Volume 7, Issue 10, pp. 31-43, 2023.
International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

Research on the Collaborative Regulation Mechanism of Big Data-Enabled Price Discrimination against Existing Customers in the Quantum Entanglement State

Haiyan Wang[1], Na Zhang[1], Shiyi Huang[1]
[1]Business School, Nanjing University of Information Science and Technology, Nanjing, China, 210044

Abstract—*The quantum cognition and decision method can solve the sequential effect and interference effect caused by the state superposition of a large amount of uncertain cognitive information in the process of coregulation of big data "killing" behavior, and develop a reasonable strategy. The game model is constructed from the perspective of the co-regulation of the government and the e-commerce platform, and the final strategy choice is based on the co-regulation strategy of both bodies. The quantum entanglement theory is used to explain the perfect regulation and perfect non-regulation modes in the strategy choice in the quantum entanglement state. The results show that the inherent mechanism of co-regulation has quantum properties based on the government and the e-commerce platform; the regulation effect is better after considering the quantum entanglement state, which can solve the free rider problem in the process of co-regulation to a certain extent; The entanglement contract can ensure that the benefits of both bodies are related to their own efforts to achieve the optimal incentive effect.*

Keywords— *Big data "killing"; collaborative regulation; quantum game; quantum entanglement; entanglement contract.*

I. Introduction

The Internet has promoted the rapid development of digital economy, especially in the field of e-commerce. In recent years, e-commerce has been boosting China's consumer demand, upgrading traditional industries and modern service industries, but various problems emerged in the process. Due to the low transaction cost and virtualization of online transactions and the information asymmetric between sellers and consumers, fake transactions and big data-enabled price discrimination against existing customers emerged [1]. Among them, big data-enabled price discrimination against existing customers has become a key problem that needs to be solved due to its unique characteristics of intelligence, systematization and concealment, which has restricted the healthy and sustainable development of e-commerce. Therefore, how to effectively restrain the phenomenon become a concern for the government, academia and the industry.

In fact, e-commerce platforms have the responsibility to supervise and manage sellers. However, as the stakeholder of platform sellers, it is impossible for platforms to effectively supervise platform sellers and may even cover up opportunistic behaviors of these sellers [2-4]. Therefore, it is far from enough to rely only on the regulation of platforms to create a fair and healthy online market environment. In fact, in addition to the platforms' role of supervisors, the government also introduces corresponding laws and regulations to prohibit such speculative behavior. For example, the E-commerce Law of the People's Republic of China brings such phenomenon that infringe the interests of consumers into legal regulation to further protect the legitimate rights and interests of consumers. Bebodies, the government will also Curb the connivance of the platforms to platform sellers. As can be seen, the government also plays a huge role in creating a fair and healthy environment for online transactions. However, due to asymmetric information of the government and high costs, government regulation is often difficult to achieve the desired effect. Therefore, it is of vital importance to strengthen the interaction between the government and e-commerce platforms, and to build a reasonable and effective cooperative regulatory and governance mechanism for the big data-enabled price discrimination of platform sellers. This will promote the standardization and legalization of platform operations and create a good environment for the development of e-commerce, thus promoting the high-quality development of e-commerce and building an open economy.

Currently, there are many academic studies on the regulation of big data-enabled price discrimination behavior. Firstly, from the perspective of regulatory body. Wang [5] further analyzed the inherent formation mechanism of the "regulation dilemma" of seller credit through simulation modeling. The game model includes the e-commerce platform, platform seller and government. Considering the complaint behavior of consumers, Wang [6] constructed a four-party evolutionary game model, involving the government, e-commerce platforms, platform sellers and consumers to analyze the decision-makings of participants for the e-commerce ecosystem. Xing [7] conducted a research on the evolutionary stability strategy of both e-commerce company and government by constructing an evolutionary game model. Zhou [8] constructed the asymmetry evolutionary game model between "government-platform-enterprise" and analyzed the influence of government subsidy intensity and platform cost sharing ratio on the system evolution and stability strategy in the numerical simulation part. Lei [9] developed an evolutionary game model under the mechanism of

International Journal of Scientific Engineering and Science
Volume 7, Issue 10, pp. 31-43, 2023. ISSN (Online): 2456-7361

collaborative regulation of the governments and consumers and designed a regulatory mechanism of big data killing behavior. Wu [10] revealed the decision-making mechanism of each party through analyzing the game evolution process and stability strategy of e-commerce platform and government by income prospect sensing matrix which is from the pay account and gain account. Secondly, from the perspective of regulatory difficulties and governance paths, Jiang [11] argued that we should focus on promoting compliance regulation, specific platform regulation, technical regulation, balanced regulation, value-oriented regulation and agile regulation, in order to maintain a well-organized market operation, balance various stakeholders' interests and maximize social benefits. Qian [12] believed that platform regulation should be combined with the three-dimensional framework of platform attribute, platform network externality and platform life cycle to form a new logical framework of platform regulation. Qu [13] argued that multi-sectoral collaborative regulation should be strengthened to strictly limit the disorderly expansion of large e-commerce platforms.

From the above review, it can be seen that the existing studies seldom take the government and the e-commerce platform as the main research objects, and examine the collaborative regulation mechanism for the phenomenon big data-enabled price discrimination. Most of studies treat them as independent bodies and study their optimal strategy choices in governance separately. In fact, there is a large amount of uncertain cognitive information superimposed in the process of collaborative regulation, and quantum cognition and decision-making methods can solve the sequential and interference effects caused by this problem, so that reasonable strategies can be developed. Quantum game is the intersection of quantum mechanics and game theory. In 1999, Eisert [14] and Meyer [15] published a paper on "coin-flipping" quantum game and "prisoner's dilemma" quantum game in Physical Review Letters, which marked the beginning of quantum game theory based on quantum mechanics. Quantum game theory is widely used in many fields such as economics, informatics, physics, and electrical engineering [16-20]. Through research, it is found that the application of quantum in game theory is superior to classical games in two main aspects: first, quantum game extends the set of strategies of classical games, making it easier for players to seek strategies; second, the introduction of quantum entangled states corrects hypothesis of rational man to a certain extent, and entangled states are an indicator of the degree of correlation between players [21-25]. Therefore, quantum game theory can solve problems that cannot be solved by classical game theory, such as quantum prisoner's dilemma [26-27] and quantum oligopoly game [28-29]. In fact, there is a moral hazard in the process of cooperative regulation of big data killing because the degree of regulation of platform sellers by the government and platforms is a continuous variable, which is similar to the quantum superposition state in quantum mechanics. Therefore, it is reasonable to use quantum evolutionary game to study the collaborative regulation mechanism of big data-enabled price discrimination against existing customers in quantum entanglement state.

In summary, the present study will therefore focus on three aspects. Firstly, construct a game model of big data-enabled price discrimination against existing customers from the perspective of between the government and e-commerce platforms and take the collaborative regulation strategy of both bodies as the final strategy choice. And use quantum entanglement theory to investigate the existence of complete regulation and complete non-regulation in the strategy choice of both bodies. Secondly, to construct a quantum game model of continuous strategy set to clarify the inner mechanism of cooperative regulation of big data "killing" behavior of platform sellers, and to compare whether to consider the regulatory effect of quantum entanglement state, which can solve the problem of "free-riding" in the process of cooperative regulation. Lastly, design an entanglement contract of collaborative regulation between the government and the e-commerce platforms, which can make up for the shortcomings of the traditional co-regulation contract. Thus, strengthening association of the two bodies in order to achieve the optimal effect.

II. Game Model Construction

A. Model Assumptions

Assuming that the basic economic benefit of the government is m_1, and the basic output of the e-commerce platform is m_2, and $m_1 > m_2$. When the government tightens regulation, it will increase the financial investment and enhance regulation capacity, etc. Assume the input degree in the regulation process be e_1, and the higher the input degree means the stronger the regulation. Correspondingly, the more the government invests, the more it costs. Therefore, assume that the cost of the government in the regulatory process is a function of the degree of its input. That is $C_1 = 0.5\gamma_1 e_1^2$, in which γ_1 is the cost coefficient of government regulation. When the government tightens regulation, it can often establish a good image, win the trust of the public and improve social reputation, which can bring social benefits E_1. Similarly, assuming that the degree of input of e-commerce platform regulation is e_2, the cost C_2 is C_2, in which γ_2 is the cost coefficient. If the platform actively fulfills their responsibilities and cooperates with the government, the resulting social reputation is E_2. If the government and the platform cooperate with each other and actively carry out collaborative regulation, there will be additional synergy benefits Ae_1e_2, where A is the coefficient of synergy benefits. The government and the platform will carry out profit distribution. Set β as the government benefit distribution coefficient ($0 < \beta < 1$), then the platform benefit distribution coefficient is $1-\beta$. In addition, the government, as the main regulatory body, needs to implement certain rewards and punishments for the behavior of the platform, and set d as the reward and punishment coefficient. $d \ge 0$ indicates that the government implements the reward policy for the platform and $d<0$ indicates the punishment policy for the platform. In the quantum entanglement state, θ_1 and θ_2 are the degree of government and platform regulation respectively. $\theta_i=0$ indicates the polarization state is "perfect regulation" and $\theta_i=1$ indicates the polarization state is "no regulation at all". According to the correlation between the polarized quantum state $|0\rangle$ and $|1\rangle$ in quantum information theory, the correlation correspondence between θ_i and e_i is:

$$\theta_i = 1-e_i, i=1,2 \qquad (1)$$

In summary, the payoff matrix of the government and the platform in the quantum entanglement state can be derived as shown in TABLE I:

TABLE I. The payoff matrix of the government and e-commerce platform.

	Ecommerce platforms make all efforts $\|0\rangle$	**Ecommerce platforms make no effort $\|1\rangle$**
Government's perfect regulation $\|0\rangle$	$(\beta-d)(m_1+E_1)+\beta A+d(m_2+E_2)-0.5\gamma_1$; $(1-\beta-d)(m_2+E_2)+(1-\beta)A+d(m_1+E_1)-0.5\gamma_2$;	$(\beta-d)(m_1+E_1)+d(m_2+E_2)-0.5\gamma_1$; $(1-\beta-d)(m_2+E_2)+d(m_1+E_1)$
No government regulation $\|1\rangle$	$(\beta-d)(m_1+E_1)+d(m_2+E_2)$ $(1-\beta-d)(m_2+E_2)+d(m_1+E_1)-0.5\gamma_2$	$(\beta-d)(m_1+E_1)+d(m_2+E_2)$; $(1-\beta-d)(m_2+E_2)+d(m_1+E_1)$

Under the quantum entanglement state, the initial state is $|00\rangle$ (The first 0 represents "no government regulation" and the second represents "government's perfect regulation". $|00\rangle=|0\rangle\otimes|0\rangle$ and $\otimes$ is tensor product). Entanglement matrix is:

$$J=\exp\left\{i\frac{\omega}{2}\sigma_x\otimes\sigma_x\right\}=\cos\frac{\omega}{2}\cdot I+i\sin\frac{\omega}{2}\cdot\begin{pmatrix}0&0&0&1\\0&0&-1&0\\0&-1&0&0\\1&0&0&0\end{pmatrix}=\begin{pmatrix}\cos\frac{r}{2}&0&0&i\sin\frac{r}{2}\\0&\cos\frac{r}{2}&-i\sin\frac{r}{2}&0\\0&-i\sin\frac{r}{2}&\cos\frac{r}{2}&0\\i\sin\frac{r}{2}&0&0&\cos\frac{r}{2}\end{pmatrix} \qquad (2)$$

where σ_x is $\begin{pmatrix}0&1\\-1&0\end{pmatrix}$, the deformation of Pauli-x matrix, I is the identity matrix, and ω is the entanglement degree(when $\omega=\frac{\pi}{2}$, the entanglement degree is at its highest). The inverse entanglement matrix is:

$$J^{\dagger}=\cos\frac{r}{2}\cdot I-i\sin\frac{r}{2}\cdot\begin{pmatrix}0&0&0&1\\0&0&-1&0\\0&-1&0&0\\1&0&0&0\end{pmatrix} \qquad (3)$$

Assume that the government's strategy matrix in the quantum entanglement state is:

$$U_1(\theta_1,\varphi_1)=\begin{pmatrix}e^{i\varphi_1}\cos\frac{\theta_1}{2}&\sin\frac{\theta_1}{2}\\-\sin\frac{\theta_1}{2}&e^{-i\varphi_1}\cos\frac{\theta_1}{2}\end{pmatrix} \qquad (4)$$

Assume that the e-commerce platform's strategy matrix in the quantum entanglement state is:

$$U_2(\theta_2,\varphi_2)=\begin{pmatrix}e^{i\varphi_2}\cos\frac{\theta_2}{2}&\sin\frac{\theta_2}{2}\\-\sin\frac{\theta_2}{2}&e^{-i\varphi_2}\cos\frac{\theta_2}{2}\end{pmatrix} \qquad (5)$$

θ_1, $\theta_2\in[0,\ \pi]$, φ_1, $\varphi_2\in\left[0,\frac{\pi}{2}\right]$. $U_1(0,0)=\begin{pmatrix}1&0\\0&1\end{pmatrix}$ and $U_1(\pi,0)=\begin{pmatrix}0&1\\-1&0\end{pmatrix}$ are the government's strategy of "perfect regulation" and "no regulation" respectively. Therefore, θ_1 can be regarded as a parameter of the degree of government regulation. $U_2(\theta_2,\varphi_2)$ does the same.

Under the quantum entanglement state:

$$\begin{aligned}|\varphi_f\rangle&=J^{\dagger}\left[U_1(\theta_1,\varphi_1)\otimes U_2(\theta_2,\varphi_2)\right]\cdot J|00\rangle\\&=\left[\cos(\varphi_1+\varphi_2)-i\cdot\cos\omega\cdot\sin(\varphi_1+\varphi_2)\right]\cos\frac{\theta_1}{2}\cos\frac{\theta_2}{2}|00\rangle+\\&\left[\cos\varphi_1-i\cdot\sin\varphi_1\cdot\cos\omega\right]\cos\frac{\theta_1}{2}\sin\frac{\theta_2}{2}|01\rangle+\left[\sin\omega\cdot\sin\varphi_2\right]\cdot\\&\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2}|01\rangle+\left[\cos\varphi_2-i\cdot\sin\varphi_2\cdot\cos\omega\right]\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2}|10\rangle\\&+\left[\sin\omega\cdot\sin\varphi_1\right]\cos\frac{\theta_1}{2}\sin\frac{\theta_2}{2}|10\rangle+\left[\sin\omega\cdot\sin(\varphi_1+\varphi_2)\right]\cdot\\&\cos\frac{\theta_1}{2}\cos\frac{\theta_2}{2}|11\rangle+\sin\frac{\theta_1}{2}\sin\frac{\theta_2}{2}|11\rangle\end{aligned} \qquad (6)$$

Therefore, the probability of each quantum state is:

$$\begin{cases}P_{00}=\left[\cos^2(\varphi_1+\varphi_2)+\sin^2(\varphi_1+\varphi_2)\cdot\cos^2\omega\right]\cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}\\P_{01}=\left[\cos^2\varphi_1+\sin^2\varphi_1\cdot\cos^2\omega\right]\cos^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2}+\left[\sin^2\varphi_2\cdot\sin^2\omega\right]\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}\\P_{10}=\left[\cos^2\varphi_2+\sin^2\varphi_2\cdot\cos^2\omega\right]\sin^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}+\left[\sin^2\varphi_1\cdot\sin^2\omega\right]\cos^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2}\\P_{11}=\left[\sin^2\omega\cdot\sin^2(\varphi_1+\varphi_2)\right]\cos^2\frac{\theta_1}{2}\cos^2\frac{\theta_2}{2}+\sin^2\frac{\theta_1}{2}\sin^2\frac{\theta_2}{2}\end{cases}$$

Let $R_1=(\beta-d)(m_1+E_1)+d(m_2+E_2)$ and $R_2=(1-\beta-d)(m_2+E_2)+d(m_1+E_1)$. The expected revenue for the government in the quantum entanglement state is:

$$ER_1=\left(R_1+\beta A-0.5\gamma_1\right)\cdot P_{00}+\left(R_1-0.5\gamma_1\right)\cdot P_{01}+R_1\cdot P_{10}+R_1\cdot P_{11} \qquad (8)$$

The expected revenue for the e-commerce platform in the quantum entanglement state is:

$$ER_2 = \left[R_2 + (1-\beta)A - 0.5\gamma_2\right]\cdot P_{00} + R_2\cdot P_{01} + \left[R_2 - 0.5\gamma_2\right]\cdot P_{10} + R_2\cdot P_{11} \quad (9)$$

θ_1, θ_2, φ_1 and φ_2 are the parameters of strategies selection. In the quantum entanglement state, the strategy selection of both bodies is actually more influenced by ω (the degree of entanglement). Therefore, in this paper, the game strategy of co-regulation of big data "killing" will be studied and discussed in two cases: whether to consider the entanglement state or not.

B. Collaborative Regulation of Big Data "Killing" in Quantum-Free Entanglement State

The collaborative regulation of big data "kill" of the government and e-commerce platform in quantum-free entanglement state is actually for the case that $\omega = 0$. $J = J^\dagger = I$. Thus:

$$\begin{aligned}\left|\varphi_f\right\rangle &= J^\dagger\cdot\left[(U_1(\theta_1,\varphi_1)\otimes U_2(\theta_2,\varphi_2)\right]\cdot J\left|00\right\rangle \\ &= e^{i(\varphi_1+\varphi_2)}\cos\frac{\theta_1}{2}\cos\frac{\theta_2}{2}\left|00\right\rangle - e^{i\varphi_1}\cos\frac{\theta_1}{2}\sin\frac{\theta_2}{2}\left|01\right\rangle \quad (10) \\ &- e^{i\varphi_2}\sin\frac{\theta_1}{2}\cos\frac{\theta_2}{2}\left|10\right\rangle + \sin\frac{\theta_1}{2}\sin\frac{\theta_2}{2}\left|11\right\rangle\end{aligned}$$

The expected revenue of the government is: $ER_1 = R_1 + (\beta A\cos^2\frac{\theta_2}{2} - 0.5\gamma_1)\cdot\cos^2\frac{\theta_1}{2}$; The expected revenue of the e-commerce platform is: $ER_2 = R_2 + \left[(1-\beta)A\cdot\cos^2\frac{\theta_1}{2} - 0.5\gamma_2\right]\cdot\cos^2\frac{\theta_2}{2}$.

Theorem 1: Assume that the initial state of the two-state quantum system composed of the government and the e-commerce platform is $\left|00\right\rangle$. When $\beta A\cos^2\frac{\theta_2}{2} - 0.5\gamma_1 < 0$ and $(1-\beta)A\cdot\cos^2\frac{\theta_1}{2} - 0.5\gamma_2 < 0$, there is a unique Nash equilibrium of the game system. The optimal strategy is $\theta_1 = \theta_2 = \pi$, i.e. "no regulation and no regulation". At this point, the expected revenue of the government and the e-commerce platform in direct proportion to its own degree of regulation.

Proof: Take the expected revenue of the government in the quantum-free entanglement state as an example, as θ_1 and θ_2 varies, the change in the government's expected revenue is: $ER_1 = R_1 + (\beta A\cos^2\frac{\theta_2}{2} - 0.5\gamma_1)\cdot\cos^2\frac{\theta_1}{2}$. When $\beta A\cos^2\frac{\theta_2}{2} - 0.5\gamma_1 > 0$, $ER_1 > 0$. At this point, ER_1 is a decreasing function of θ_1, which means that the greater the degree of government regulation, the greater the government's expected revenue. When $\beta A\cos^2\frac{\theta_2}{2} - 0.5\gamma_1 < 0$, the result will be the opposite(as shown in Figure 1-3). The expected revenue for the e-commerce platform in the quantum-free entanglement state can be obtained in the same way, without further elaboration.

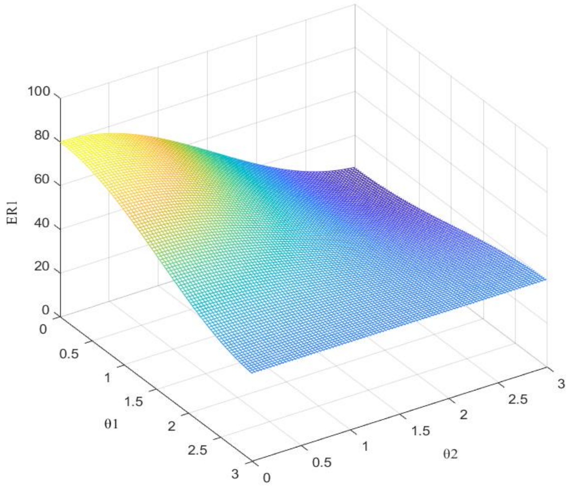

Fig. 1. Variation of expected government benefits with θ_1 and θ_2 for the quantum-free entanglement state

Assume $R_1 = 40$, $\beta = 0.6$, $A = 90$, $\gamma_1 = 30$. As can be seen from Fig. 1., θ_2 tends to 0 or π will directly affect the trend in the government's expected revenue. When θ_2 tends to 0, the government's expected revenue is a decreasing function of θ_1 and there is a clear trend. When θ_2 tends to π, the government's expected revenue is an increasing function of θ_1 but there is an insignificant trend. To get a more intuitive view of the relationship between the government's expected revenue and θ_1, set $\theta_2 = \frac{\pi}{4}$ and $\theta_2 = \frac{3\pi}{4}$. Fig. 2. and Fig. 3. can be obtained.

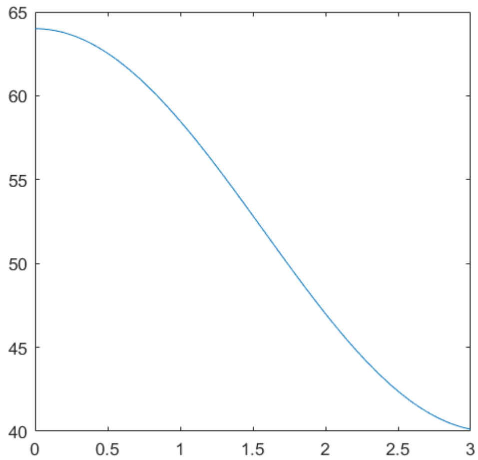

Fig. 2. The variation of the expected revenue of the government for θ_1 with $\theta_2 = \frac{\pi}{4}$ in the quantum-free entanglement state

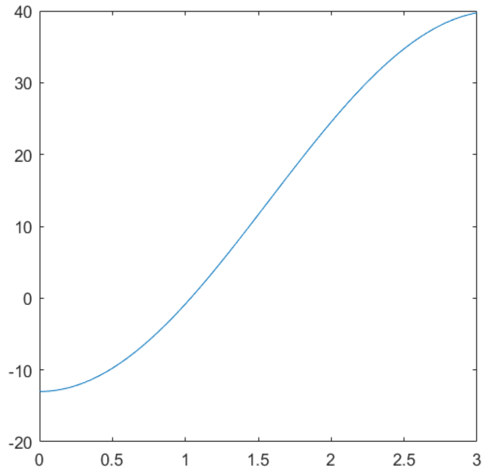

Fig. 3. The variation of the expected revenue of the government for θ_1 with $\theta_2=\frac{3\pi}{4}$ in the quantum-free entanglement state

As seen in Fig. 2. and Fig. 3., when $\theta_2=\frac{\pi}{4}$, $\beta A\cos^2\frac{\theta_2}{2}-0.5\gamma_1>0$, so $ER_1>0$ and ER_1 is a decreasing function of θ_1; when $\theta_2=\frac{3\pi}{4}$, $\beta A\cos^2\frac{\theta_2}{2}-0.5\gamma_1<0$, so $ER_1<0$ and ER_1 is an increasing function of θ_1.

From the quantum theory, θ_1 and θ_2 are equal to 0 or π, which is a special case. The payoff matrix for both regulatory bodies at this point is shown in TABLE II.

In the entanglement-free state, the gains of both regulatory bodies are not affected by φ_1 or φ_2, but only by θ_1 and θ_2, showing "wave function collapse" and at that time the quantum superposition state instantly becomes the eigenstate. In the eigenstate, when the government completely regulates and the e-commerce platform does not, the presence or absence of the entanglement state does not affect the government's expected revenue. At the same time, in the unentangled state, the cooperation strategy between the two bodies still does not get rid of the "prisoner's dilemma" problem, which is a problem that must be solved in the current study.

TABLE II. Special cases of revenue for both bodies of regulation in the entanglement-free state

	$\theta_2=0,\varphi_2=0$	$\theta_2=0,\varphi_2=\frac{\pi}{2}$	$\theta_2=\pi,\varphi_2=0$	$\theta_2=\pi,\varphi_2=\frac{\pi}{2}$
$\theta_1=0,\varphi_1=0$	$R_1+\beta A-0.5\gamma_1$; $R_2+(1-\beta)A-0.5\gamma_2$	$R_1+\beta A-0.5\gamma_1$; $R_2+(1-\beta)A-0.5\gamma_2$	$R_1-0.5\gamma_1$; R_2	$R_1-0.5\gamma_1$; R_2
$\theta_1=0,\varphi_1=\frac{\pi}{2}$	$R_1+\beta A-0.5\gamma_1$; $R_2+(1-\beta)A-0.5\gamma_2$	$R_1+\beta A-0.5\gamma_1$; $R_2+(1-\beta)A-0.5\gamma_2$	$R_1-0.5\gamma_1$; R_2	$R_1-0.5\gamma_1$; R_2
$\theta_1=\pi,\varphi_1=0$	R_1 ; $R_2-0.5\gamma_2$	R_1 ; $R_2-0.5\gamma_2$	R_1 ; R_2	R_1 ; R_2
$\theta_1=\pi,\varphi_1=\frac{\pi}{2}$	R_1 ; $R_2-0.5\gamma_2$	R_1 ; $R_2-0.5\gamma_2$	R_1 ; R_2	R_1 ; R_2

C. Collaborative Regulation of Big Data "Killing" in Quantum Entanglement State

The collaborative regulation of big data "kill" of the government and e-commerce platform in quantum entanglement state is actually for the case that $0<\omega\le\frac{\pi}{2}$. In order to investigate more clearly the nature of the strategy of both bodies of the regulation, Take $\omega=\frac{\pi}{2}$ as an example for analysis.

Theorem 2: Considering the quantum entangled state ($\omega=\frac{\pi}{2}$), if the government or e-commerce platform adopts a perfect quantum strategy ($\varphi_1=\frac{\pi}{2}$ or $\varphi_2=\frac{\pi}{2}$), the ratio of sufficient and necessary conditions for ER_1 and ER_2 to increase with the enhancement of their own regulatory degrees e_1 and e_2 is: $\sin^2\varphi_2\cdot\cos^2\frac{\theta_2}{2}>0$, $\sin^2\varphi_1\cdot\cos^2\frac{\theta_1}{2}>0$. At this point, the optimal strategy for both regulatory bodies are: $\theta_1=\theta_2=0$, i.e., "perfect regulation and perfect regulation".

Proof: As an example, the expected revenue of the government in the quantum entanglement state with a perfect quantum strategy ($\omega=\frac{\pi}{2}$, $\varphi_1=\frac{\pi}{2}$) varies with θ_1 and θ_2 is: $ER_1=R_1+(\beta A\cos^2\frac{\theta_1}{2}-0.5\gamma_1)\cdot\sin^2\varphi_2\cos^2\frac{\theta_2}{2}$. Since $\beta A\cos^2\frac{\theta_1}{2}$ is a decreasing function of θ_1, it is only when $\sin^2\varphi_2\cos^2\frac{\theta_2}{2}>0$ that the government's expected revenue is a decreasing function of θ_1. The greater the degree of e_1 (government regulation), the greater the government's expected revenue. The expected revenue of the e-commerce platform is: $ER_2=R_2+\left[(1-\beta)A\cos^2\frac{\theta_2}{2}-0.5\gamma_2\right]\cdot\sin^2\varphi_1\cos^2\frac{\theta_1}{2}$. Since $(1-\beta)A\cos^2\frac{\theta_2}{2}$ is a decreasing function of θ_2, it is

International Journal of Scientific Engineering and Science
Volume 7, Issue 10, pp. 31-43, 2023. ISSN (Online): 2456-7361

only when $\sin^2\varphi_1 \cdot \cos^2\frac{\theta_1}{2} > 0$ that ER_2 is a decreasing function of θ_2. The greater the degree of e_2, the greater the government's expected revenue.

From Theorem 2, it can be seen that for both bodies of the game, when one side adopts quantum strategy, as long as the other side also adopts quantum strategy, i.e., $0 < \varphi_i \le \frac{\pi}{2}(i=1,2)$, and there is no complete lack of effort $\theta_i \ne \pi(i=1,2)$, then their expected revenue is an increasing function of the degree of regulation, and this idealized state is a very good incentive for both bodies (as shown in Fig.4 to 6). In fact, as long as the regulatory bodies agree on the "entanglement contract" before the collaborative regulation, it can increase the bonding degree of the regulatory bodies and ensure that the benefits of both bodies are related to their own efforts to achieve the optimal incentive effect.

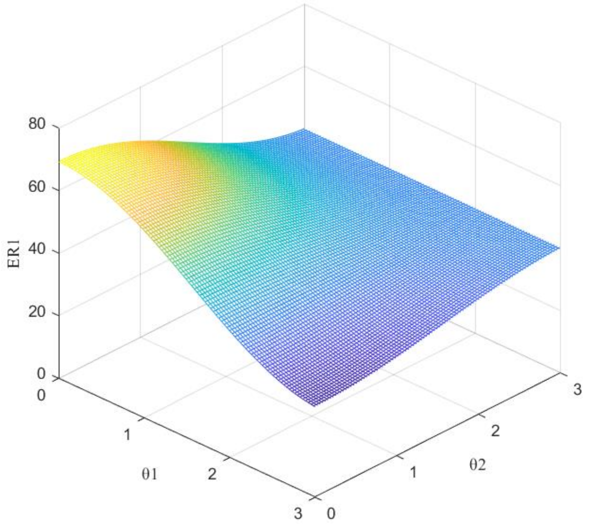

Fig. 4. Variation of expected government revenue with θ_1 and θ_2 in the quantum entanglement state

From Fig. 4., it can be seen that θ_2 tends to 0 or π directly affects the trend of the government's expected revenue; when θ_2 tends to 0, the government's expected revenue is a decreasing function of θ_1, and the trend is obvious. When θ_2 tends to π, the functional relationship between the government's expected revenue and θ_1 is not obvious. To get a more intuitive view of the relationship between the government's expected revenue and θ_1, set $\theta_2 = \frac{\pi}{4}$ and $\theta_2 = \frac{3\pi}{4}$ then Figure 5 and Figure 6 can be obtained. In fact, because $\sin^2\varphi_2 \cos^2\frac{\theta_2}{2} > 0$ is constant, it is guaranteed that the government expected revenue is a decreasing function of θ_1 when $\theta_2 = \frac{\pi}{4}$ and $\theta_2 = \frac{3\pi}{4}$ Therefore, the greater the government regulation, the greater the government revenue, in accordance with Theorem 2.

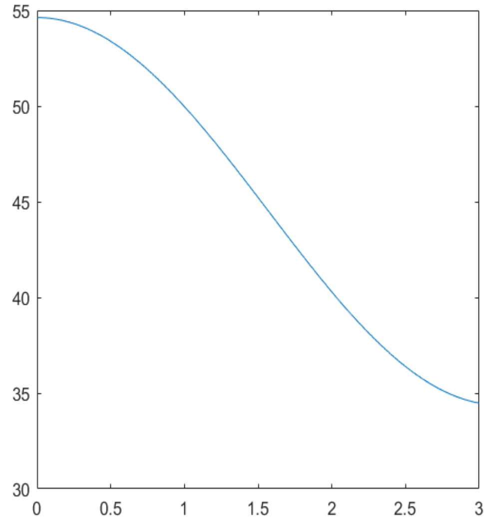

Fig. 5. Variation of expected government revenue with θ_1 when $\theta_2 = \frac{\pi}{4}$ in the quantum entanglement state

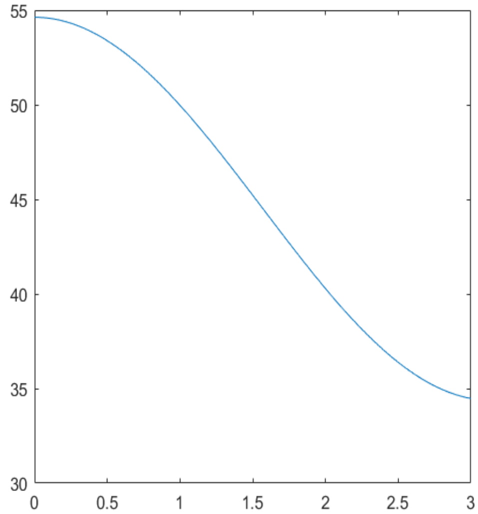

Fig. 6. Variation of expected government revenue with θ_1 when $\theta_2 = \frac{3\pi}{4}$ in the quantum entanglement state

Theorem 3: Considering the quantum entangled state ($\omega = \frac{\pi}{2}$), if the government or the e-commerce platform adopts a non-quantum strategy ($\varphi_1 = 0$ or $\varphi_2 = 0$), the ratio of sufficient and necessary conditions for ER_1 and ER_2 to increase with the enhancement of their own regulatory degrees e_1 and e_2 is: $(\beta A - 0.5\gamma_1)\cdot\cos^2\varphi_2 \cdot \cos^2\frac{\theta_2}{2} - 0.5\gamma_1 \cdot \sin^2\frac{\theta_2}{2} \ge 0$ and $\sin^2\varphi_2 \cdot \cos^2\frac{\theta_2}{2} \ge 0$ are true at the same time and do not take the equal sign at the same time;

International Journal of Scientific Engineering and Science
Volume 7, Issue 10, pp. 31-43, 2023. ISSN (Online): 2456-7361

$\left[(1-\beta)A-0.5\gamma_2\right]\cdot\cos^2\varphi_1\cdot\cos^2\frac{\theta_1}{2}-0.5\gamma_2\cdot\sin^2\frac{\theta_1}{2}\geq 0$ and $\sin^2\varphi_1\cdot\cos^2\frac{\theta_1}{2}\geq 0$ old simultaneously and do not take the equal sign at the same time. At this point, the optimal strategy for both regulatory bodies are: $\theta_1=\theta_2=0$, i.e., "perfect regulation and perfect regulation".

Proof: As an example, the expected revenue of the government in the quantum entanglement state with a non-quantum strategy ($\omega=\frac{\pi}{2}$, $\varphi_1=0$) varies with θ_1 and θ_2 is:

$$ER_1=R_1+\left[(\beta A-0.5\gamma_1)\cdot\cos^2\varphi_2\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\sin^2\frac{\theta_2}{2}\right]\cdot\cos^2\frac{\theta_1}{2}-0.5\gamma_1\cdot\sin^2\varphi_2\cos^2\frac{\theta_2}{2}\sin^2\frac{\theta_1}{2}$$

. In fact, the second term on the right side of the equation is a decreasing function of θ_1 when $(\beta A-0.5\gamma_1)\cdot\cos^2\varphi_2\cdot\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\sin^2\frac{\theta_2}{2}\geq 0$, i.e., it increases with the enhancement of its own regulatory degree (e_1). When $\sin^2\varphi_2\cdot\cos^2\frac{\theta_2}{2}\geq 0$, the third term on the right side of the equation is a decreasing function of θ_1. Thus, only when $(\beta A-0.5\gamma_1)\cdot\cos^2\varphi_2\cdot\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\sin^2\frac{\theta_2}{2}\geq 0$ and $\sin^2\varphi_2\cdot\cos^2\frac{\theta_2}{2}\geq 0$ are true at the same time but do not take equal signs at the same time, can we ensure that the government revenue increases with the increase in its own degree of regulation e_1. This is similar for the e-commerce platform and will not be repeated.

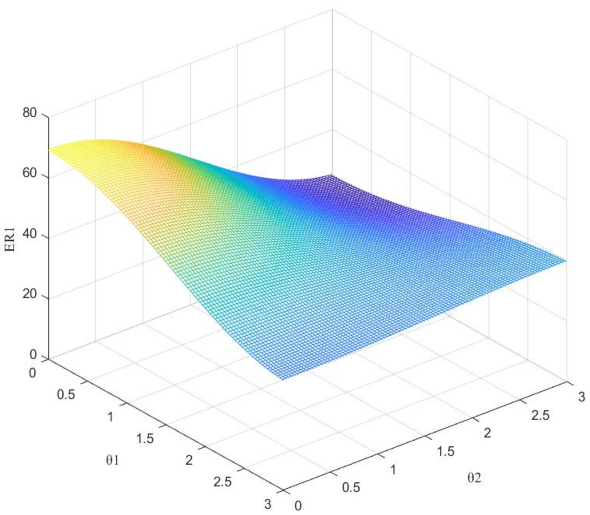

Fig. 7. Variation of government expected revenue with θ_1 and θ_2 when non-quantum strategy in the quantum entanglement state

Theorem 4: Considering the quantum entangled state ($\omega=\frac{\pi}{2}$), if the government or the e-commerce platform adopts a general quantum strategy ($0<\varphi_1\leq\frac{\pi}{2}$ or $0<\varphi_2\leq\frac{\pi}{2}$), the sufficient and necessary conditions for ER_1 and ER_2 to increase with the enhancement of their own regulatory degrees e_1 and e_2 is: $(\beta A-0.5\gamma_1)\cdot\cos^2(\varphi_1+\varphi_2)\cdot\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\cos^2\varphi_1\sin^2\frac{\theta_2}{2}\geq 0$ and $\sin^2\varphi_2\cdot\cos^2\frac{\theta_2}{2}\geq 0$ are true at the same time and do not take the equal sign at the same time; $\left[(1-\beta)A-0.5\gamma_2\right]\cdot\cos^2(\varphi_1+\varphi_2)\cdot\cos^2\frac{\theta_1}{2}-0.5\gamma_2\cdot\cos^2\varphi_2\sin^2\frac{\theta_1}{2}\geq 0$ and $\sin^2\varphi_1\cdot\cos^2\frac{\theta_1}{2}\geq 0$ are true at the same time and do not take the equal sign at the same time. At this point, the optimal strategy for both of them is $\theta_1=\theta_2=0$, i.e. "perfect regulation and perfect regulation" .

Proof: Taking the government as an example, when the government adopts a non-quantum strategy the revenue is:

$$ER_1=R_1+\left[(\beta A-0.5\gamma_1)\cdot\cos^2(\varphi_1+\varphi_2)\cdot\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\cos^2\varphi_1\sin^2\frac{\theta_2}{2}\right]\cdot\cos^2\frac{\theta_1}{2}-0.5\gamma_1\cdot\sin^2\varphi_2\cos^2\frac{\theta_2}{2}\sin^2\frac{\theta_1}{2}$$

. When $(\beta A-0.5\gamma_1)\cdot\cos^2(\varphi_1+\varphi_2)\cdot\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\cos^2\varphi_1\sin^2\frac{\theta_2}{2}>0$, the second term on the right side of the equation decreases as θ_1 increases, and the third term on the right side of the equation decreases as θ_1 increases when $\sin^2\varphi_2\cdot\cos^2\frac{\theta_2}{2}\geq 0$. Therefore, when both equations are true at the same time nor take equal signs at the same time, only then can we ensure that the government revenue increases with the degree of regulation. It is similar for e-commerce the platform.

As an example, the expected revenue of the government in the quantum entanglement state with a general quantum strategy ($0<\varphi_1\leq\frac{\pi}{2}$ or $0<\varphi_2\leq\frac{\pi}{2}$) changes as θ_1 and θ_2 is:

$$ER_1=R_1+\left[(\beta A-0.5\gamma_1)\cdot\cos^2(\varphi_1+\varphi_2)\cdot\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\cos^2\varphi_1\sin^2\frac{\theta_2}{2}\right]\cdot\cos^2\frac{\theta_1}{2}-0.5\gamma_1\cdot\sin^2\varphi_2\cos^2\frac{\theta_2}{2}\sin^2\frac{\theta_1}{2}$$

. In fact, the second term on the right side of the equation can be satisfied when $(\beta A-0.5\gamma_1)\cdot\cos^2(\varphi_1+\varphi_2)\cdot\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\cos^2\varphi_1\sin^2\frac{\theta_2}{2}\geq 0$ is a decreasing function of θ_1, i.e., it increases with the enhancement of its own regulatory degree e_1. When $\sin^2\varphi_2\cdot\cos^2\frac{\theta_2}{2}\geq 0$, the third term on the right side of the equation is a decreasing function of θ_1. Therefore, only when $(\beta A-0.5\gamma_1)\cdot\cos^2(\varphi_1+\varphi_2)\cdot\cos^2\frac{\theta_2}{2}-0.5\gamma_1\cdot\cos^2\varphi_1\sin^2\frac{\theta_2}{2}\geq 0$ and

International Journal of Scientific Engineering and Science
Volume 7, Issue 10, pp. 31-43, 2023. ISSN (Online): 2456-7361

$\sin^2\varphi_2 \cdot \cos^2\frac{\theta_2}{2} \ge 0$ are true simultaneously but do not take equal signs at the same time can we ensure that the government expected revenue increases with the degree of its own regulation e_1. This is similar for the e-commerce platform.

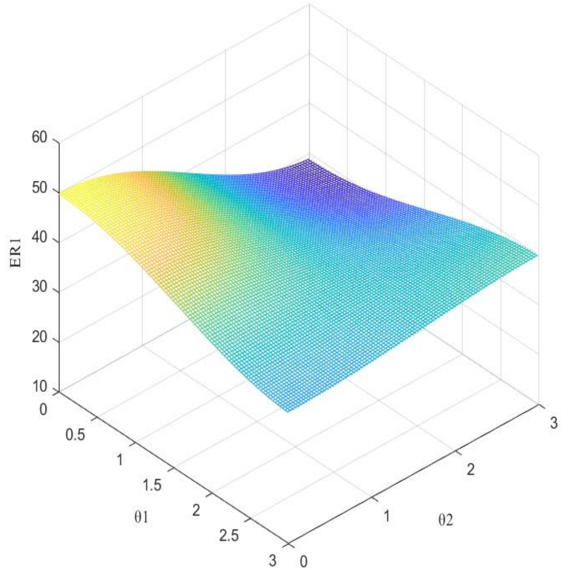

Fig. 8. Variation of government expected revenue with θ_1, θ_2 when using a general quantum strategy in quantum entanglement state

It can be seen from Fig. 8. that the government expected revenue is a decreasing function of θ_1 regardless of the value of θ_2, but this trend is more obvious when θ_2 tends to 0.

The study of Theorem 2 to 4 shows that the government expected revenue is a decreasing function of θ_1 regardless of the value of θ_2 in the quantum entanglement state, but this trend is more obvious when θ_2 tends to 0. This shows that the effort of the e-commerce platform regulation in the quantum entanglement state is a decreasing function of the government's expected revenue, but for the government, the greater its own effort, the greater its expected revenue still shows an increasing trend, and the government will achieve the optimal incentive effect. Similarly, the e-commerce platform regulation also shows the same characteristics. In fact, the regulation under the quantum entanglement state not only increases the bonding degree of both regulatory bodies and achieves the optimal incentive effect, but also solves the "prisoner's dilemma" of cooperation strategy between regulatory bodies and avoid the free rider problem.

III. Case Study

In order to further verify the above analysis results, this paper compares whether to consider the entanglement state on the behavioral strategy choice of both bodies of the regulation and the related influencing factors in the context of relevant cases, and further verifies that the regulation under the quantum entanglement state can achieve the optimal incentive effect.

On March 7, 2020, a well-known online shopping mall was exposed to serious price discrimination in the process of selling goods, with at least five different prices for the same product and nearly double the difference between the lowest and highest prices. In response to this phenomenon, the government and the platform carried out collaborative governance. The government's regulatory input in this event is between 240,000 and 480,000, i.e. $24 < e_1 < 48$ (e_1 is the degree of government regulatory input). The regulatory input for the platform is between 160,000 and 320,000, i.e. $16 < e_2 < 32$ (e_2 is the degree of platform regulatory input). In the quantum evolutionary game model, the strategy selection of both regulatory bodies is: $\theta_1, \theta_2 \in [0,\pi]$, $\varphi_2 \in [0,\frac{\pi}{2}]$. Thus, $\theta_1 = 2\pi - \frac{\pi}{24}e_1$ and $\theta_2 = 2\pi - \frac{\pi}{16}e_2$.

A. Disregarding the Quantum Entanglement State

If no relevant metrics are set that can monitor the degree of effort of both regulatory bodies when the government and the platform carry out collaborative regulation, i.e., when the quantum entanglement state is not considered, the expected revenue for the government and the platform are: $ER_1 = R_1 + (\beta A\cos^2(\pi - \frac{\pi}{32}e_2) - 0.5\gamma_1)\cdot\cos^2(\pi - \frac{\pi}{48}e_1)$ and $ER_2 = R_2 + \left[(1-\beta)A\cos^2(\pi - \frac{\pi}{48}e_1) - 0.5\gamma_2\right]\cdot\cos^2(\pi - \frac{\pi}{32}e_2)$.

The derivative of the expected revenue are: $ER_1' = \frac{\pi}{48}\cdot\sin(2\pi - \frac{\pi}{24}e_1)\cdot\left[\beta A\cos^2(\pi - \frac{\pi}{32}e_2) - 0.5\gamma_1\right]$ and $ER_2' = \frac{\pi}{32}\cdot\sin(2\pi - \frac{\pi}{16}e_2)\cdot\left[(1-\beta)A\cos^2(\pi - \frac{\pi}{48}e_1) - 0.5\gamma_2\right]$.

When $e_1 \in [24,48]$ and $e_2 \in [16,32]$, the functional relationship of expected revenue of the government and e_1 depends on the positive or negative of $\beta A\cos^2(\pi - \frac{\pi}{32}e_2) - 0.5\gamma_1$. The functional relationship of the expected revenue of the platform and e_2 depends on the positive or negative of $(1-\beta)A\cos^2(\pi - \frac{\pi}{48}e_1) - 0.5\gamma_2$. That is, the optimal strategy selection of the government and the platform is influenced by the size of their profit distribution and regulatory costs, which in turn depends on the size of the profit distribution coefficient and the synergy benefit. The following discussion is divided into situations:

SITUATION 1: The impact of regulatory cost changes on the optimal strategy

Through the research data, this regulatory process, the basic benefits of the government is 600,000 yuan, the basic benefits of the platform is 400,000 yuan, the additional benefits during the co-regulation is 300,000 yuan. The government's benefit distribution coefficient is 0.6, then the

International Journal of Scientific Engineering and Science
Volume 7, Issue 10, pp. 31-43, 2023. ISSN (Online): 2456-7361

government obtained co-regulation benefits of 180,000 yuan, the platform obtained co-regulation benefits of 120,000 yuan. Considering that the strategy selection of each side is affected by the size of the distribution of regulatory costs and benefits, the impact of exploring the cost on the behavioral selection of each side is divided into two cases: cost is greater than the governance benefits and cost is less than the governance benefits.

(1) Costs outweigh the benefits of governance

Set the base cost of the government collaborative regulation 200,000 yuan, the base cost of platform collaborative regulation 150,000 yuan, at this time, the cost of regulation of each body is greater than the synergy benefits. The expected revenue of the government is: $ER_1 = 60 + \left[18\cos^2(\pi - \frac{\pi}{32}e_2) - 20\right] \cdot \cos^2(\pi - \frac{\pi}{48}e_1)$. The expected revenue of the platform is: $ER_2 = 40 + \left[12\cos^2(\pi - \frac{\pi}{48}e_1) - 15\right] \cdot \cos^2(\pi - \frac{\pi}{32}e_2)$. The derivatives are: $ER_1' = \frac{\pi}{48} \cdot \sin(2\pi - \frac{\pi}{24}e_1) \cdot \left[18\cos^2(\pi - \frac{\pi}{32}e_2) - 20\right]$ and $ER_2' = \frac{\pi}{32} \cdot \sin(2\pi - \frac{\pi}{16}e_2) \cdot \left[12\cos^2(\pi - \frac{\pi}{48}e_1) - 15\right]$. The equation is true if $ER_1' < 0$ and $ER_2' < 0$ when $e_1 \in [24, 48]$ and $e_2 \in [16, 32]$, which means the expected revenue of both the government and the platform decrease as their effort rises. So it can be found that the optimal selection of the government is $e_1^* = 24$, and the optimal choice of the platform is $e_2^* = 16$. In the case that the cost outweighs the benefit, both the government and the platform take the minimum input as the optimal selection. This indicates that although the government and carry out collaborative regulation, the choice of each is still interest-oriented. When the revenue of each body cannot cover the cost of regulation, in order to reduce cost, they will take the minimum input as the optimal selection. The platform, in the process of collaborative regulation, will shirk the main responsibility of regulation and governance to the government to protect its own interests from damage. Thus, free rider problem arises.

(2) Cost less than the benefits of governance

According to the research, the government co-regulation base cost is 150,000 yuan, the platform for 100,000 yuan. the revenue functions of the government and platform are: $ER_1 = 60 + \left[18\cos^2(\pi - \frac{\pi}{32}e_2) - 15\right] \cdot \cos^2(\pi - \frac{\pi}{48}e_1)$ and $ER_2 = 40 + \left[12\cos^2(\pi - \frac{\pi}{48}e_1) - 10\right] \cdot \cos^2(\pi - \frac{\pi}{32}e_2)$. And the derivatives are: $ER_1' = \frac{\pi}{48} \cdot \sin(2\pi - \frac{\pi}{24}e_1) \cdot \left[18\cos^2(\pi - \frac{\pi}{32}e_2) - 15\right]$ and $ER_2' = \frac{\pi}{32} \cdot \sin(2\pi - \frac{\pi}{16}e_2) \cdot \left[12\cos^2(\pi - \frac{\pi}{48}e_1) - 10\right]$. The monotonicity of the government's expected revenue depends on $18\cos^2(\pi - \frac{\pi}{32}e_2) - 15$. Let the zero of this equation be e_2^* ($e_2^* \approx 25$, calculated through Matlab). When $16 \le e_2 \le e_2^*$, the derivative is less than 0, and the government's expected revenue decreases with the increase of its regulatory input, when the government's optimal strategy is $e_1^* = 24$. When $e_2^* < e_2 \le 32$, the derivative is less than 0, and the government's expected revenue increases with the increase of its regulatory input, when the optimal strategy is $e_1^* = 48$. Similarly, for the e-commerce platform, the monotonicity of the platform's expected revenue depends on $12\cos^2(\pi - \frac{\pi}{48}e_1) - 10$. Let the zero of this equation be e_1^* ($e_1^* \approx 47$, calculated through Matlab). When $24 \le e_1 \le e_1^*$, the derivative is less than 0, and expected revenue decreases with the increase of its regulatory input, when the optimal strategy is $e_2^* = 16$. When $e_1^* < e_1 \le 48$, the derivative is less than 0, and the expected revenue increases with the increase of its regulatory input, when the optimal strategy is $e_2^* = 32$. Above all, when the cost of both regulatory bodies is less than the benefit, the behavioral strategy of both bodies is not the minimum input when it is not fully chosen, but will depend on the other party's input due to the entanglement state. Only when the other party's input is higher than a certain threshold, each regulatory body will take the maximum input as the optimal strategy. In addition, it is not difficult to find that the e-commerce platform as a profit-oriented organization, in the process of collaborative regulation, only when the government takes nearly the highest input as the cost, the platform will accordingly take the highest input as the optimal strategy. This shows that, platforms' free ride problem is more serious. This further illustrates the lack of interest involvement in the process between the two. Even if the cost of regulation is less than the benefit of collaborative regulation, the high input still faces high risk and also bears the additional loss caused by "betrayal". Only when the other side provides a higher input than a certain threshold will each regulatory side choose the maximum input.

SITUATION 2: Effect of changes in profit distribution on optimal strategies of both bodies

According to the research: in the process of co-regulation, the basic benefit of the government is 600,000 yuan, the regulatory base cost is 200,000 yuan, the basic benefit of the platform is 400,000 yuan and the regulatory base cost is 150,000 yuan.

Effect of profit distribution coefficient on behavioral selection of both bodies

Government and platform co-regulation generated benefits of 300,000 yuan. In order to investigate the influence of the profit distribution coefficient on the choice of strategy, the revenue distribution coefficients are 0.4, 0.5, 0.6, 0.7, 0.8. When the revenue distribution is 0.4, 0.5, the government's expected revenue will decrease with the increase of regulatory efforts and the government's optimal strategy is $e_1^* = 24$. At

International Journal of Scientific Engineering and Science
Volume 7, Issue 10, pp. 31-43, 2023. ISSN (Online): 2456-7361

this point, the input decision of the platform depends on the degree of government input, and the optimal strategy of the platform is $e_2^* = 16$ when the government input is lower than the threshold, and the optimal strategy of the platform is $e_2^* = 32$ when the government input is higher than the threshold. The Matlab calculation shows that the government threshold is 25 when the revenue distribution coefficient is 0.4 and 48 when the coefficient is 0.5. When the coefficient is 0.6, both government and platform revenue decreases with the increase of their regulatory efforts, and the optimal strategies are $e_1^* = 24$, $e_2^* = 16$. It can be seen that when the government revenue distribution is small, active regulation is not motivated enough, and will take the minimum input as the optimal choice. Although the platform can obtain higher revenue distribution, the essence of chasing profit makes it be dependent on the government and shirks the responsibility to the government, and this dependence will be more obvious as the revenue distribution decreases. When the coefficient is 0.7, 0.8, at this time, the revenue of the platform decreases with the increase of its regulatory input, and the optimal strategy is $e_2^* = 16$. The government's optimal strategy selection depends to some extent on the degree of regulatory input of the platform. When the platform input is lower than the threshold, the optimal strategy of the government is $e_1^* = 24$. When the platform input is higher than the threshold, the optimal strategy of the government is $e_1^* = 48$. The Matlab calculation shows: the e-commerce platform input threshold is 30 when the revenue distribution coefficient is 0.7, and the threshold is 28 when the coefficient is 0.8. It can be seen that when the platform revenue distribution is low, the platform will choose the minimum input with the benefit as the starting point At this point, the government's decision depends to a certain extent on the choice of the e-commerce platform. In the case of low input of the platform, the government will face greater risk of high input and bear the cost of "betrayal", so the government will take the minimum input as the optimal choice. When the input of the platform is high, the government faces a certain degree of risk mitigation. At the same time, the government, because of its main regulatory responsibility in the market, will not only establish a good image by increasing the input, but also win public trust, gain a good reputation and bring greater social benefits, so the government will take the highest input as its optimal choice.

Impact of synergistic benefits on behavioral choices of both bodies

The coefficient of revenue distribution in collaborative regulation is 0.6. Assume the synergistic benefits are 20, 25, 30, 35, and 40 to investigate the influence of synergistic benefits on the optimal strategy choice of both regulatory bodies. For the government, when the synergy benefits are 20, 25, and 30, the government expected revenue to decrease with the increase of regulatory input, and the government's optimal strategy choice is $e_1^* = 24$ at this time. This suggests that when the benefits generated by co-regulation are low, there is little incentive for the government to actively regulate, and therefore, the government will consider the least input. When the synergistic benefits are 35 and 40, the optimal government strategy at this time depends to some extent on the input of the platform. When the input of platform is low, the optimal strategy of the government is $e_1^* = 24$, and when the input of platform is high, the optimal strategy of the government is $e_1^* = 48$. The government's optimal strategy depends to a certain extent on the highest input, but it also varies depending on the choice of the platform. When the input of the platform is low, the government's effort to reduce the risk of "betrayal" will be minimized. When the input of the platform is high and the benefits of co-regulation are high, the government will also obtain benefits with a higher input. The optimal strategy for the platform is $e_2^* = 16$ when the synergistic benefits are 20, 25, 30 and 35. Only when the synergy benefit is 400,000 yuan and the government input is higher than 470,000 yuan, the platform will choose to use the highest input as the optimal strategy. It can be seen that without sufficient benefit attraction in the process of co-regulation, the platform will not actively make the highest input.

From the above study, it can be found that: without considering quantum entanglement, the behavior of both regulatory bodies tends to take the minimum input as the optimal strategy more often. Only under the condition that the regulatory cost is low, or the benefit obtained from co-regulation is high and the other bodies has higher input, the bodies will take the highest input as the optimal strategy. This indicates that when the entanglement state is not considered, the optimal strategy of each regulatory bodies is easily influenced by various factors such as regulatory cost, benefit distribution coefficient and synergistic benefit, and the stability of strategy selection is insufficient. The interest connection among the bodies is weak, and the behavioral strategy selection is more based on their own interests. In order to reduce the risk in collaborative regulation and the loss caused by "betrayal", the behavioral strategies of each bodies depend largely on the input of the other party, and the free ride problem is more serious.

B. *Considering the Quantum Entanglement State*

Quantum entanglement refers to the situation that $0 < \omega < \frac{\pi}{2}$, in which ω refers to the degree of entanglement. Entanglement means tie the interests of the two together to increase the relevance of their interests. The larger the ω, the greater the degree of entanglement. Under the quantum entanglement state, the government and the platform of needs to sign an entanglement contract before co-regulation. This paper takes the maximum entanglement degree ($\omega = \frac{\pi}{2}$) as an example. The expected net benefits for the government and the platform are:

$$ER_1 = R_1 + \left[(\beta A - 0.5\gamma_1)\cdot\cos^2(\varphi_1+\varphi_2)\cdot\cos^2\frac{\theta_2}{2} - 0.5\gamma_1\cdot\cos^2\varphi_1\sin^2\frac{\theta_2}{2}\right]\cdot\cos^2\frac{\theta_1}{2} - 0.5\gamma_1\cdot\sin^2\varphi_2\cos^2\frac{\theta_2}{2}\sin^2\frac{\theta_1}{2}$$

and

$$ER_2 = R_2 + \left[\left(A - \beta A - 0.5\gamma_2\right) \cdot \cos^2(\varphi_1 + \varphi_2) \cdot \cos^2\frac{\theta_1}{2} - 0.5\gamma_2 \cdot \cos^2\varphi_2 \sin^2\frac{\theta_1}{2} \right] \cdot \cos^2\frac{\theta_2}{2} - 0.5\gamma_2 \cdot \sin^2\varphi_1 \cos^2\frac{\theta_1}{2} \sin^2\frac{\theta_2}{2}$$

. Then the revenue of government and platform is:

$$ER_1 = R_1 + \left[(\beta A - 0.5\gamma_1) \cdot \cos^2(\varphi_1 + \varphi_2) \cdot \cos^2(\pi - \frac{\pi}{32}e_2) - 0.5\gamma_1 \cdot \cos^2\varphi_1 \sin^2(\pi - \frac{\pi}{32}e_2) \right] \cdot \cos^2(\pi - \frac{\pi}{48}e_1) - 0.5\gamma_1 \cdot \sin^2\varphi_2 \cos^2(\pi - \frac{\pi}{32}e_2) \sin^2(\pi - \frac{\pi}{48}e_1)$$

and

$$ER_2 = R_2 + \left[\left(A - \beta A - 0.5\gamma_2\right) \cdot \cos^2(\varphi_1 + \varphi_2) \cdot \cos^2(\pi - \frac{\pi}{48}e_1) - 0.5\gamma_2 \cdot \cos^2\varphi_2 \sin^2(\pi - \frac{\pi}{48}e_1) \right] \cdot \cos^2(\pi - \frac{\pi}{32}e_2) - 0.5\gamma_2 \cdot \sin^2\varphi_1 \cos^2(\pi - \frac{\pi}{48}e_1) \sin^2(\pi - \frac{\pi}{32}e_2)$$

. The derivations are:

$$ER_1' = \frac{\pi}{48} \left[(\beta A - 0.5\gamma_1) \cdot \cos^2(\varphi_1 + \varphi_2) \cdot \cos^2(\pi - \frac{\pi}{32}e_2) - 0.5\gamma_1 \cdot \cos^2\varphi_1 \sin^2(\pi - \frac{\pi}{32}e_2) \right] \cdot \sin(2\pi - \frac{\pi}{24}e_1) + \frac{\pi}{48} \cdot 0.5\gamma_1 \cdot \sin^2\varphi_2 \cos^2(\pi - \frac{\pi}{32}e_2) \sin(2\pi - \frac{\pi}{24}e_1)$$

and

$$ER_2' = \frac{\pi}{32} \left[\left(A - \beta A - 0.5\gamma_2\right) \cdot \cos^2(\varphi_1 + \varphi_2) \cdot \cos^2(\pi - \frac{\pi}{48}e_1) - 0.5\gamma_2 \cdot \cos^2\varphi_2 \sin^2(\pi - \frac{\pi}{48}e_1) \right] \cdot \sin(2\pi - \frac{\pi}{16}e_2) + \frac{\pi}{32} \cdot 0.5\gamma_2 \cdot \sin^2\varphi_1 \cos^2(\pi - \frac{\pi}{48}e_1) \sin(2\pi - \frac{\pi}{16}e_2)$$

It is clear that the variation of the relationship between the expected revenue of the two bodies considering quantum entanglement with their degree of input depends only on the degree of quantization of the strategy (variation of φ_i).

According to the relevant data, the basic benefit of the government in the process of co-regulation is 600,000 yuan, the basic cost of regulation is 200,000 yuan, the basic benefit of platform e-commerce is 400,000 yuan, the basic cost of regulation is 150,000 yuan, the benefit distribution coefficient is 0.6, and the benefit of co-regulation is 300,000 yuan. This paper assumes that before the formal cooperation between the government and the platform company, they signed an entanglement contract: the government sets the target of less than 10% media exposure, the platform sets the target of less than 10% consumer complaints about price discrimination. The government agreed that if the platform is actively supervised, it will give the platform 40% of the difference in revenue between the two bodies as a reward and the reward factor is 0.4. On the contrary, if the platform negatively regulates, it will charge 40% of the difference in revenue between the two bodies as a penalty. In the quantum game model: $\varphi_i = \frac{\pi}{2} \times \frac{P_i^{real}}{P_i^{goal}}$, where P_i^{real} is the actual goal achieved and P_i^{goal} is the overall goal. The actual degree of completion of each regulatory body determines the relationship between government benefits and the degree of its input.

When the actual completion rate of each body is low, let the degree of quantization be $\varphi_1 = \varphi_2 = \frac{\pi}{6}$. At this point the revenue of the government and the platform is

$$ER_1 = 60 + \left[-0.5\cos^2(\pi - \frac{\pi}{32}e_2) - 15\sin^2(\pi - \frac{\pi}{32}e_2) \right] \cdot \cos^2(\pi - \frac{\pi}{48}e_1) - 5 \cdot \sin^2(\pi - \frac{\pi}{32}e_1) \cdot \cos^2(\pi - \frac{\pi}{32}e_2)$$

and

$$ER_2 = 40 + \left[-0.75\cos^2(\pi - \frac{\pi}{48}e_1) - 11.25\sin^2(\pi - \frac{\pi}{48}e_1) \right] \cdot \cos^2(\pi - \frac{\pi}{32}e_2) - 3.75\cos^2(\pi - \frac{\pi}{48}e_1)\sin^2(\pi - \frac{\pi}{32}e_2)$$

. The derivations are:

$$ER_1' = \frac{\pi}{48}\sin(2\pi - \frac{\pi}{24}e_1)\left[4.5\cos^2(\pi - \frac{\pi}{32}e_2) - 15\sin^2(\pi - \frac{\pi}{32}e_2) \right]$$

and

$$ER_2' = \frac{\pi}{32}\left[3\cos^2(\pi - \frac{\pi}{48}e_1) - 11.25\sin^2(\pi - \frac{\pi}{48}e_1) \right] \cdot \sin(2\pi - \frac{\pi}{16}e_2).$$

Let the zero point of $4.5\cos^2(\pi - \frac{\pi}{32}e_2) - 15\sin^2(\pi - \frac{\pi}{32}e_2)$ be e_2^* ($e_2^* \approx 29$,calculated through Matlab). When $16 \le e_2 \le e_2^*$, the government's expected benefit decreases as the degree of input increases, and the government's optimal strategy is $e_1^* = 24$. When $e_2^* < e_2 \le 32$, the expected revenue decreases as the level of input increases, and the optimal strategy is $e_1^* = 48$. Similarly, let the zero point of $3\cos^2(\pi - \frac{\pi}{48}e_1) - 11.25\sin^2(\pi - \frac{\pi}{48}e_1)$ be e_1^* ($e_1^* \approx 41$, calculated through Matlab). When $24 \le e_1 \le e_1^*$, the expected return of the platform decreases as its degree of input increases and the optimal strategy is $e_2^* = 16$. When $e_1^* < e_1 \le 48$, the expected revenue5 increases with its degree of input and the optimal strategy is $e_2^* = 32$.

Quantum maximization is reached when the actual objectives of both regulatory bodies reach the overall goal, when $\varphi_1 = \varphi_2 = \frac{\pi}{2}$. Therefore, once the government and the platform complete their tasks according to the agreed target, the actual expected revenue of the government is

$$ER_1 = 60 - 2 \cdot \cos^2(\pi - \frac{\pi}{32}e_2) \cdot \cos^2(\pi - \frac{\pi}{48}e_1) - 20\cos^2(\pi - \frac{\pi}{32}e_2)\sin^2(\pi - \frac{\pi}{48}e_1)$$

. The derivation is $ER_1' = \frac{3\pi}{8} \cdot \cos^2(\pi - \frac{\pi}{32}e_2) \cdot \sin(2\pi - \frac{\pi}{24}e_1)$ (constantly greater than 0 on a given interval). That is to say the government's expected revenue increase with its degree of regulation, and the optimal choice is $e_1^* = 48$. The actual expected revenue of the platform is

$$ER_2 = 40 - 3\cos^2(\pi - \frac{\pi}{48}e_1) \cdot \cos^2(\pi - \frac{\pi}{32}e_2) - 15\cos^2(\pi - \frac{\pi}{48}e_1)\sin^2(\pi - \frac{\pi}{32}e_2).$$

The derivation is $ER_2' = \frac{3\pi}{8} \cdot \cos^2(\pi - \frac{\pi}{48}e_1) \cdot \sin(2\pi - \frac{\pi}{16}e_2)$ (constantly greater than 0 on a given interval). That is to say the platform's expected revenue increases with its degree of regulation, and the optimal choice is $e_2^* = 32$.

The above analysis shows that after considering quantum entanglement, the strategies of the game bodies are only affected by the degree of quantization, i.e., they only vary with the degree of accomplishment of the actual goals of each regulatory body, and the strategy choice is more stable.

Because of the entanglement contract before regulation, the interests of both bodies are closely linked. When the degree of quantization is low, the strategy choices of both have a certain dependency. This dependency decreases as the degree of quantization increases. When the quantum level reaches the highest level, that is, when the actual goal of each party reaches the overall goal, the expected benefits of both bodies will rise with the increase of their regulation, and they do not have to bear the cost of betrayal of each other. The entanglement contract between the government and the e-commerce platform further binds the interests of them, and both bodies will do their best to invest as much as possible to ensure the overall regulation effect.

IV. CONCLUSION

By analyzing the relationship between the co-regulatory bodies, this paper constructs a game model of big data-enabled price discrimination against existing customers in quantum entanglement state, compares the influence of entanglement state or not on the choice of regulatory strategy selection, and clarifies the mechanism of co-regulation of big data-enabled price discrimination against existing customers in entanglement state. The specific conclusions are as follows:

(1) The regulatory effect is better and more stable in the quantum entanglement state. When quantum entanglement is not considered, the strategy selection of both regulatory bodies is influenced by the cost of regulation, the benefit distribution coefficient and the synergistic benefit of regulation, which has more influencing factors and are not stable enough. When the quantum entanglement is considered, the "prisoner's dilemma" problem can be solved in the process of co-regulation. As the entanglement deepens, the bonding degree of both regulatory bodies can be improved to achieve the optimal incentive.

(2) Considering the entanglement state, when the two regulatory bodies adopt different quantum strategies, the conditions for achieving the “perfect regulation and perfect regulation” strategy are different. When the complete quantum strategy is adopted, the optimal incentive is achieved under a relatively simple constraint. When both regulatory bodies consider the entanglement state and adopt the complete quantum strategy, the regulatory bodies can be motivated to cooperate with maximum effort when the condition of entanglement contract is reached. At this time, if the government reaches the agreed goal, the e-commerce platform will also achieve “perfect regulation”.

(3) Entanglement contract can stimulate the cooperation of both regulatory bodies. In the quantum entanglement state, in order to optimize the cooperation in the regulatory process, it is necessary to solve the problem of the cost of “betrayal”, that is, the classical "prisoner's dilemma" problem. Therefore, an entanglement contract is needed. This will directly affect the stickiness and information symmetry of the regulatory bodies, to ensure both of them are not motivated to take non-quantum strategies, thus achieving the full quantum strategy optimization under the maximum effort.

(4) It is reasonable to use quantum evolutionary game to study the collaborative regulatory mechanism of big data-enabled price discrimination against existing customers in quantum entanglement state. there is a moral hazard in the process of cooperative regulation of big data killing because the degree of regulation of platform sellers by the government and platforms is a continuous variable, which is similar to the quantum superposition state in quantum mechanics. The quantum strategy set introduced by the quantum game greatly expands the strategy set in the classical game, so the research in this paper is reasonable and scientific.

REFERENCES

[1] X. H. Wang and X. X. Ren, “Research on the dynamic evolutionary game of platform e-commerce credit regulation from the perspective of government governance,” *Chinese Management Science*, vol. 29, issue 12, pp. 29–41, 2021.

[2] T. C. Lin, H. K. Cheng, F. S. Wang and K. J. Chang, “A study of online auction sellers’ intention to switch platform: The case of Yahoo! Kimo versus Ruten_eBay,” *Decision Sciences*, vol. 43, issue 2, pp. 241-272, 2012.

[3] R. Grewal, A. Chakravarty and A. Saini, “Governance mechanisms in Business-to-Business electronic markets,” *Journal of Marketing*, vol. 74, issue 3, pp. 46-62, 2010.

[4] E. L. Plambeck and T. A. Taylor, “Supplier evasion of a buyer’s audit: Implications for motivating supplier social and environmental responsibility,” *Manufacturing and Service Operations Management*, vol. 18, issue 2, pp. 184-197, 2016.

[5] X. H. Wang and X. X. Ren, “Research on platform e-commerce credit supervision mechanism based on evolutionary game,” *Systems Engineering Theory and Practice*, vol. 40, issue 10, pp. 2617-2630, 2020.

[6] X. X. Wang, Y. K. Cheng, X. M. Tian, Z. Q. Xu and J. M. Chen, “Study on the four-way evolutionary game of e-commerce ecosystem,” *Journal of Operations Research*, vol. 26, issue 01, pp. 23–42, 2022.

[7] G. S. Xing, F. Lu, Z. B. Zhou and J. L. Ye, “Can data portability control "Big data killing"?,” *Chinese Management Science*, vol. 30, issue 03, pp. 85–95, 2022.

[8] X. Y. Zhou, F. Zhao, Y. Liu and S. Y. Wang, “How do Government subsidies and cost sharing affect platform and firm strategy choices: Based on a tripartite evolutionary game,” *Control and Decision-making*, vol. 37, issue 02, pp. 293-302, 2022.

[9] L. C. Lei, S. Gao and R. X. Chen, “Big data "kill cooked" how to break? An evolutionary game based on government-consumer collaborative regulation,” *Journal of Systems Management*, vol. 30, issue 04, pp. 664-675, 2021.

[10] B. Wu, J. Cheng and Y. Song, “An evolutionary game analysis of the phenomenon of "killing ripe" on e-commerce platforms from the perspective of psychological accounts,” *Operation Research and Management*, vol. 29, issue 11, pp. 37-44, 2020.

[11] X. J. Jiang and Y. X. Huang, “Market order, market regulation and platform governance in the digital age,” *Economic Research*, vol. 56, issue 12, pp. 20-41, 2021.

[12] G. M. Qian, Z. Yang and J. Chen, “Reflection and reconstruction of platform supervision logic -- and re-reflection of the concept of inclusive prudential supervision,” *Journal of Xi 'an Jiaotong University (Social Science Edition)* , vol. 42, issue 01, pp. 131-140, 2022.

[13] C. Qu and X. C. Wang, “The characteristics, causes and regulatory strategies of Internet platform monopoly behavior,” *Reformation*, issue 05, pp. 53-63, 2021.

[14] D. A. Meyer, “Quantum strategies,” *Physical Review Letters*, vol. 82, issue 5, pp. 1052-1059, 1999.

[15] J. Eisert, M. Wilkens and M. Lewenstein, “Quantum games and quantum strategies,” *Physical Review Letters*, vol. 83, issue 15, pp. 3077-3080, 1999.

[16] N. Allahyaribeik, H. Nikoomaram, S. Allahyaribeik and R.F. Rahnamay, “A quantum Model for the stock Market,” *Advances in Mathematical Finance and Applications*, vol. 7, issue 1, pp. 1-17, 2022.

[17] P. M. Ney, S. Notarnicola , S. Montangero and G. Morigi, “Entanglement in the quantum Game of Life,” *Physical Review A* , vol. 105, issue 1, pp. 012416, 2022.

Volume 7, Issue 10, pp. 31-43, 2023. *ISSN (Online): 2456-7361*

[18] S. Lloyd and C. Weedbrook, "Quantum generative adversarial learning," *Physical Review Letters*, vol. 121, issue 4, pp. 040502, 2018.
[19] Y. T. He and F. G. Xie, "Research on incentive mechanism of industry-university-research collaborative innovation based on quantum game," *Systems Engineering Theory and Practice*, vol. 39, issue 06, pp. 1435-1448, 2019.
[20] A. Coladangelo, "A two-player dimension witness based on embezzlement, and an elementary proof of the non-closure of the set of quantum correlations," *Quantum*, issue 04, pp. 282, 2020.
[21] A. Iqbal, J. M. Chappell and D. Abbott, "The equivalence of Bell's inequality and the Nash inequality in a quantum game-theoretic setting," *Physics Letters A*, vol. 382, issue 40, pp. 2908-2913, 2018.
[22] S. S. Roy, A. Bera and G. Sierra, "Simulating violation of causality using a topological phase transition," *Physics Review A*, vol. 105, issue 03, pp. 032432, 2022.
[23] Q. L. Wang, H. F. Ren and Z. H. Li, "Research on the realization of quantum homology or gate by using single coin quantum game," *Journal of Quantum Optics*, vol. 25, issue 01, pp. 36-39, 2019.
[24] J. X. Yao and L. Y. Gong, "The influence of quantum entanglement and quantum manipulation on the superiority of CHSH quantum game," *Journal of Quantum Electronics*, vol. 32, issue 05, pp. 581-586, 2015.
[25] S. S. Szigeti, O. Hosten and S. A. Haine, "Improving cold-atom sensors with quantum entanglement: Prospects and challenges," *Applied Physics Letters*, vol. 118, issue 14, pp. 140501, 2021.
[26] A. S. Elgazzar, "Unique solution to the quantum prisoner's dilemma game," *Journal of the Physical Society of Japan* , vol. 88, issue 3, pp. 034801, 2019.
[27] G. Siopsis, R. Balu and N. Solmeyer, "Quantum prisoners' dilemma under enhanced interrogation," *Quantum Information Processing*, vol. 17, issue 6, pp. 1-12, 2018.
[28] R. Alonso-Sanz, "Simulation of the quantum Cournot duopoly game," *Physica A: Statistical Mechanics and its Applications*, vol. 534, pp. 122116, 2019.
[29] R. Alonso-Sanz and S. Martin-Gutierrez, "The free-rider in the quantum Stackelberg duopoly game," *Physica A: Statistical Mechanics and its Applications* , vol. 553, pp. 124271, 2020.