Service Quality Decision in Service Supply Chain Considering Supervision Behavior Based on Quantum Game

Peng Xing, Cuihua Zhang* and Shui Yu

School of Business Administration, Northeastern University, Shen Yang, Liao Ning 110819, PR China

*Corresponding author

Abstract—Service quality decisions of both members in service supply chain consisting of one service integrator and one service provider with stochastic demand are investigated, wherein service integrator supervises the service quality of service provider. By considering service quality and supervision level, members' profit functions are established. Meanwhile, based on quantum game, Nash equilibrium and quantum equilibrium are used to optimize the models. The optimal service quality of two members are obtained. Finally, mathematical reasoning and numerical simulations demonstrate that (1) quantum equilibrium solutions are superior to Nash equilibrium solutions under certain condition. If entanglement degree equals to zero, equilibrium solutions of quantum game are the same as the results of Nash equilibrium. (2) Service quality of service integrator increases in entanglement degree and decreases in supervision level. (3) Service quality of service provider decreases in entanglement degree and increases in supervision level.

Keywords—service quality; quantum game; nash equilibrium; quantum entanglement; service supply chain

I. INTRODUCTION

Nowadays, Chinese service industry has developed very quickly. In 2015, added value of Chinese tertiary industry was 34.1567 trillion RMB and reached 50.5% of GDP. Meanwhile, the growth of tertiary industry's added value is 8.3% faster than secondary industry (6.0%) and primary industry (3.9%). It marks China's economy officially entered 'Service Time' and means Chinese economy quickly transform from industry leading to service leading. These specific data are released from Chinese national bureau of statistics and the national economic and social development statistical bulletin in 2015. Therefore, service industry will become a new "engine" of economic growth in China. However, compared with developed countries, service quality of Chinese service industry is left behind. Consequently, service supply chain (SSC) and service quality become a hot topic in academia and business..

II. MODEL FORMULATIONS AND ASSUMPTIONS

In the case of demand uncertainty, we consider a two-echelon SSC model only containing one service integrator and one service provider. Business flow of SSC is seen in Fig. 1.

FIGURE 1. BUSINESS FLOW OF SSC.

Assumption 1. To provide services for its clients, service integrator acquires primary services from service provider and sells its value-added service to the market. Hence, service quality of service integrator determines the final service quality to clients.

Assumption 2. The model assumes that in the first cooperation or early cooperation between members in SSC, both members are not well acquainted with each other. Therefore, service integrator needs to supervise service quality provided by service provider, in order to obtain desired service quality. Notations used are presented in Table 1.

TABLE I. NOTATIONS OF PARAMETERS AND VARIABLES

Notations	Means
i	$i = v$ means service integrator, $i = s$ means service provider
j	The different strategies of SSC $j, j = Q, N$. N is Nash equilibrium and Q is quantum equilibrium.
x_i^j	Service quality of member i . x_i^j is decision variable.
x_v^o	Service quality of consumer expectations. $x_v^o > 0$.
x_s^o	Service quality of integrator expectation. $x_s^o > 0$.
w_i	Unit revenue of member i . $w_i > 0$
ρ	Supervision level prescribed by service integrator. $0 \leq \rho \leq 1$.
γ	Entanglement degree. $\gamma \geq 0$.
c_i	Coefficient of service quality cost. $c_i > 0$.
K	Incentive or penalty factor to service supply provider.
Π_i	Profit of member i .

We express demand function of SSC as follows:

$$D = D_0 + \alpha(x_v - x_v^o) \quad (1)$$

Where D_0 is potential intrinsic demand, x_v is actual service quality of service integrator. x_v^o is service quality of consumer expectations. α is effect factor of $x_v - x_v^o$. When service quality is relatively high, satisfaction degree of purchasers will be high, contributing to improve the image of service integrator and expand demand scale. On the contrary, when the service quality is relatively low, consumers will be dissatisfied with one sector or even the whole service quality in supply chain, bringing a certain demand loss of SSC.

We assume that primary supervision cost function of service provider is as follows

$$T_c = \beta \tan \frac{\pi \rho}{2} \quad (2)$$

Where β is the elasticity of supervision cost T_c .

Meanwhile, we assume that service quality with cost of functions [1, 2] is as follow:

$$T_i = \frac{1}{2} c_i x_i^2 \quad (3)$$

The profits functions of Π_i can be expressed by following equations:

$$\begin{aligned} \Pi_s &= [w_s + \rho(x_s - x_s^o)K]D - T_s \\ &= [w_s + \rho(x_s - x_s^o)K][D_0 + \alpha(x_v - x_v^o)] - \frac{1}{2} c_s x_s^2 \end{aligned} \quad (4)$$

$$\begin{aligned} \Pi_v &= [w_v - \rho(x_s - x_s^o)K]D - T_v - T_c \\ &= [w_v - \rho(x_s - x_s^o)K][D_0 + \alpha(x_v - x_v^o)] \\ &\quad - \frac{1}{2} c_v x_v^2 - \beta \tan \frac{\pi \rho}{2} \end{aligned} \quad (5)$$

Where $x_s - x_s^o$ means service quality of service provider whether reach service quality of service integrator expectation under supervision level ρ . If $x_s - x_s^o > 0$, K is the incentive factor to service supply provider. However, If $x_s - x_s^o < 0$, K will become the penalty factor to service supply provider.

III. OPTIMAL SOLUTIONS UNDER DIFFERENT METHODS

A. NASH Equilibrium

Proposition 1. In SSC, optimal service quality of service integrator and provider under Nash equilibrium are given by

$$x_s^{N*} = \frac{\alpha(c_s w_v - D_0 K^2 \rho^2 + \alpha x_v^o K^2 \rho^2 + c_s K \rho x_s^o)}{\alpha^2 K^2 \rho^2 + c_s c_v} \quad (6)$$

$$x_v^{N*} = \frac{K \rho (D_0 c_v + \alpha^2 w_v - \alpha c_v x_v^o + \alpha^2 K \rho x_s^o)}{\alpha^2 K^2 \rho^2 + c_s c_v} \quad (7)$$

Corollary 1. In Nash equilibrium,

- (1) ① If $\frac{2K\alpha\rho c_v x_v^o + c_v c_s x_s^o}{K^2 \alpha^2 x_v^o \rho^2 + 2w_v K \alpha^2 \rho + 2c_v D_0 K \rho} > 1$, x_s^{N*} increases in ρ . ② If < 1 , x_s^{N*} decreases in ρ . ③ If $= 1$, x_s^{N*} has no correlation with ρ .
- (2) ① If $\frac{\alpha^2 c_v c_s w_v + D_0 c_s c_v^2 + 2K\alpha^2 c_s c_v x_v^o \rho + c_v K^2 \alpha^3 x_v^o \rho^2}{K^2 \alpha^4 w_v \rho^2 + K^2 \alpha^2 D_0 c_v \rho^2 + \alpha c_v^2 c_s x_v^o} > 1$, x_v^{N*} increases in ρ . ② If < 1 , x_v^{N*} decreases in ρ . ③ If $= 1$, x_v^{N*} has no correlation with ρ .

B. Quantum Game

FIGURE II. QUANTIZATION OF THE MODEL.

$\bar{D}_1, \bar{D}_2$ are players' decisions, $\bar{J}(\gamma)$ is an operator that entangles the players' qubits. A disentangling gate $\bar{J}(\gamma)^+$ is applied prior to taking a measurement on the final state and the payoff is subsequently computed from the classical payoff matrix [3].

Through Fig. 2, the final state [4] before measurement is

$$|\psi_f\rangle = \bar{J}(\gamma)^+ (\bar{D}_1 \otimes \bar{D}_2) \bar{J}(\gamma) \otimes |vac_1\rangle \otimes |vac_2\rangle \quad (8)$$

γ is known as the squeezing parameter of the pair and can be reasonably perceived as a measure of entanglement, here we suppose that γ is nonnegative real numbers. When $\gamma \rightarrow \infty$ which is the infinite squeezing limit, the relevant pair will be approximate to the EPR state.

The basic form of entanglement operator [5] is

$$\bar{J}(\gamma) = \exp \left\{ -\gamma \left[\sum_{i,j=1,i \neq j}^n (\bar{a}_i^+ \bar{a}_j^+ - \bar{a}_i \bar{a}_j) \right] \right\} \quad (9)$$

Using the 'momentum' operator $\bar{P}_j = i(\bar{a}_j^+ - \bar{a}_j) / \sqrt{2}$ and the formula of Baker-Campbell-Hausdoff, we get

$$\begin{aligned} \bar{J}(\gamma)^+ \bar{D}_1(x_1) \bar{J}(\gamma) &= \exp \left\{ -ix_1 \left[\left[\bar{P}_1 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) + \bar{P}_2 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) \right] \right] \right\} \\ \bar{J}(\gamma)^+ \bar{D}_2(x_2) \bar{J}(\gamma) &= \exp \left\{ -ix_2 \left[\left[\bar{P}_1 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) + \bar{P}_2 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) \right] \right] \right\} \end{aligned} \quad (10)$$

So the final state is

$$\begin{aligned} |\psi_f\rangle &= \exp \left\{ -i \left[\left[x_1 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) \right] \bar{P}_1 \right] \right\} |vac_1\rangle \otimes \\ &\exp \left\{ -i \left[\left[x_1 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) \right] \bar{P}_2 \right] \right\} |vac_2\rangle \end{aligned} \quad (11)$$

Then measuring corresponding service quality of two members are

$$\begin{aligned} x_s &= x_1 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) \\ x_v &= x_1 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) \end{aligned} \quad (12)$$

We can get

$$\begin{aligned} \Pi_s &= [w_s + \rho(x_1 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) - x_s^o) K_s] \\ &\cdot [D_0 + \alpha(x_1 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) - x_v^o)] \\ &- \frac{1}{2} c_s (x_1 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}))^2 \end{aligned} \quad (13)$$

$$\begin{aligned} \Pi_v &= [w_v - \rho(x_1 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) - x_s^o) K_s] \\ &\cdot [D_0 + \alpha(x_1 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}) - x_v^o)] \\ &- \frac{1}{2} c_v (x_1 \cdot \frac{1}{2} (e^\gamma + e^{-\gamma}) + x_2 \cdot \frac{1}{2} (e^\gamma - e^{-\gamma}))^2 - \beta \tan \frac{\pi \rho}{2} \end{aligned} \quad (14)$$

$$\frac{\partial \Pi_s}{\partial x_2} = \frac{\partial \Pi_v}{\partial x_1} = 0 \quad (15)$$

Thus we will obtain the optimal equilibrium solutions x_1^*, x_2^* ,

$$\begin{aligned} x_1^* &= \frac{2(e^\gamma + e^{-\gamma})^3 (\alpha^2 K^2 \rho^2 + w_s K \alpha \rho - c_s x_s^o K \alpha \rho + D_0 K \alpha \rho) - (e^\gamma - e^{-\gamma})^3 \rho K^2 (\alpha D_0 + \alpha^2 x_s^o)}{(e^{2\gamma} - e^{-2\gamma}) [(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)]} \\ &\frac{(e^\gamma + e^{-\gamma})^2 (e^\gamma - e^{-\gamma}) (\alpha c_s w_v - \alpha c_v w_s + K^2 \alpha^2 \rho x_s^o - D_0 K^2 \rho^2 + K \alpha \rho x_s^o + K \alpha \rho x_s^o)}{(e^{2\gamma} - e^{-2\gamma}) [(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)]} \\ &+ \frac{(e^\gamma + e^{-\gamma}) (e^\gamma - e^{-\gamma})^2 \rho K \alpha w_v + 2K \alpha^2 w_s + D_0 K c_s - K^2 \alpha^2 \rho x_s^o - K \alpha c_s x_s^o)}{(e^{2\gamma} - e^{-2\gamma}) [(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)]} \end{aligned} \quad (16)$$

$$\begin{aligned} x_2^* &= \frac{2(e^\gamma - e^{-\gamma})^3 K \alpha^2 (w_s \rho + \rho x_s^o) + \alpha (e^\gamma + e^{-\gamma})^3 (D_0 K^2 \rho - c_s w_v - K \alpha x_s^o - \alpha K^2 \rho x_s^o)}{(e^{2\gamma} - e^{-2\gamma}) [(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)]} \\ &+ \frac{(e^\gamma + e^{-\gamma}) (e^\gamma - e^{-\gamma})^2 (\alpha^2 K^2 \rho x_s^o - D_0 K^2 \rho^2 - K \alpha c_s x_s^o)}{(e^{2\gamma} - e^{-2\gamma}) [(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)]} \\ &+ \frac{(e^\gamma + e^{-\gamma})^2 (e^\gamma - e^{-\gamma}) \rho \alpha^2 K^2 \rho x_s^o + 2\alpha^2 K w_s + D_0 K c_v + D_0 K c_s - \alpha K c_v x_s^o - \alpha K c_s x_s^o)}{(e^{2\gamma} - e^{-2\gamma}) [(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)]} \end{aligned} \quad (17)$$

Proposition 2. In SSC, optimal service quality under quantum game model is given by

$$\begin{aligned} x_v^Q &= \frac{(e^\gamma + e^{-\gamma})^2 K \alpha D_0 c_v + \alpha^2 w_v - \alpha c_v x_v^o + \alpha^2 K \rho x_s^o}{(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)} \\ &+ \frac{(e^\gamma - e^{-\gamma})^2 (\alpha^2 w_s K \rho - \alpha^2 K^2 \rho x_s^o) + (e^{2\gamma} - e^{-2\gamma}) \alpha c_v (w_s - x_s^o K \rho)}{(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)} \end{aligned} \quad (18)$$

$$\begin{aligned} x_s^Q &= \frac{(e^\gamma + e^{-\gamma})^2 \alpha c_s w_v - D_0 K^2 \rho^2 + \alpha^2 K^2 \rho^2 + c_s K \rho x_s^o}{(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)} \\ &+ \frac{(e^\gamma - e^{-\gamma})^2 K^2 \rho (\alpha D_0 - \alpha^2 x_s^o) - (e^{2\gamma} - e^{-2\gamma}) \rho K [\alpha^2 (w_v + w_s) + c_s D_0 - \alpha c_s x_s^o]}{(e^\gamma + e^{-\gamma})^2 (\alpha^2 K^2 \rho^2 + c_s c_v) - \alpha^2 K^2 \rho (e^\gamma - e^{-\gamma})^2 + \alpha K \rho (e^{2\gamma} - e^{-2\gamma}) (c_s - c_v)} \end{aligned} \quad (19)$$

Corollary 2. We can find that equilibrium solutions of quantum game are equal to results of Nash equilibrium, if $\gamma = 0$. However, equilibrium solutions of quantum game are different from the results of Nash equilibrium, if $\gamma \rightarrow +\infty$.

(1) When $\gamma \rightarrow 0$,

$$\lim_{\gamma \rightarrow 0} x_v^{Q*} = x_v^{N*} = \frac{K\rho(D_0c_v + \alpha^2w_v - \alpha c_v x_v^o + \alpha^2 K\rho x_s^o)}{\alpha^2 K^2 \rho^2 + c_s c_v},$$

$$\lim_{r \rightarrow 0} x_s^{Q*} = x_s^{N*} = \frac{\alpha(c_s w_v - D_0 K^2 \rho^2 + \alpha x_v^o K^2 \rho^2 + c_s K\rho x_s^o)}{\alpha^2 K^2 \rho^2 + c_s c_v},$$

(2) When $\gamma \rightarrow +\infty$,

$$\lim_{\gamma \rightarrow +\infty} x_v^{Q*} = \frac{K\rho(D_0c_v + 2\alpha^2w_v - \alpha c_v x_v^o) + \alpha c_v (w_s - x_s^o K\rho)}{c_s c_v + \alpha K\rho(c_s - c_v)},$$

$$\lim_{r \rightarrow +\infty} x_s^{Q*} = \frac{\alpha(c_s w_v + c_s K\rho x_s^o) - \rho K[\alpha^2(w_v + w_s) + c_s D_0 - \alpha c_s x_v^o]}{c_s c_v + \alpha K\rho(c_s - c_v)}.$$

Corollary 3. When $c_s = c_v = c$, we can infer that quantum equilibrium solutions are superior than Nash equilibrium solutions under certain condition.

(1) ① If $\frac{K^2 \rho^2 [K\rho(D_0c + 2\alpha^2w_v) + \alpha c w_s] + w_v c^2}{K\rho[\alpha K\rho(x_s^o + x_v^o) + x_s^o c^2]} > 1$,

$$\lim_{\gamma \rightarrow +\infty} x_v^{Q*} > \lim_{\gamma \rightarrow 0} x_v^{Q*} = x_v^{N*}.$$

② If < 1 , $\lim_{\gamma \rightarrow +\infty} x_v^{Q*} < \lim_{\gamma \rightarrow 0} x_v^{Q*} = x_v^{N*}$.

③ If $= 1$, $\lim_{\gamma \rightarrow +\infty} x_v^{Q*} = \lim_{\gamma \rightarrow 0} x_v^{Q*} = x_v^{N*}$.

(2) ① $\lim_{r \rightarrow +\infty} x_s^{Q*} > \lim_{r \rightarrow 0} x_s^{Q*} = x_s^{N*}$,

if $\frac{(\alpha^2 K^2 \rho^2 + c^2)(\alpha(w_v + K\rho x_s^o) + \rho K + \alpha x_v^o) + \alpha^2 D_0 K^2 \rho^2}{(\alpha^2 K^2 \rho^2 + c^2)\rho K[\alpha^2(w_v + w_s) + c D_0] + \alpha^2(\alpha x_v^o K^2 \rho^2 + c K\rho x_s^o)} > 1$.

② If < 1 , $\lim_{r \rightarrow +\infty} x_s^{Q*} < \lim_{r \rightarrow 0} x_s^{Q*} = x_s^{N*}$.

③ If $= 1$, $\lim_{r \rightarrow +\infty} x_s^{Q*} = \lim_{r \rightarrow 0} x_s^{Q*} = x_s^{N*}$.

IV. NUMERICAL SIMULATION

In this section, we use a numerical example to illustrate the effect of entanglement γ and supervision level ρ on optimal service quality x_i^{j*} and profits Π_i^j . We use a fictitious but representative data set which resembles the data structure available in practice, as follows:

$$w_s = 10, w_v = 10, x_v^o = 50, x_s^o = 50, \alpha = 20, K = 1, D_0 = 100,$$

$$\beta = 1, c_v = 1, c_s = 1.$$

A. Without Considering the Entanglement Degree

(1) The impact of ρ on x_v^{N*} and x_s^{N*}

FIGURE III. THE IMPACT OF ρ ON x_v^{N*} AND x_s^{N*} .

From Fig. 3, we can find that optimal service quality x_s^{N*} of service provider decreases in supervision level ρ and closes to 50. With improvement of supervision level ρ and the influence of service cost, service quality of service provider constantly tends to service standards required by service integrator. When $0 < \rho < 0.05$, the optimal service quality x_v^{N*} of service integrator increases in supervision level ρ and increases to 102.5. When $\rho > 0.05$, the optimal service quality x_v^{N*} of service integrator decreases in ρ and constantly tends to 58. Hence, if service integrator takes a certain supervision level ρ , it is advantageous for service integrator to obtain expected service quality from service provider. Meanwhile, it is indispensable guarantee to service integrator to provide better value-added services.

(2) The impact of x_v and ρ on Π_v^N

We assume that service quality x_s of service provider equals to 55. Fig. 4 demonstrates that profit Π_v^N of service integrator increases in service quality x_v and increases in supervision level ρ . When $x_v = 50$, service quality of service provider fails to meet the requirements by service integrator, service integrator will lose money, no matter what the value of supervision level ρ is. Because the profit caused by the demand scale is less than the total costs (service cost + supervision cost). When the service integrator has a certain value of service quality, the profit Π_v^N of service integrator increases in supervision level ρ , namely when $x_v = 70$, $\Pi_v^{\rho=0.9} > \Pi_v^{\rho=0.5} > \Pi_v^{\rho=0.2}$.

FIGURE IV. THE IMPACT OF x_v AND ρ ON Π_v^N .

(3) The impact of x_v and ρ on Π_s^N

FIGURE V. THE IMPACT OF x_s AND ρ ON Π_s^N .

We assume that service quality x_v of service provider equals to 70. Fig. 5 manifests the profit Π_s^N of service provider increases in supervision level ρ of service integrator. Simultaneously, Fig. 5 shows that there exists a specific supervision level ρ^* , when $\rho < \rho^*$, profit Π_s^N of service provider decreases in service quality x_s . However, considering the cost of service quality, when $\rho > \rho^*$, the profit Π_s^N of service provider increases in service quality x_s . Meanwhile, under the influence of certain incentive factor K , the changing tendency of service provider's profit function must be changed accordingly. We can find when service quality $x_s < 50$, the profit Π_s^N of service provider decreases in supervision level ρ , namely, when $x_s = 45$, $\Pi_s^{\rho=0.9} < \Pi_s^{\rho=0.5} < \Pi_s^{\rho=0.1}$. When service quality $x_v > 50$, the profit Π_s^N of service provider increases in supervision level ρ , namely, when $x_s = 70$, $\Pi_s^{\rho=0.9} > \Pi_s^{\rho=0.5} > \Pi_s^{\rho=0.1}$.

B. Considering Entanglement Degree

(1) The impact of γ and ρ on x_v^{Q*}

FIGURE VI. THE IMPACT OF γ AND ρ ON x_v^{Q*}

Fig. 6 demonstrates optimal service quality x_v^{Q*} of service integrator increases in entanglement degree γ , however, x_v^{Q*} decreases in supervision level ρ . When $0 < \gamma < 2.25$, $x_v^{Q*\rho=0.1} < x_v^{Q*\rho=0.5} < x_v^{Q*\rho=0.8}$. When $2.25 < \gamma < 2.5$, $x_v^{Q*\rho=0.1} < x_v^{Q*\rho=0.8} < x_v^{Q*\rho=0.5}$. When $2.5 < \gamma < 3.25$,

$x_v^{Q*\rho=0.8} < x_v^{Q*\rho=0.1} < x_v^{Q*\rho=0.5}$. When $\gamma > 3.25$, $x_v^{Q*\rho=0.1} > x_v^{Q*\rho=0.5} > x_v^{Q*\rho=0.8}$. Meanwhile, Fig. 6 shows that change trend of service integrator's the optimal service quality is obvious under lower supervision level ρ . Therefore, a higher supervision level ρ is advantageous for service quality of service integrator to maintain a stable state.

(2) The impact of γ and ρ on x_s^{Q*}

FIGURE VII. THE IMPACT OF γ AND ρ ON x_s^{Q*} .

From Fig. 7, optimal service quality x_s^{Q*} of service provider decreases in entanglement degree γ and x_s^{Q*} increases in supervision level ρ of service integrator. When $0 < \gamma < 2.16$, $x_s^{Q*\rho=0.1} > x_s^{Q*\rho=0.5} > x_s^{Q*\rho=0.8}$. When $0.216 < \gamma < 0.42$, $x_s^{Q*\rho=0.1} > x_s^{Q*\rho=0.8} > x_s^{Q*\rho=0.5}$. When $0.42 < \gamma < 0.445$, $x_s^{Q*\rho=0.8} > x_s^{Q*\rho=0.1} > x_s^{Q*\rho=0.5}$. When $\gamma > 0.445$, $x_s^{Q*\rho=0.1} < x_s^{Q*\rho=0.5} < x_s^{Q*\rho=0.8}$. When entanglement degree γ is higher, supervision level ρ of service integrator is higher as well. Furthermore, service quality of service provider is higher. Because higher service quality will bring higher cost of service quality and influence the profit of SSC members. Consequently, in early cooperation of SSC members, an appropriate supervision level is beneficial for service provider to obtain a superior service quality.

(3) The impact of γ and ρ on Π_v^Q

FIGURE VIII. THE IMPACT OF γ AND ρ ON Π_v^Q .

From Fig. 8, as entanglement degree γ increases gradually, the profit of service integrator Π_v^Q constantly increases. The profit of service integrator Π_v^Q increases in supervision level

ρ of service integrator. When supervision level $\gamma > 0.4$, the change trend of service integrator's profit Π_v^Q is obvious with entanglement degree γ and growth slope become bigger. Finally, the profit of service integrator Π_v^Q tends to a stable value. Similarly, when entanglement degree $\gamma > 3$, growth slope of service integrator's profit Π_v^Q becomes bigger with supervision level ρ of service integrator and keeps in a fix value at last. Thus, in order to obtain more profits, service integrator should take a higher entanglement degree γ and supervision level ρ in SSC.

(4) The impact of γ and ρ on Π_s^Q

From Fig. 9, we set the inflection point in the graphics as γ_1^* . γ_1^* increases in supervision level ρ . Under the condition of a certain supervision level, when $0 < \gamma < \gamma_1^*$, the profit of service provider Π_s will increase in entanglement degree γ gradually. When $\gamma > \gamma_1^*$, Π_s will decrease in entanglement degree γ . When $\Pi_s < 0$, the model have no practical significance. Meanwhile, through further analysis of Fig. 9, we will find that various entanglement degree γ will lead to different impact trends of supervision level ρ on Π_s . When $0 < \gamma < \gamma_1^*$, the profit of service provider Π_s will increase in supervision level ρ gradually. There will be a value of entanglement degree γ_2^* , when $\gamma_1^* < \gamma < \gamma_2^*$, the profit of service provider Π_s will increase in ρ at first and then decrease as supervision level ρ increases; until $\Pi_s < 0$, supervision level cannot be improved anymore. When $\gamma_2^* < \gamma$, the profit of service provider Π_s will decrease in supervision level ρ . Entanglement degree γ is a crucial factor to get the optimal profit of service provider in SSC.

FIGURE IX. THE IMPACT OF γ AND ρ ON Π_s^Q .

V. CONCLUSION

In this paper, we investigate service quality decisions of both members in SSC including one service integrator and one services provider with stochastic demand. On the basis of Nash

equilibrium and quantum game, we obtain optimal service quality and optimal profits of service provider and service integrator. Among them, quantum game combines quantum information theory and game theory together. Since quantum system has the characteristics of superposition and entanglement, when a classic game is put in the framework of quantization, a superior solution or a better utility value can often be obtained.

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