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Research on the Synergetic Innovation Between Pharmaceutical Enterprises and Scientific Research Institutions Based on the Quantum Game

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ABSTRACT Synergetic innovation between pharmaceutical enterprises and scientific research institutions is extremely important for the development of innovative drugs. However, it is unstable in the pharmaceutical industry, which seriously hinders the development of innovative drugs in the World. China is the country with the biggest population, and therefore problems in this country are ones of the most important. In this context, we studied the influence of strengthening correlation degree on synergetic innovation between pharmaceutical enterprises and scientific research institutions by using quantum game. Through the establishment of quantum game model, we obtain the optimal strategy of both players in different case. The results show that the quantum game can solve the problem of "prisoner's dilemma" existing in the game between pharmaceutical enterprises and scientific research institutions; it is easier for the two players to choose complete synergy when they are entangled state and quantum strategy has been adopted; when pharmaceutical enterprises and scientific research institutions are not in a state of entanglement, the quantum game has no difference with classical game in this case.

INDEX TERMS Innovative drugs, pharmaceutical enterprises, quantum game, synergetic innovation, scientific research institutions.

I. INTRODUCTION

The pharmaceutical industry is a vital and indispensable industry for a country, and it requires constant investment and innovation. Innovation is the foundation of any contemporary economy and any sustainable country. It includes the implementation of innovative ideas, the development of innovative technologies, bringing novel products and services to the market [1]. China's pharmaceutical industry has become an important industry since Reform and Opening. However, the development of innovative drugs in China still lags behind developed countries. There is still a certain gap between the innovation capability of China's pharmaceutical industry and developed countries. In order to realize the transition from the pharmaceutical big country to powerful country, pharmaceutical enterprises should establish a strategic alliance of synergetic innovation and carry out in-depth cooperation with scientific research institution. Synergetic innovation is the creation of innovations across firms, perhaps industry or other institutions, by breaking through the barriers among them and collecting the innovation resources and elements, including talents, capital, information and technology, to achieve deep cooperation. As synergetic innovation has become an important part of innovation system in China, industry-university-research cooperation has gradually deepened and entered the stage of industry-university-research synergetic innovation. Synergetic innovation is different from cooperative innovation, and it focus on integration and in-depth collaboration. In addition, synergetic innovation emphasizes the interaction between innovation subjects. It is an effective way to integrate innovation resources and improve innovation efficiency, even though it is a more complex innovation mode [2], [3].

According to the "synergetic", synergy is the process of coordination, cooperation, and synchronization among multiple subsystems which was put forward by Haken [4]. Finally, synergy makes subsystems form a unified whole, which is

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an amplification effect. By establishing synergetic innovation system, the industry can integrate various innovative elements including talent, capital, information and technology. Besides, after in-depth cooperation and resources integration, the industry can reduce risks and costs, and improve overall innovation strength [5]–[8]. In recent years, industry-university-research synergetic innovation has obtained some achievements in China. However, its overall level is not so high and its development is uneven. The development of synergetic innovation is unstable especially in the pharmaceutical industry, which seriously hinders the development of innovative drugs in China [9], [10]. Therefore, in order to achieve rational distribution, promote innovation and development, and form the whole advantage in pharmaceutical industry, how to encourage pharmaceutical enterprises to synergy with scientific research institutions and improve the efficiency of synergetic innovation has very important research value.

The main bodies of collaborative synergetic system in pharmaceutical industry are pharmaceutical enterprises and scientific research institutions. The relationship between the two parties is different from the traditional relationship between enterprises and employees. Therefore, it is more difficult to encourage the two parties to synergize. Some scholars believe that, incentive mechanisms should be designed in line with the characteristics for specific synergistic relations, so that synergistic innovation subjects can cooperate more efficiently [11], [12]. Stephen believes that it is feasible to maximize the total profits by effectively motivating the interaction, willingness and cooperative relationship of each party [13]. And Sun Xinbo put forward that the incentive of synergetic innovation system mainly includes explicit incentive and implicit incentive, and the incentive mechanism should be designed hierarchically to improve efficiency [14]. And Wu Shaobo believes that the design of incentive contracts is very important for the innovation of strategic emerging industries, and he built the incentive effect model of synergetic innovation using the principal-agent model [15]. In addition, some scholars have also proved that policy guidance, financial support, and technical support will also promote the development of synergetic innovation [16]–[18]. However, the above incentive mechanism still has weak binding force on synergetic innovation between pharmaceutical enterprises and scientific research institutions, due to high-investment, high-risk, and long-cycle process of research and development. Hence, this paper will discuss the influence of enhancing the correlation degree between the two parties on synergetic innovation based on the quantum game.

Quantum game theory is an interdisciplinary research area, which studies the game theory by using quantum information theory as a tool. And the theory began with researches of Wiesner on quantum money. Vaidman perhaps used the term game in quantum context first, and Meyer and Eisert *et al.* first applied quantum game theory to penny flip game and prisoners dilemma, respectively [19]–[22]. Subsequently, quantum game has been widely used in economics [23]–[27], informatics [28]–[32], and other fields. The application of quantum in game theory is superior to the classical game, mainly reflected in the following two aspects: First, the quantum game expands the strategy set of classical game, making it easier for the players to seek strategies that meet the conditions. Second, the introduction of entangled states corrects the assumption that "rational person" to some extent, and the entangled state is a measure of the degree of correlation between players [33]–[36]. As a result, quantum game theory tends to solve problems that classical game theory cannot, such as the prisoners' dilemma [37], [38]. Due to the existence of moral hazard problems in the process of synergetic innovation between pharmaceutical enterprises and scientific research institutions, the degree of synergy between the two players is a continuous variable, and in the intermediate state of "complete coordination" and "complete non-coordination", which is similar to the superposition state in quantum mechanics. So, it is reasonable to analyze the influence of strengthening correlation degree on synergetic innovation between pharmaceutical enterprises and scientific research institutions using quantum game.

The rest of the paper is organized in such a way that the second part describes the quantum game model of synergetic innovation between pharmaceutical companies and scientific research institutions. The third part of the paper analyzes the optimal strategy of both players in the unentangled and entangled state. And the forth part is the conclusions and offers some suggestions on how to strengthen the correlation degree between pharmaceutical enterprises and scientific research institutions.

II. MODEL DESCRIPTION

In this paper, we consider pharmaceutical enterprises as player 1, and scientific research institutions as player 2. The synergy degrees of the two players are denoted as σ_1 and σ_2, respectively, representing the level of contribution to synergetic innovation. We assume that the two players will cost C_1 and C_2 respectively in the process of synergetic innovation, and the cost can be written as $C_1 = M\frac{\sigma_1^2}{2}$ and $C_2 = M\frac{\sigma_2^2}{2}$. We denote the benefit for this system as R, which represented as $R = H\sigma_1\sigma_2$. And we let α and $1-\alpha$ be the proportion of benefit distribution for player 1 and player 2, respectively. Then, $R_1 = \alpha R$ and $R_2 = (1-\alpha)R$.

Based on the parameters setting, the profit functions for the player 1 and player 2, π_1 and π_2, are given by

$$\pi_1 = \alpha H\sigma_1\sigma_2 - M\frac{\sigma_1^2}{2} \tag{1}$$

$$\pi_2 = (1-\alpha)H\sigma_1\sigma_2 - M\frac{\sigma_2^2}{2} \tag{2}$$

According to the quantum game, we assume that the $|0>$ state corresponds to the "complete synergy" state of the players, that is, $\sigma_i = 1$; and $|1>$ state corresponds to the "complete non-synergy" state, which means $\sigma_i = 0$. Then

TABLE 1. Expectation payoff matrix of the game.

player/strategy		player 2	
		|0>	|1>
player 1	|0>	αH−1/2M, (1−α) H−1/2M	−1/2M, 0
	|1>	0, −1/2M	0, 0

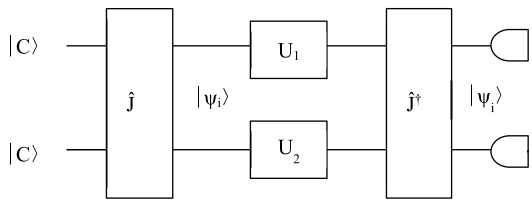

FIGURE 1. Scheme of a two-party quantum game.

the payoff matrix of the two player's game is thus given by table 1.

From table 1, we know that only if both of pharmaceutical enterprises and scientific research institutions choose "complete synergy", then this system can achieve the Pareto Optimality. However, there are two pure strategy nash equilibrium when both of them choose "complete synergy" or "complete non-synergy". Therefore, we quantize this game according to the scheme of a two-party quantum game to solve this problem. The scheme is introduced in fig. 1. In addition, we have the following functions based on the perspective of quantum game according to the payoff matrix:

$$E_1 = (\alpha - 1/2)P_{00} - 1/2\,P_{01} \tag{3}$$

$$E_2 = (1/2 - \alpha)P_{00} - 1/2\,P_{10} \tag{4}$$

where E_i $(i = 1, 2)$ is the payoff of pharmaceutical enterprises or scientific research institutions. $P_{\sigma\sigma'}$ is the probability of the final state $\sigma\sigma'$, where the first and second entries refer to pharmaceutical enterprises' and scientific research institutions' choice, respectively.

A strategy space was assumed with 2-parameter set of unitary 2 × 2 matrices. And the strategy spaces for player 1 and player 2 are introduced respectively in the following (5) and (6), as shown at the bottom of this page, where θ_i $(i = 1, 2)$ is also the parameter of synergy level of each player, and φi is the parameter of quantum strategy degree adopted by the two players. When $\theta_i = 0$ and $\varphi_i = 0$ $(i = 1, 2)$, which means both of the two players choose "complete synergy", the strategy space was denoted as $U = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$. And when $\theta_i = \pi$ and $\varphi_i = 0$ $(i = 1, 2)$, which means both of them choose "complete non-synergy", the strategy space is $U= \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$.

We assume the game's initial state by $|\psi_0>=|00>=|0> \otimes|0>$, which is a separable state. Then quantum operation was conducted with a quantum entangling network. And $\hat{J}$ was denoted as a unitary operator which is known to both players and described as follows (7), as shown at the bottom of this page. And for $\hat{J}^{\dagger}$, we can write

$$\hat{J}^{\dagger} = \begin{pmatrix} \cos\frac{\lambda}{2} & 0 & 0 & -i\sin\frac{\lambda}{2} \\ 0 & \cos\frac{\lambda}{2} & i\sin\frac{\lambda}{2} & 0 \\ 0 & i\sin\frac{\lambda}{2} & \cos\frac{\lambda}{2} & 0 \\ -i\sin\frac{\lambda}{2} & 0 & 0 & \cos\frac{\lambda}{2} \end{pmatrix}. \tag{8}$$

where λ represents the degree of entanglement and $\lambda \in [0, \pi/2]$. When $\lambda = 0$, it means that pharmaceutical enterprises and scientific research institutions are unentangled. And if $\lambda = \pi/2$, they will reach the maximum degree of entanglement.

$$U_1(\theta_1, \varphi_1) = \begin{pmatrix} e^{i\varphi_1}\cos\frac{\theta_1}{2} & \sin\frac{\theta_1}{2} \\ -\sin\frac{\theta_1}{2} & e^{-i\varphi_1}\cos\frac{\theta_1}{2} \end{pmatrix}, \quad \theta_1 \in [0, \pi],\ \varphi_1 \in [0, \frac{\pi}{2}] \tag{5}$$

$$U_2(\theta_2, \varphi_2) = \begin{pmatrix} e^{i\varphi_2}\cos\frac{\theta_2}{2} & \sin\frac{\theta_2}{2} \\ -\sin\frac{\theta_2}{2} & e^{-i\varphi_2}\cos\frac{\theta_2}{2} \end{pmatrix}, \quad \theta_2 \in [0, \pi],\ \varphi_2 \in [0, \frac{\pi}{2}] \tag{6}$$

$$\hat{J} = \exp(i\frac{\lambda}{2}\sigma_x \otimes \sigma_x) = \begin{pmatrix} \cos\frac{\lambda}{2} & 0 & 0 & i\sin\frac{\lambda}{2} \\ 0 & \cos\frac{\lambda}{2} & -i\sin\frac{\lambda}{2} & 0 \\ 0 & -i\sin\frac{\lambda}{2} & \cos\frac{\lambda}{2} & 0 \\ i\sin\frac{\lambda}{2} & 0 & 0 & \cos\frac{\lambda}{2} \end{pmatrix} \tag{7}$$

Then the conjugate operator of $\hat{J}$ was applied to get the final state as the postoperation. And the final quantum state $|\psi_f>$ is calculated by $|\psi_f>= \hat{J}^{\dagger}U_1\otimes U_2\hat{J}|00>$, and described as equation (9), as shown at the bottom of this page.

III. MODEL ANALYSIS IN DIFFERENT SITUATIONS

In this section, we analyze the quantum game between pharmaceutical enterprises and scientific research institutions in different situation.

Situation 1: Pharmaceutical enterprises and scientific research institutions are not entangled (i.e. $\lambda = 0$) in this situation.

Then we can get the final quantum state below.

$$|\psi_f\rangle = \begin{pmatrix} e^{i\varphi_1+i\varphi_2}\cos\frac{\theta_1}{2}\cos\frac{\theta_2}{2} \\ -e^{i\varphi_1}\cos\frac{\theta_1}{2}\sin\frac{\theta_2}{2} \\ -e^{i\varphi_2}\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2} \\ \sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2} \end{pmatrix} \tag{10}$$

The probability of the state of the game spanned by the classical game basis $|00>$, $|01>$, $|10>$, and $|11>$ are as follows, respectively.

$$\begin{aligned} P_{00} &= \cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} \\ P_{01} &= \cos^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2} \\ P_{10} &= \sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} \\ P_{11} &= \sin^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2} \end{aligned}$$

Thus, the payoff of pharmaceutical enterprises in this case is described as

$$\begin{aligned} E_1 &= (\alpha H - \frac{1}{2}M)P_{00} - \frac{1}{2}MP_{01} \\ &= (\alpha H - \frac{1}{2}M)\cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} - \frac{1}{2}M\cos^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2}. \end{aligned} \tag{11}$$

And for the same reason, scientific research institutions' payoff is

$$\begin{aligned} E_2 &= [(1-\alpha) - \frac{1}{2}M]P_{00} - \frac{1}{2}MP_{10} \\ &= [(1-\alpha) - \frac{1}{2}M]\cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} - \frac{1}{2}M\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}. \end{aligned} \tag{12}$$

Based on the above analysis, we can draw a conclusion that the value of φ_i does not affect the payoff of both players when pharmaceutical enterprises and the scientific research institutions are unentangled. Besides, the payoff of the player who chose "complete synergy" will lost when the other player chose the exact opposite decision. In this situation, there is no difference between the game of them and the classical game. Therefore, in the situation of that pharmaceutical enterprises and the scientific research institutions are not in a state of entanglement, there is still a "prisoner's dilemma". And it is difficult to ensure complete synergy between the two players in this situation.

Situation 2: Pharmaceutical enterprises and scientific research institutions are entangled (i.e. $0 < \lambda \leq \frac{\pi}{2}$) in this situation. For the sake of convenience, the case of maximum entanglement with $\lambda = \frac{\pi}{2}$ is considered in this paper.

In this situation, the final quantum state becomes (13), as shown at the bottom of the next page.

And the probability of the state respectively is

$$\begin{aligned} P_{00} &= \cos^2(\varphi_1+\varphi_2)\cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} \\ P_{01} &= \cos^2\varphi_1\cos^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2} + \sin^2\varphi_2\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} \\ P_{10} &= \cos^2\varphi_2\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} + \sin^2\varphi_1\cos^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2} \\ P_{11} &= \sin^2(\varphi_1+\varphi_2)\cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} + \sin^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2} \end{aligned}$$

Hence, the payoff of pharmaceutical enterprises in this situation is calculated as follows.

$$\begin{aligned} E_1 &= (\alpha H - \frac{1}{2}M)P_{00} - \frac{1}{2}MP_{01} \\ &= (\alpha H - \frac{1}{2}M)\cos^2(\varphi_1+\varphi_2)\cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} \\ &\quad - \frac{1}{2}M(\cos^2\varphi_1\cos^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2} + \sin^2\varphi_2\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}) \end{aligned} \tag{14}$$

And the payoff of scientific research institutions can be written as

$$\begin{aligned} E_2 &= [(1-\alpha) - \frac{1}{2}M]P_{00} - \frac{1}{2}MP_{10} \\ &= [(1-\alpha) - \frac{1}{2}M]\cos^2(\varphi_1+\varphi_2)\cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} \\ &\quad - \frac{1}{2}M(\cos^2\varphi_2\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2} + \sin^2\varphi_1\cos^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2}). \end{aligned} \tag{15}$$

$$|\psi_f>= \begin{pmatrix} (e^{i\varphi_1+i\varphi_2}\cos^2\frac{\lambda}{2} - i^2e^{-i\varphi_1-i\varphi_2}\sin^2\frac{\lambda}{2})\cos\frac{\theta_1}{2}\cos\frac{\theta_2}{2} \\ \left(i^2e^{-i\varphi_2}\sin^2\frac{\lambda}{2} - e^{i\varphi_1}\cos^2\frac{\lambda}{2}\right)\cos\frac{\theta_1}{2}\sin\frac{\theta_2}{2} + (ie^{-i\varphi_2} - ie^{i\varphi_2})\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2}\sin\frac{\lambda}{2}\cos\frac{\lambda}{2} \\ \left(i^2e^{-i\varphi_2}\sin^2\frac{\lambda}{2} - e^{i\varphi_2}\cos^2\frac{\lambda}{2}\right)\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2} + (-ie^{i\varphi_1} + ie^{-i\varphi_2})\cos\frac{\theta_1}{2}\sin\frac{\theta_2}{2}\sin\frac{\lambda}{2}\cos\frac{\lambda}{2} \\ \left(-i^2e^{i\varphi_1+i\varphi_2} + ie^{-i\varphi_1-i\varphi_2}\right)\cos\frac{\theta_1}{2}\cos\frac{\theta_2}{2}\sin\frac{\lambda}{2}\cos\frac{\lambda}{2} + (i^2\sin^2\frac{\lambda}{2} + \cos^2\frac{\lambda}{2})\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2} \end{pmatrix} \tag{9}$$

Case 1: When pharmaceutical enterprises adopt quantum strategy and $\varphi_1 = \frac{\pi}{2}$, its payoff is represented as follows,

$$E_1 = [(\alpha H - \frac{1}{2}M)\cos^2\frac{\theta_1}{2} - \frac{1}{2}M\sin^2\frac{\theta_1}{2}]\sin^2\varphi_2\cos^2\frac{\theta_2}{2}.$$

In this case, as long as condition $\sin^2\varphi_2\cos^2\frac{\theta_2}{2} > 0$ is satisfied, E_1 will decrease as θ_1 increase. In other words, its payoff will increase with the increase of synergy degree. Therefore, the optimal strategy is "complete synergy" for pharmaceutical enterprises. Similarly known, if scientific research institutions adopt quantum strategy, and $\sin^2\varphi_1\cos^2\frac{\theta_1}{2} > 0$, its payoff will increase as θ_1 decrease. And that is, it will increase when synergy degree increases. Samely, the optimal strategy of scientific research institutions also is "complete synergy". It can be seen, if one player adopts quantum strategy and does not choose "complete non-synergy", the payoff will increase as the increase of synergy degree. And in such case, "complete synergy" will be the optimal strategy for the other player.

Case 2: When pharmaceutical enterprises does not adopt quantum strategy (i.e. $\varphi_1 = 0$), its payoff is written as

$$E_1 = [(\alpha H - \frac{1}{2}M)\cos^2\varphi_2\cos^2\frac{\theta_2}{2} - \frac{1}{2}M\sin^2\frac{\theta_2}{2}]\cos^2\frac{\theta_1}{2} - \frac{1}{2}M\sin^2\varphi_2\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}.$$

In this case, if

$$(\alpha H - \frac{1}{2}M)\cos^2\varphi_2\cos^2\frac{\theta_2}{2} - \frac{1}{2}M\sin^2\frac{\theta_2}{2} \geq 0$$

and $\sin^2\varphi_2\cos^2\frac{\theta_2}{2} \geq 0$, and "=" is not established at the same time, E_1 will decrease as θ_1 increase. And we can say that it will increase with the increase of synergy degree. In such condition, the optimal strategy is "complete synergy" for pharmaceutical enterprises. For the same reason, if scientific research institutions does not adopt quantum strategy, and when

$$[(1-\alpha)H - \frac{1}{2}M]\cos^2\varphi_1\cos^2\frac{\theta_1}{2} - \frac{1}{2}M\sin^2\frac{\theta_1}{2} \geq 0$$

and $\sin^2\varphi_1\cos^2\frac{\theta_1}{2} \geq 0$, and "=" is not established simultaneously, its payoff will increase as θ_2 decrease. That is to say, it will increase when synergy degree increases. The optimal strategy of scientific research institutions is "complete synergy" in this case. So, the condition is more complicated to choose "complete synergy" if quantum strategy is not adopted for one player. For example, the premises that pharmaceutical enterprises will choose "complete synergy" are that scientific research institutions adopt quantum strategy, and do not choose "complete non-synergy", and $\cos^2\frac{\theta_2}{2} \geq \frac{1/2M}{(\alpha H - 1/2M)\cos^2\varphi_2 + 1/2M}$.

Case 3: When pharmaceutical enterprises adopt quantum strategy and $0 < \varphi_1 \leq \frac{\pi}{2}$, its payoff is written as

$$E_1 = [(\alpha H - \frac{1}{2}M)\cos^2(\varphi_1 + \varphi_2)\cos^2\frac{\theta_2}{2} - \frac{1}{2}M\cos^2\varphi_1\sin^2\frac{\theta_2}{2}]\cos^2\frac{\theta_1}{2} - \frac{1}{2}M\sin^2\varphi_2\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}.$$

In this case, If

$$(\alpha H - \frac{1}{2}M)\cos^2(\varphi_1 + \varphi_2)\cos^2\frac{\theta_2}{2} - \frac{1}{2}M\cos^2\varphi_1\sin^2\frac{\theta_2}{2} \geq 0$$

and $\sin^2\varphi_2\cos^2\frac{\theta_2}{2} \geq 0$, and meanwhile, "=" is not established, the payoff of pharmaceutical enterprises will increase as θ_1 decrease. That is, its payoff will increase when the degree of synergy is increasing. Hence, it is the optimal strategy for pharmaceutical enterprises to choose "complete synergy" in such case. So similarly, if scientific research institutions also adopt the same strategy, its payoff will increase as θ_2 decrease or with the increase of synergy degree when

$$[(1-\alpha)H - \frac{1}{2}M]\cos^2(\varphi_1 + \varphi_2)\cos^2\frac{\theta_1}{2} - \frac{1}{2}M\cos^2\varphi_2\sin^2\frac{\theta_1}{2} \geq 0$$

and $\sin^2\varphi_1\cos^2\frac{\theta_1}{2} \geq 0$, and "=" is not established at the same time. And the optimal strategy for scientific research institutions also is "complete synergy". As it describes, the condition is also more complicated to choose "complete synergy" if general quantum strategy is adopted for one player. For instance, when scientific research institutions adopt quantum strategy, and does not choose "complete non-synergy", and

$$\cos^2\frac{\theta_2}{2} \geq \frac{1/2M\cos^2(\varphi_1+\varphi_2)}{[(1-\alpha)H - 1/2M]\cos^2(\varphi_1+\varphi_2) + 1/2M\cos^2\varphi_2},$$

the pharmaceutical enterprises will choose "complete synergy".

Through above analysis and discussions, when pharmaceutical enterprises and scientific research institutions are

$$|\psi_f> = \begin{pmatrix} \frac{1}{2}(e^{i\varphi_1+i\varphi_2} - e^{-i\varphi_1-i\varphi_2})\cos\frac{\theta_1}{2}\cos\frac{\theta_2}{2} \\ \frac{1}{2}(i^2e^{-i\varphi_2} - e^{i\varphi_2})\cos\frac{\theta_1}{2}\sin\frac{\theta_2}{2} + \frac{1}{2}(ie^{-i\varphi_2} - e^{i\varphi_2})\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2} \\ \frac{1}{2}(i^2e^{-i\varphi_2} - e^{i\varphi_2})\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2} + \frac{1}{2}(ie^{-i\varphi_2} - e^{i\varphi_1})\cos\frac{\theta_1}{2}\sin\frac{\theta_2}{2} \\ \frac{1}{2}(-ie^{i\varphi_1+i\varphi_2} + ie^{-i\varphi_1-i\varphi_2})\cos\frac{\theta_1}{2}\cos\frac{\theta_2}{2} + \frac{1}{2}(1-i^2)\sin\frac{\theta_1}{2}\sin\frac{\theta_2}{2} \end{pmatrix}. \quad (13)$$

in a state of entanglement, the prisoner's dilemma can be eliminated. As long as one of the players does not choose "complete non-synergy" and the synergy level satisfied some conditions, it is easier to achieve that its payoff will increase as the synergy level increases for the other player. Furthermore, when the entanglement degree is maximal, it is easier to achieve this state when a complete quantum strategy is adopted for one player, and only provided that the other player does not choose "complete non-synergy".

IV. CONCLUSIONS AND SUGGESTIONS

Based on the quantum game model, this paper analyzes the influence of strengthening the correlation degree (i.e. entanglement degree), between pharmaceutical enterprises and scientific research institutions on synergetic innovation. And we draw the following conclusions:

(1) The quantum game can solve the problem of "prisoner's dilemma" existing in the game between pharmaceutical enterprises and scientific research institutions. In addition, it improves the dual-strategy game of "complete synergy" and "complete non-synergy" in the classical game. And the strategies of both players in the game are continuous variables, which is more reasonable.

(2) It is easier for both players to adopt the quantum strategy to achieve that their payoff increase with the increase of the synergy degree.

(3) When pharmaceutical enterprises and scientific research institutions are not in a state of entanglement, the payoff of both players of the game has nothing to do with the use of quantum game. That is to say, the quantum game has no difference with classical game in this case.

(4) When pharmaceutical enterprises and scientific research institutions are in a state of entanglement, it is easier for the two players to choose complete synergy. Besides, when the entanglement degree is maximal, it is easier to achieve that their payoff increase with the increase of the synergy degree by means of complete quantum game.

Therefore, it has a positive incentive to synergetic innovation to strengthen the correlation degree between pharmaceutical enterprises and scientific research institutions. In order to promote the synergetic innovation of pharmaceutical enterprises and scientific research institutions in China, this paper proposes the following suggestions for reference:

(1) Sign an agreement to link the interests of both parties. In order to make the pharmaceutical enterprises and scientific research institutions form a state of entanglement, it is particularly important to sign an agreement. And in this way, they can form an interest community and their interests can be combined.

(2) Strengthen communication to lower information asymmetry effectively. In order to ensure that pharmaceutical enterprises and scientific research institutions can maintain the synergetic innovation relation, both of them should strengthen communication. In this way, they can effectively avoid moral hazard caused by information asymmetry. And they can synergize on the basis of full trust.

(3) Quantify performance indicators and develop appraisal mechanisms. In order to enable the two parties to synergize efficiently, the performance appraisal indicators should be quantified. By this means, both of parties can objectively evaluate the other party's synergy level so as to make a reasonable decision.

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