits, the synergistic benefits include reputation and praise [48]. Suppose the doctor's trust in the patient is δ_i, the patient's trust in the doctor is δ_j, the synergistic benefit of the doctor is $M_i = \delta_i\Lambda_i$, the synergistic benefit obtained by the patient is $M_j = \delta_j\Lambda_j$.

Based on the above assumptions, we construct an evolution game payment matrix about the doctor-patient relationship, as shown in Table 1.

B. EVOLUTIONARY GAME MODEL

As shown in Table 1, the payment matrix of doctors and patients is as follows: At the t moment, the doctor selects a cooperative strategy, and his return is μ_{11}.

$$\mu_{11} = y(\Pi_i + \delta_i\Lambda_i - \beta_i\Lambda_i) + (1-y)(\Pi_i - \beta_i\Lambda_i) \quad (1)$$

The doctor selects a conflict strategy, and his return is μ_{12}.

$$\mu_{12} = y(\Pi_i + \alpha_i\Lambda_j) + (1-y)\Pi_i \quad (2)$$

The doctor's average expected return is $\bar{u_1}$.

$$\begin{aligned}\bar{u_1} &= xu_{11} + (1-x)u_{12} \\ &= x(y(\Pi_i + \delta_i\Lambda_i - \beta_i\Lambda_i) + (1-y)(\Pi_i - \beta_i\Lambda_i)) \\ &\quad + (1-x)(y(\Pi_i + \alpha_i\Lambda_j) + (1-y)\Pi_i)\end{aligned} \quad (3)$$

Further, the doctor's replication dynamic equation is $\frac{dx}{dt}$.

$$\frac{dx}{dt} = x(\mu_{11} - \bar{u_1}) = x(1-x)[y(\delta_i\Lambda_i - \alpha_i\Lambda_j) - \beta_i\Lambda_i] \quad (4)$$

Also, the patient selects a cooperative strategy, and his return is μ_{21}.

$$\mu_{21} = x(\Pi_j + \delta_j\Lambda_j - \beta_j\Lambda_j) + (1-x)(\Pi_j - \beta_j\Lambda_j) \quad (5)$$

The patient selects a conflict strategy, and his return is μ_{22}.

$$\mu_{22} = x(\Pi_j + \alpha_j\Lambda_i) + (1-x)\Pi_j \quad (6)$$

The patient's average expected return is $\bar{u_2}$.

$$\begin{aligned}\bar{u_2} &= yu_{21} + (1-y)u_{22} \\ &= y(x(\Pi_j + \delta_j\Lambda_j - \beta_j\Lambda_j) + (1-x)(\Pi_j - \beta_j\Lambda_j)) \\ &\quad + (1-y)(x(\Pi_j + \alpha_j\Lambda_i) + (1-x)\Pi_j)\end{aligned} \quad (7)$$

Further, the patient's replication dynamic equation is $\frac{dy}{dt}$.

$$\frac{dy}{dt} = y(\mu_{21} - \bar{u_2}) = y(1-y)[x(\delta_j\Lambda_j - \alpha_j\Lambda_i) - \beta_j\Lambda_j] \quad (8)$$

It can be obtained from equations (4) and (8), and the dynamic equations of replication for doctors and patients are:

$$f(x) = \frac{dx}{dt} = x(1-x)[y(\delta_i\Lambda_i - \alpha_i\Lambda_j) - \beta_i\Lambda_i] \quad (9)$$

$$f(y) = \frac{dy}{dt} = y(1-y)[x(\delta_j\Lambda_j - \alpha_j\Lambda_i) - \beta_j\Lambda_j] \quad (10)$$

By solving the above two-dimensional dynamic equations, we can obtain five equilibrium points: $E(0,0)$, $S(1,0)$, $N(0,1)$, $D(1,1)$, $P(\frac{\beta_j\Lambda_j}{\delta_j\Lambda_j - \alpha_j\Lambda_i}, \frac{\beta_i\Lambda_i}{\delta_i\Lambda_i - \alpha_i\Lambda_j})$.

Furthermore, we can obtain the Jacobian matrix J.

$$J = \begin{bmatrix} \frac{df(x)}{dx} & \frac{df(x)}{dy} \\ \frac{df(y)}{dx} & \frac{df(y)}{dy} \end{bmatrix} = \begin{bmatrix} (1-2x)[y(\delta_i\Lambda_i - \alpha_i\Lambda_j) - \beta_i\Lambda_i] & x(1-x)(\delta_i\Lambda_i - \alpha_i\Lambda_j) \\ y(1-y)(\delta_j\Lambda_j - \alpha_j\Lambda_i) & (1-2y)[x(\delta_j\Lambda_j - \alpha_j\Lambda_i) - \beta_j\Lambda_j] \end{bmatrix} \quad (11)$$

The determinant and trace values of the Jacobian matrix at $E(0,0)$, $S(1,0)$, $N(0,1)$, $D(1,1)$, $P(\frac{\beta_j\Lambda_j}{\delta_j\Lambda_j - \alpha_j\Lambda_i}, \frac{\beta_i\Lambda_i}{\delta_i\Lambda_i - \alpha_i\Lambda_j})$ are shown in Table 2.

TABLE 2. The determinant and trace values at each equilibrium point.

Equilibrium point	Determinant	Trace
$E(0,0)$	$(\beta_i\Lambda_i)(\beta_j\Lambda_j)$	$-(\beta_i\Lambda_i+\beta_j\Lambda_j)$
$S(1,0)$	$\beta_i\Lambda_i(\delta_j\Lambda_j-\alpha_j\Lambda_i-\beta_j\Lambda_j)$	$\beta_i\Lambda_i+(\delta_j\Lambda_j-\alpha_j\Lambda_i-\beta_j\Lambda_j)$
$N(0,1)$	$\beta_j\Lambda_j(\delta_i\Lambda_i-\alpha_i\Lambda_j-\beta_i\Lambda_i)$	$\beta_j\Lambda_j+(\delta_i\Lambda_i-\alpha_i\Lambda_j-\beta_i\Lambda_i)$
$D(1,1)$	$(\delta_i\Lambda_i-\alpha_i\Lambda_j-\beta_i\Lambda_i)*(\delta_j\Lambda_j-\alpha_j\Lambda_i-\beta_j\Lambda_j))$	$-[(\delta_i\Lambda_i-\alpha_i\Lambda_j-\beta_i\Lambda_i)+(\delta_j\Lambda_j-\alpha_j\Lambda_i-\beta_j\Lambda_j)]$
$P(\frac{\beta_j\Lambda_j}{\delta_j\Lambda_j-\alpha_j\Lambda_i},\frac{\beta_i\Lambda_i}{\delta_i\Lambda_i-\alpha_i\Lambda_j})$	$-(\beta_i\Lambda_i)(\beta_j\Lambda_j)(1-\frac{\beta_j\Lambda_j}{\delta_j\Lambda_j-\alpha_j\Lambda_i})(1-\frac{\beta_i\Lambda_i}{\delta_i\Lambda_i-\alpha_i\Lambda_j})$	0

TABLE 3. Stability of Jacobian matrix at each equilibrium point.

Theorem	Condition	Equilibrium points	Determinant's symbol	Trace's symbol	Stability
Theorem 1	$0<\alpha_j\Lambda_i<\delta_j\Lambda_j-\beta_j\Lambda_j$ $0<\alpha_i\Lambda_j<\delta_i\Lambda_i-\beta_i\Lambda_i$	$E(0,0)$	+	-	ESS
		$S(1,0)$	+	+	Unstable
		$N(0,1)$	+	+	Unstable
		$D(1,1)$	+	-	ESS
		$P(x,y)$	-	0	Saddle point

C. EVOLUTIONARY STABILITY ANALYSIS

According to the symbol of the Jacobian matrix's determinant and trace, we can determine the evolutionary stability strategy, and there are three situations.

Theorem 1: When the benefits obtained by the partners through moral hazard are less than the difference between the synergistic benefits of the partners and the information asymmetry costs, the partners will choose the follow strategy, that is, one party chooses the cooperation strategy, and the other party also chooses the cooperation strategy. If one party chooses the conflict strategy, the other party will also choose a conflict strategy.

Proof: When $0<\beta_j\Lambda_j<\delta_j\Lambda_j-\alpha_j\Lambda_i$, $0<\beta_i\Lambda_i<\delta_i\Lambda_i-\alpha_i\Lambda_j$, that is $0<\alpha_j\Lambda_i<\delta_j\Lambda_j-\beta_j\Lambda_j$, $0<\alpha_i\Lambda_j<\delta_i\Lambda_i-\beta_i\Lambda_i$, if a patient selects the cooperation strategy, and the doctor also selects the cooperation strategy, then the doctor can get more return. At this time, the doctor's rational strategy is cooperation. If the patient selects the conflict strategy and the doctor selects the conflict strategy too, then the doctor can get more return, so the conflict cooperation strategy is consequently a rational strategy for the doctor.

Theorem 2: When the benefits obtained by the partners through moral hazard are higher than the difference between the synergistic benefits of the partners and the information asymmetry costs, the partners finally choose the conflict strategy.

Proof: When $\beta_j\Lambda_j>\delta_j\Lambda_j-\alpha_j\Lambda_i>0$, $\beta_i\Lambda_i>\delta_i\Lambda_i-\alpha_i\Lambda_j>0$, that is $\alpha_j\Lambda_i>\delta_j\Lambda_j-\beta_j\Lambda_j>0$, $\alpha_i\Lambda_j>\delta_i\Lambda_i-\beta_i\Lambda_i>0$, if a patient selects the cooperation strategy, the doctor can get more return when he selects the conflict strategy, and therefore the rational strategy for the doctor is the conflict strategy. On the other hand, if the patient selects the conflict strategy, the doctor can get more return when he selects the conflict strategy. Therefore the doctor's rational strategy is the conflict strategy.

Theorem 3: When the benefits obtained by the partners through moral hazard are higher than the synergies between the two parties, the partners finally choose the conflict strategy.

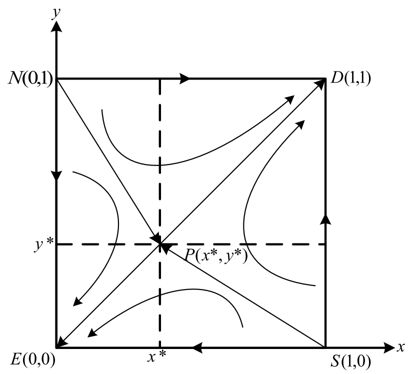

FIGURE 1. Evolution phase diagram of the system based on Theorem 1.

Proof: When $\delta_j\Lambda_j-\alpha_j\Lambda_i<0$, $\delta_i\Lambda_i-\alpha_i\Lambda_j<0$, that is $\delta_j\Lambda_j<\alpha_j\Lambda_i$, $\delta_i\Lambda_i<\alpha_i\Lambda_j$, if the patient selects the cooperation strategy, the doctor can get more return when he selects the conflict strategy, then, the doctor chooses conflict strategy as his rational strategy. If the patient selects the conflict strategy, the doctor can get more return when he selects the conflict, and the doctor chooses the conflict strategy as a rational strategy.

In **Theorem 1**, there are 5 equilibrium points in the system. The symbol and the equilibrium state about determinant and the trace of the Jacobian matrix are shown in table 3.

Based on **Theorem 1**, we can get the evolution phase diagram of the system in figure 1.

As shown in figure 1, when the equilibrium value $P(x^*, y^*)$ moves in the quadrilateral $ENDS$. If $P(x^*, y^*)$'s initial state value is different, the strategies of the doctor the patients are different. If $x^*<\frac{1}{2}$, $y^*<\frac{1}{2}$, the quadrilateral $PNDS$'s area is more than the $ENPS$'s area, the final strategy of the system will be stable at $D(1,1)$. At this moment, the strategies of the doctor the patients are cooperation.

On the other hand, If $x^*=\frac{1}{2}$, $y^*=\frac{1}{2}$, quadrilateral $DNPS$'s area will be equal to the area of quadrilateral $ENPS$, then the final strategy of the system will stable at $D(1,1)$ or $E(0,0)$. At this moment, the strategies of the doctor the

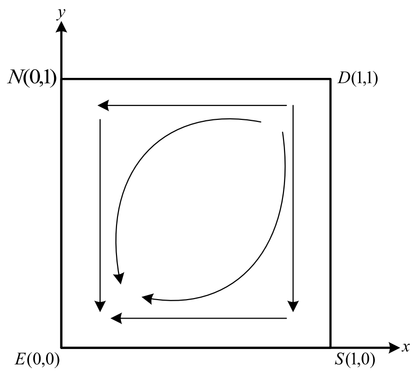

FIGURE 2. Evolution phase diagram of the system based on Theorem 2and Theorem 3.

patients are cooperation or the conflict. If $x^* > \frac{1}{2}$, $y^* > \frac{1}{2}$, the area of *DNPS* quadrilateral is less than quadrilateral *ENPS*, the final strategy of the system will be stable at $E(0, 0)$. The strategies of doctor and patient are conflict.

In **Theorem 2** and **Theorem 3**, there are four equilibrium points in the system. The symbol and the equilibrium state about determinant and the trace of the Jacobian matrix is shown in table 3.

Based on **Theorem 2** and **Theorem 3**, we can get the evolution phase diagram of the system in figure 2 below.

In firgure 2, we can find that $D(1, 1)$ is the unstable point, $E(0, 0)$ is the stable point. At this moment, $D(1, 1)$ will follow the path *DNE* and the *DSE* approach to point $E(0, 0)$. Finally, it will be stable at point $E(0, 0)$; now, the strategies of the doctor and the patient are conflict.

III. NUMERICAL SIMULATION AND ANALYSIS

According to the previous study [49], [50], we can use numerical simulation to verify the feasibility of our model. In our model, we use the software MATLAB R2018b to do the simulation and set the initial parameters as follows: The resources invested by doctors and patients are $\Lambda_i = 2$ and $\Lambda_j = 2$; initial ratio of two types of strategies between doctors and patients is $x_0 = y_0 = 0.5$; we keep above parameters unchanged and keep other parameters changed: The information asymmetry coefficient of doctor and patient, the degree of trust of doctor and patient, the moral hazard coefficients of the doctor and patient. Section A is the simulation result of the system evolution path under different initial ratios between doctor and patient. Section B depicts the influence result of information asymmetry, trust degree and moral hazard coefficient on the evolution of the doctor-patient cooperation system.

A. SYSTEM EVOLUTION PATH SIMULATION

In this section, we select some data to simulate the evolution path of the doctor-patient system based on the different theorem. Firstly, we choose the initial proportion of the doctor and the patient less than $\frac{1}{2}$ based on **Theorem 1**. For example, we set the initial proportion as follows: $\beta_i = 0.1, \beta_j = 0.2, \delta_i = 0.8, \delta_j = 0.8, \alpha_i = 0.2, \alpha_j = 0.2$, that is

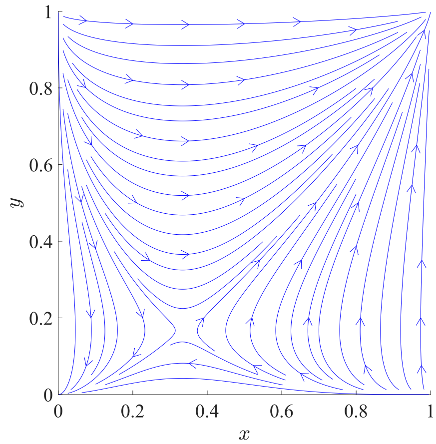

FIGURE 3. System evolution phase diagram when $\Lambda_i = 2, \Lambda_j = 2, \beta_i = 0.1, \beta_j = 0.2, \delta_i = 0.8, \delta_j = 0.8, \alpha_i = 0.2, \alpha_j = 0.2$, that is $x^* = 0.3333$, $y^* = 0.1667$, there are 5 equilibrium points in the system, this moment, the initial proportion $x^* < \frac{1}{2}, y^* < \frac{1}{2}$, the doctors and patients' final strategy is cooperation.

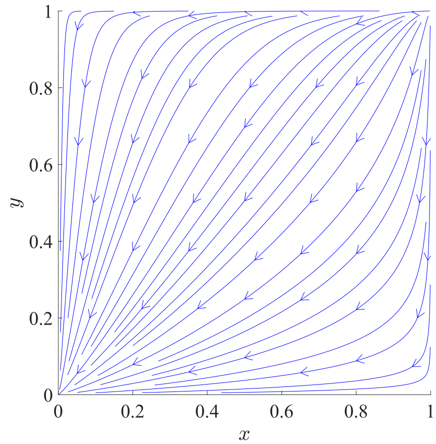

FIGURE 4. System evolution phase diagram when $\Lambda_i = 2, \Lambda_j = 2, \beta_i = 0.8, \beta_j = 0.9, \delta_i = 0.8, \delta_j = 0.8, \alpha_i = 0.2, \alpha_j = 0.2$, that is $x^* = 1.5000, y^* = 1.3333$, there are 4 equilibrium points in the system, this moment, the initial proportion $x^* > \frac{1}{2}, y^* > \frac{1}{2}$, the doctors and patients' final strategy is conflict.

$x^* = 0.3333$, $y^* = 0.1667$, which is less than $\frac{1}{2}$, the simulation result is in figure 3.

As shown in figure 3, there are one saddle point, two stable points, and two unstable points. The system's evolution path will change according to the initial x^* and y^*. When $x^* < \frac{1}{2}$, $y^* < \frac{1}{2}$, the system's evolution path will move to $D(1, 1)$ and the strategy between doctor and the patient are cooperation.

Furthermore, we choose the initial proportion of the doctor and the patient more than $\frac{1}{2}$ based on **Theorem 2**. For example, we set the initial proportion as follows: $\beta_i = 0.8$, $\beta_j = 0.9, \delta_i = 0.8, \delta_j = 0.8, \alpha_i = 0.2, \alpha_j = 0.2$, that is $x^* = 1.5000, y^* = 1.3333$, the simulation result is in figure 4.

As shown in figure 4, there are one unstable point, one stable point, and two saddle points. The system's evolution path will approach the stable point from an unstable point. The final strategy will stable at conflict.

TABLE 4. Stability of Jacobian matrix at each equilibrium point.

Theorem	Condition	Equilibrium points	Determinant's symbol	Trace's symbol	Stability
Theorem 2	$\alpha_j\Lambda_i > \delta_j\Lambda_j - \beta_j\Lambda_j > 0$ $\alpha_i\Lambda_j > \delta_i\Lambda_i - \beta_i\Lambda_i > 0$	$E(0,0)$	+	-	ESS
		$S(1,0)$	-	Uncertain	Saddle point
		$N(0,1)$	-	Uncertain	Saddle point
		D(1,1)	+	+	Unstable
Theorem 3	$\delta_j\Lambda_j < \alpha_j\Lambda_i$ $\delta_i\Lambda_i < \alpha_i\Lambda_j$	$E(0,0)$	+	-	ESS
		$S(1,0)$	-	Uncertain	Saddle point
		$N(0,1)$	-	Uncertain	Saddle point
		$D(1,1)$	+	+	Unstable

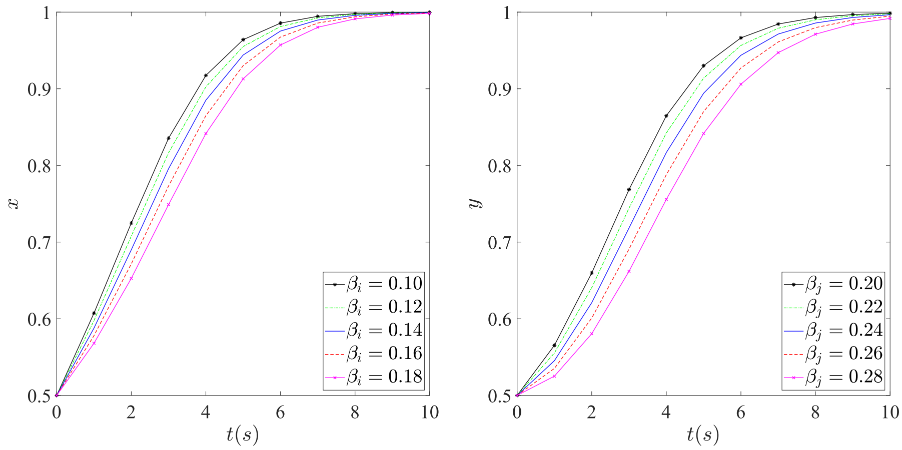

FIGURE 5. The left figure indicates the influence of doctor's information asymmetry on the system's evolution path, the right figure displays the influence of patient's information asymmetry on the system's evolution path, the parameters $\Lambda_i = 2$, $\Lambda_j = 2$, $\delta_i = 0.8$, $\delta_j = 0.8$, $\alpha_i = 0.2$, $\alpha_j = 0.2$, the doctor's information asymmetry coefficient $\beta_i = 0.10, 0.12, 0.14, 0.16, 0.18$ in the left figure; the patient's information asymmetry coefficient $\beta_j = 0.20, 0.22, 0.24, 0.26, 0.28$ in the right figure. The system's evolution path is gradually extended form 8 to 10 when β_i increases from 0.10 to 0.18 in the left figure; the system's evolution path is gradually extended form 9 to more than10 when β_j increases from 0.20 to 0.28 in the right figure; doctor's proportion of cooperation strategy is larger than the patient's when $\beta_i = 0.18$, $\beta_j = 0.28$.

B. THE INFLUENCE OF VARIOUS FACTORS ON THE EVOLUTION OF DOCTOR-PATIENT COOPERATION SYSTEM

1) INFORMATION ASYMMETRY

We set the parameter of doctor's information asymmetry as $\beta_i = 0.10, 0.12, 0.14, 0.16, 0.18$ and the patient's information asymmetry as $\beta_j = 0.20, 0.22, 0.24, 0.26, 0.28$, other parameters are set as follows: $\Lambda_i = 2$, $\Lambda_j = 2$, $\delta_i = 0.8$, $\delta_j = 0.8$, $\alpha_i = 0.2$, $\alpha_j = 0.2$. The simulation result about the influence of information asymmetry on the system's evolution path between doctor and patient is shown in figure 5.

As shown in figure 5, the left figure indicates the influence of the doctor's information asymmetry on the system's evolution path, the right figure displays the influence of the patient's information asymmetry on the system's evolution path. In the left figure, we can know that the system's evolution step is gradually extended from 8 to 10 when the doctor's information asymmetry increases from 0.10 to 0.18. The result indicates that the system's evolution step extends gradually when doctors' information asymmetry deepens. In the right figure, we find that the system's evolution step is gradually extended from 9 to more than 10 when the patient's information asymmetry increases from 0.20 to 0.28. It indicates that the system's evolution step extends gradually when patients' information asymmetry deepens. Besides, when $\beta_i = 0.18$, $\beta_j = 0.28$, we know that doctor's proportion of cooperation strategy is larger than the patient's. At this time, because the doctor's degree of information asymmetry is less than the patients, they can grasp more information than the patient. Therefore, the doctor selects the cooperation strategy more readily. From the above simulation, it concludes that we can promote the cooperative consensus between the doctors and patients and achieve cooperation activities by reducing the degree of information asymmetry of patients more effectively.

2) TRUST DEGREE

We set the parameter of doctor's and patient's trust degree as $\beta_i = \beta_j = 0.50, 0.52, 0.54, 0.56, 0.58$, other parameters are set as follows: $\Lambda_i = 2$, $\Lambda_j = 2$, $\beta_i = 0.1$, $\beta_j = 0.2$, $\alpha_i = 0.2$, $\alpha_j = 0.2$. Furthermore, the simulation result about the influence of trust degree on the system's evolution path is shown in figure 6 respectively.

As shown in figure 6, the left figure indicates the influence of a doctor's trust degree on the system's evolution path,

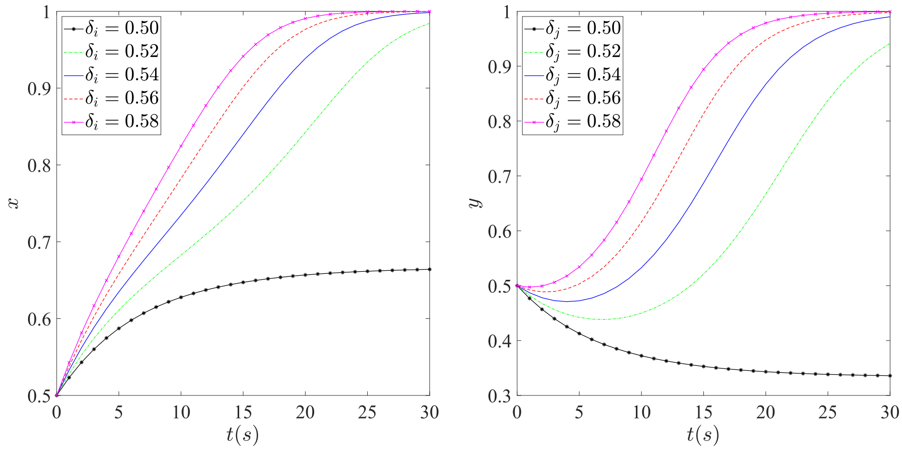

FIGURE 6. **The left figure indicates the influence of doctor's trust degree on the system's evolution path, the right figure displays the influence of patient's trust degree on the system's evolution path, the parameters $\Lambda_i = 2$, $\Lambda_j = 2$, $\beta_i = 0.1$, $\beta_j = 0.2$, $\alpha_i = 0.2$, $\alpha_j = 0.2$. The doctor's trust degree $\delta_i = 0.50, 0.52, 0.54, 0.56, 0.58$ in the left figure; the patient's trust degree $\delta_j = 0.50, 0.52, 0.54, 0.56, 0.58$ in the right figure. The system's evolution step is gradually shortened form more than 30 to 25 when δ_i increases from 0.50 to 0.58 in the left figure; the system's evolution step shortens gradually when patient's trust degree increases from 0.50 to 0.58, especially, the system's evolution strategy is transforming from conflict to the cooperation when δ_j increases from 0.50 to 0.52 in the right figure; doctor chooses the cooperation strategy, but the patient chooses the conflict strategy when $\delta_i = 0.50$, $\delta_j = 0.50$.**

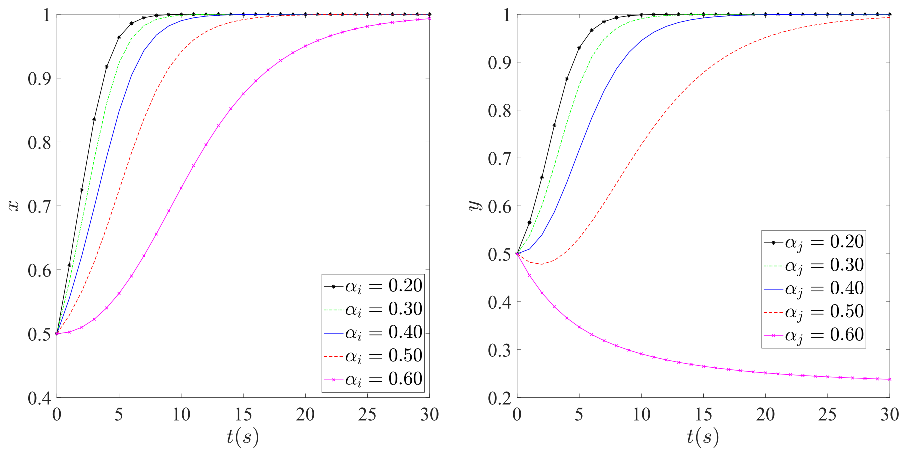

FIGURE 7. **The left figure indicates the influence of the doctor's moral hazard on the system's evolution path, the right figure displays the influence of the patient's moral hazard on the system's evolution path, $\Lambda_i = 2$, $\Lambda_j = 2$, $\beta_i = 0.1$, $\beta_j = 0.2$, $\delta_i = 0.8$, $\delta_j = 0.8$. The doctor's moral hazard coefficient $\alpha_i = 0.2, 0.3, 0.4, 0.5, 0.6$ in the left figure; the patient's moral hazard coefficient $\alpha_j = 0.2, 0.3, 0.4, 0.5, 0.6$ in the right figure. The system's evolution step is gradually extended from 5 to 30 when α_i increases from 0.20 to 0.60 in the left figure; the system's evolution step is gradually extended from 10 to positive infinity gradually when the patient's trust degree α_j increases from 0.20 to 0.60, especially, the system's evolution strategy is transforming from cooperation to conflict when α_j increases from 0.50 to 0.60 in the right figure; the doctor chooses the cooperation strategy, but the patient chooses the conflict strategy when $\alpha_i = 0.60$, $\alpha_j = 0.60$.**

the right figure displays the influence of the patient's trust degree on the system's evolution path. In the left figure, the system's evolution step is gradually shortened form more than 30 to 25 when δ_i increases from 0.50 to 0.58. This result indicates that the system's evolution step shortens gradually when the doctor's trust degree increases. Similarly, we discover that the system's evolution step shortens gradually when the patient's trust degree increases from 0.50 to 0.58 in the right figure, especially, patient's strategy transforms from the conflict to the cooperation when the patient's trust degree increases from 0.50 to 0.52. Moreover, doctor chooses the cooperation strategy, but the patient chooses the conflict strategy when $\delta_i = 0.50$, $\delta_j = 0.50$. The above results indicate that focusing on promoting the patient's trust degree can promote cooperation between doctors and patients more effectively.

3) MORAL HAZARD COEFFICIENT

We set the parameter of the doctor's and patient's moral hazard coefficient of and patient as 0.20, 0.30, 0.40, 0.50, 0.60, respectively. The simulation result about the influence of the moral hazard coefficient on the system's evolution path is shown in figure 7.

As shown in figure 7, the left figure indicates the influence of the doctor's moral hazard on the system's evolution path, the right figure displays the influence of the patient's moral hazard on the system's evolution path. In the left figure, we discover that the system's evolution step is gradually extended from 5 to 30 when the moral hazard coefficient of the doctor increases from 0.20 to 0.60, and it will finally stabilize at the cooperation strategy. It indicates that the moral hazard has a negative influence on the doctor-patient system evolution path. At the same time, the system's evolution step is gradually extended from 10 to positive infinity gradually when patient's trust degree α_j increases from 0.20 to 0.60 in the right figure, especially, the system's evolution strategy is transforming from cooperation to conflict when α_j increases from 0.50 to 0.60. Also, when $\alpha_i = 0.6$, $\alpha_j = 0.6$, the patient selects the conflict strategy. However, the doctor selects the cooperation strategy. At this time, we can know that reducing the moral hazard coefficient of patients can improve the relationship and promote harmonious development more effectively between doctors and patients.

IV. CONCLUSION

In conclusion, after an in-depth study of doctor-patient at home and abroad, a game model of doctor-patient relationship evolution is constructed. This paper offers a practical solution through numerical simulation to improve the doctor-patient relationship: Firstly, to reduce the degree of information asymmetry between the doctors and patients; secondly, to improve the degree of trust between doctors and patients, and lastly to reduce the degree of moral hazard between doctors and patients. The specific conclusion is: (1) In the doctor-patient relationship, the choice of doctors and patients will eventually stabilize in the (cooperative, cooperative) state or (conflict, conflict) state, and the doctor-patient relationship can form a zero-sum game or a win-win situation. The situation is closely related to the initial parameters of the evolutionary game model and the payment matrix of the evolutionary game. (2) Reducing the degree of information asymmetry, increasing the trust level and reducing the moral hazard coefficient between doctors and patients can promote the evolution of the doctor-patient relationship in the direction of cooperation consequently. (3) For doctors, reducing the degree of information asymmetry of patients, improving the patient's trust in doctors, and reducing the level of moral hazard of patients can promote the harmonious and healthy development of doctor-patient relationships more efficiently.

Based on the above research, the following suggestions are proposed to improve the current doctor-patient relationship: (1) Reduce the degree of information asymmetry, and improve the efficiency of communication between doctors and patients. In order to reduce the degree of information asymmetry, the government should propagate some basic medical knowledge, and let people understand the doctor's authority and professional medical knowledge. Meanwhile, the good communication is important to transmit information between doctors and patients, the reason of some medical disputes in the news is the poor communication, so the hospital and the related department should help doctors and patients improve their communication skills to eliminate the degree of information asymmetry gradually. In addition, on the doctor's side, it is necessary to understand the patient's multifaceted information as much as possible, and keep good communication with patients especially when the patient is facing a serious illness. In this way, the degree of information asymmetry can be reduced and a good discourse communication system between doctors and patients could be established gradually, and then the contradiction between doctors and patients will alleviate effectively.

(2) Strengthen the trust of doctors and patients and ease the tension between doctors and patients. In the doctor-patient relationship, if the patient will actively cooperate with the treatment, abide by the doctor's order, and not hide the condition, the trust between doctor and patient will increase. Similarly, if the doctor could treat patients reasonably and don't let them do some over-consumption in medicine and treatment, the trust will build up persistently. Moreover, the government can establish a medical coordination center to coordinate the trust between doctors and patients, the coordination center can also reconstruct the damaged relationship between doctors and patients when a conflict has occurred.

(3) Reduce the moral hazard of doctors and patients and improve the level of doctor-patient cooperation. In order to alleviate the phenomenon of "violent attack on doctors", both doctors and patients should reduce the moral hazard. At the institutional level, it is necessary to introduce reasonable incentives and punishment mechanisms to reduce the possibility of moral hazard. Meanwhile, evaluating the diagnosis and treatment process and the quality reasonably, in this way, can reduce the possibility of the patient's moral hazard. Meanwhile, the government and the related departments could take extensive actions to improve the public's civic ethics and make people reduce moral hazard spontaneously.

In a word, scholars have used the evolutionary game theory to do some researches associated human behavior at present. However, there are few studies focusing on the cooperation between doctors and patients from the view of evolutionary game theory, our research explores the cooperation between doctors and patients from the aspects of information asymmetry, trust degree and the moral hazard, we obtain some valuable conclusions, and this method and research mode also can be applied to other fields, such as the game of regional pollution control, innovation dependence between enterprises and governments, management of highway overload behavior and other aspects. These fields can be explored in the future by using the above models and methods.

ACKNOWLEDGMENT

The authors are grateful to give thanks to the valuable review comments of every expert and editor.

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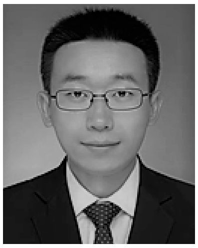

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