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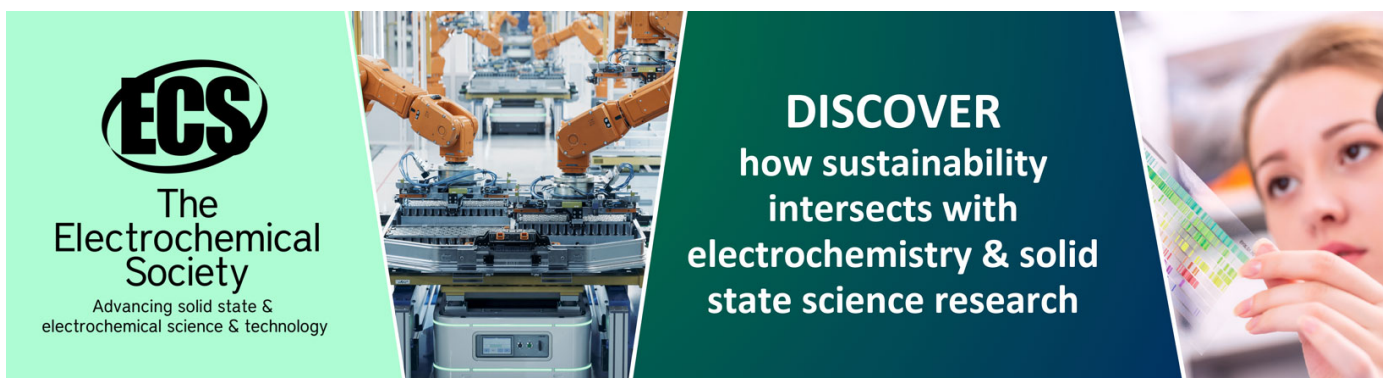
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Cooperative Incentive Model of Supply Chain Quality Control Based on Cost-sharing Contract

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Abstract. In order to motivate suppliers to invest more efforts to improve product quality, a game-theoretic optimization model was used to build a retailer-multi-vendor cooperative quality control incentive model based on cost-sharing contracts, and the effectiveness and rationality of the model are verified by an example. The results show that the quality control cooperation incentive model can improve the coordination effect and share the supplier's quality control costs through retailers to promote suppliers to invest more quality efforts, increase the profits of retailers and suppliers, and thus achieve the overall profit of the supply chain maximize.

Keywords. Cost-sharing contract, Cooperative incentive, Quality control effort level, Coordination effort level, Supply chain.

1. Introduction

With the advent of the Internet era, retailers and suppliers with online sales channels have switched from a simple production and sales relationship to a collaborative production and sales relationship. In the process of production and sales, due to the decentralized decision of retailers and suppliers, maximizing the interests of all parties will damage the interests of other members and the supply chain. At present, many researches have been carried out from the aspects of supply chain conflict of interest coordination and supply chain incentive mechanism. Gerard [1] designs a distribution model based on the economic income of all parties in the supply chain. Kannan et al. [2] and Omkar [3] both proceed from the setting of the revenue sharing contract and set the benefit sharing factor to achieve the coordination of maximizing the profit of the entire supply chain. In terms of incentive mechanism, research mainly focuses on analyzing incentive obstacles, establishing incentive mechanisms, setting incentive ratios, and incentive strategies. Naini et al. [4] and Ghosh et al. [5] analyze the profit distribution incentive problem under symmetric information, and use the game model to solve the Pareto optimality of effort level and return. Liu qianwen et al. [6] studied the influence of consumers' preference for delivery speed and quality control level of fresh agricultural products on the pricing and ordering strategy of supply chain under the e-commerce environment of fresh agricultural products. From the perspective of cost sharing, this paper considers the dominance of retailers in the supply chain, and uses game theory and optimization models to build a cost-sharing contract for retailer-multi-vendor collaborative quality control in order to help supply chain managers and Decision makers address incentives.



2. The Optimal Cost-sharing Incentive Model for Quality Control

It is an urgent problem for retailers. In order to highlight the effect of cooperation incentive, this paper discusses the coordination level of retailers separately, and separates the cooperation incentive in supply chain coordination, and constructs a revenue sharing model based on quality control effort level, active cooperation level and coordination effort level, and then designs the cooperation incentive strategy based on cost sharing contract.

2.1. Basic Assumptions

(1) There are a retailer and n suppliers, all of which aim to maximize their own interests, and the retailer has advantages in information, status, etc. The retailer is in a dominant position in the supply chain system, and can implement coordination and control. While the supplier is in a subordinate position and cooperates with the retailer's coordination to provide them with corresponding products or services, thereby forming a stable cooperative relationship.

(2) In the process of supply chain production and sales, the level of quality control efforts of suppliers, the level of quality control efforts of retailers, and the level of coordination efforts have a significant impact on maximizing the overall supply chain revenue.

(3) In the process of production and sales of supply chain, after the general contract is signed, the price and quantity are often relatively fixed. The supplier's quality control efforts, active cooperation and coordination with retailers are the focus of retailers' attention. This paper selects the quality control effort level, active cooperation level, and coordinated effort level as the three reference variables, regardless of factors such as price and quantity that affect the entire supply chain. Q_i and C_{0i} are respectively the quality control effort level and active cooperation level of supplier i ($i=1,2,\dots,n$). Q_0 and O_{0i} are the level of quality effort of the retailer and the level of coordination

effort for the supplier, in general, $Q_i, C_{0i}, Q_0, O_{0i} \in (0,1]$, and $\sum_{i=1}^n O_{0i} \leq 1$.

2.2. Cost Sharing Incentive Mechanism

The cost-sharing incentive mechanism is divided into two categories for analysis according to the incentive situation of retailers.

Considering that it takes a lot of cost to improve the quality of the products, sharing the production cost of the supplier can reduce the production risk of the supplier, improve the capital turnover ability, and motivate the supplier to cooperate with the retailer. It can be seen that sharing supplier costs is an effective way to motivate suppliers. Let the retailer share the supplier's (i) quality control costs as a proportion θ_i ($0 < \theta_i < 1$). Because the retailer implements measures to share the supplier's quality control costs, a balance between Nash and Shapely is created between the retailer and the supplier, so the retailer's and supplier's related revenue coefficient, quality control effort cost coefficient and coordination effort level coefficient all change.

In this case, the supplier's profit function is

$$\begin{aligned}\bar{P}_i(C_{0i}, Q_i, \theta_i) &= \bar{R}_i(C_{0i}, Q_i) - (1 - \theta_i) \bar{E}_i(Q_i) - d_i \\ &= r_i + \bar{a}_i \left(C_{0i} \sum_{i=1}^n C_{0i} \right) Q_i^{e_i} - (1 - \theta_i) \bar{b}_i Q_i^{h_i} - d_i(C_{01}, \Lambda, C_{0i}, \Lambda, C_{0n})\end{aligned}$$

In this formula: $\bar{R}_i(C_{0i}, Q_i) = r_i + \bar{a}_i \left(C_{0i} \sum_{i=1}^n C_{0i} \right) Q_i^{e_i}$ is revenue function, $\bar{E}_i(Q_i) = \bar{b}_i Q_i^{h_i}$ is

quality control effort cost function. When the retailer takes incentive measures, the retailer's profit function is

$$\begin{aligned}\overline{P}_0(C, Q_0, O, \theta_i) &= \overline{R}_0(C, Q_0, O) - \overline{E}_0(Q_0) - \overline{F}_0(O) - \sum_{i=1}^n \theta_i \overline{E}_i(Q_i) \\ &= r_0 + \left[\overline{a}_0 Q_0^{e_0} + \overline{f}_0 \left(\sum_{i=1}^n O_{0i} \right)^{g_0} \right] \left(\sum_{i=1}^n C_{0i} \right) - \overline{b}_0 Q_0^{h_0} - \overline{c}_0 \left(\sum_{i=1}^n O_{0i} \right)^{j_0} - \sum_{i=1}^n \theta_i \overline{b}_i Q_i^{h_i}\end{aligned}$$

In this formula: $\overline{R}_0(C, Q_0, O) = r_0 + \left[\overline{a}_0 Q_0^{e_0} + \overline{f}_0 \left(\sum_{i=1}^n O_{0i} \right)^{g_0} \right] \left(\sum_{i=1}^n C_{0i} \right)$ is revenue function;

$\overline{E}_0(Q_0) = \overline{b}_0 Q_0^{h_0}$ is quality control effort cost function; $\overline{F}_0(O) = \overline{c}_0 \left(\sum_{i=1}^n O_{0i} \right)^{j_0}$ is coordinated effort

cost function.

With the incentive measures, the profit function of the supply chain system is

$$\begin{aligned}\overline{P}(C, Q, O) &= \overline{P}_0(C, Q_0, O_{0i}, \theta_i) + \sum_{i=1}^n \overline{P}_i(C_{0i}, Q_i, \theta_i) \\ &= r_0 + \left[\overline{a}_0 Q_0^{e_0} + \overline{f}_0 \left(\sum_{i=1}^n O_{0i} \right)^{g_0} \right] \left(\sum_{i=1}^n C_{0i} \right) - \overline{b}_0 Q_0^{h_0} - \overline{c}_0 \left(\sum_{i=1}^n O_{0i} \right)^{j_0} \\ &\quad + \sum_{i=1}^n \left[m_i + \overline{a}_i \left(C_{0i} \sum_{i=1}^n C_{0i} \right) Q_i^{e_i} - \overline{b}_i Q_i^{h_i} - d_i(C_{01}, \Lambda, C_{0i}, \Lambda, C_{0n}) \right]\end{aligned}$$

Theorem 1 In the supply chain system, when the retailer implements incentives to the supplier, the optimal quality control effort level of the retailer and the supplier and the optimal coordination effort level of the retailer are as follows:

$$Q_0^{**} = \left(\overline{a}_0 e_0 \sum_{i=1}^n \frac{C_{0i}}{b_0 h_0} \right)^{\frac{1}{h_0 - e_0}}; Q_i^{**} = \left[\overline{a}_i e_i \left(C_{0i} \sum_{i=1}^n C_{0i} \right) / \left(\overline{b}_i h_i \right) \right]^{\frac{1}{h_i - e_i}}; \left(\sum_{i=1}^n O_{0i} \right)^{**} = \left(\overline{f}_0 g_0 \sum_{i=1}^n \frac{C_{0i}}{c_0 j_0} \right)^{\frac{1}{j_0 - g_0}}$$

In the case of incentives implemented by retailers, the optimal level of quality control efforts of retailers and suppliers and the optimal level of coordination efforts of retailers are substituted into the retailer's and supplier's profit function expressions. The profit function of the retailer and supplier under the incentive measures and the profit function of the supply chain system are as follows:

$$\begin{aligned}\overline{P}_0^{**}(C, Q_0^{**}, O^{**}, \theta_i) &= r_0 + \frac{\left(\overline{a}_0 \sum_{i=1}^n C_{0i} \right)^{\frac{h_0}{h_0 - e_0}}}{\overline{b}_0^{\frac{e_0}{h_0 - e_0}}} \left[\left(\frac{e_0}{h_0} \right)^{\frac{e_0}{h_0 - e_0}} - \left(\frac{e_0}{h_0} \right)^{\frac{h_0}{h_0 - e_0}} \right] + \frac{\left(\overline{f}_0 \sum_{i=1}^n C_{0i} \right)^{\frac{j_0}{j_0 - g_0}}}{\overline{c}_0^{\frac{g_0}{j_0 - g_0}}} \left[\left(\frac{g_0}{j_0} \right)^{\frac{g_0}{j_0 - g_0}} - \left(\frac{g_0}{j_0} \right)^{\frac{j_0}{j_0 - g_0}} \right] \\ &\quad - \sum_{i=1}^n \theta_i \frac{\left(\overline{a}_i C_{0i} \sum_{i=1}^n C_{0i} \right)^{\frac{h_i}{h_i - e_i}}}{\overline{b}_i^{\frac{e_i}{h_i - e_i}}} \left(\frac{e_i}{h_i} \right)^{\frac{h_i}{h_i - e_i}}\end{aligned} \quad (1)$$

$$\overline{P}_i^{**}(C_{0i}, Q_i^{**}, \theta_i) = r_i - d_i + \frac{\left(\overline{a}_i C_{0i} \sum_{i=1}^n C_{0i} \right)^{\frac{h_i}{h_i - e_i}}}{\overline{b}_i^{\frac{e_i}{h_i - e_i}}} \left[\left(\frac{e_i}{h_i} \right)^{\frac{e_i}{h_i - e_i}} - (1 - \theta_i) \left(\frac{e_i}{h_i} \right)^{\frac{h_i}{h_i - e_i}} \right] \quad (2)$$

Correspondingly, the overall profit function of the supply chain is

$$\overline{P}^{**}(C, Q^{**}, O^{**}) = \overline{P}_0^{**}(C, Q_0^{**}, O^{**}, \theta_i) + \sum_{i=1}^n \overline{P}_i^{**}(C_{0i}, Q_i^{**}, \theta_i)$$

when a retailer adopts incentive measures, it is necessary to guarantee that the profits of the retailer and the supplier after the incentive shall not be less than those before the incentive.

$$\frac{\partial \overline{P}_i^{**}(C_{0i}, Q_i^{**}, \theta_i)}{\partial \theta_i} = \frac{\left(\overline{a}_i C_{0i} \sum_{i=1}^n C_{0i} \right)^{\frac{h_i}{h_i - e_i}}}{\overline{b}_i^{\frac{e_i}{h_i - e_i}}} \left(\frac{e_i}{h_i} \right)^{\frac{h_i}{h_i - e_i}} > 0; \quad \frac{\partial \overline{P}_0^{**}(C, Q_0^{**}, O^{**}, \theta_i)}{\partial \theta_i} = - \sum_{i=1}^n \left[\frac{\left(\overline{a}_i C_{0i} \sum_{i=1}^n C_{0i} \right)^{\frac{h_i}{h_i - e_i}}}{\overline{b}_i^{\frac{e_i}{h_i - e_i}}} \left(\frac{e_i}{h_i} \right)^{\frac{h_i}{h_i - e_i}} \right] < 0$$

Based on this, the goal is to maximize the sum of the squares of the added value of the profits of the retailers and suppliers, and the profit of retailers and suppliers under the non-incentive condition is taken as the negotiation deterrence point. A retailer multi supplier cooperative quality control incentive model based on cost sharing contract is constructed, as follows:

$$\begin{aligned} & \max \left[(\Delta P_0)^2 + \sum_{i=1}^n (\Delta P_i)^2 \right] \\ & \text{s.t.} \begin{cases} \Delta P_0 = \overline{P}_0^{**}(C, Q_0^{**}, O^{**}, \theta_i) - P_0^*(C, Q_0^*, O^*) \geq 0 \\ \Delta P_i = \overline{P}_i^{**}(C_{0i}, Q_i^{**}, \theta_i) - P_i^*(C_{0i}, Q_i^*) \geq 0 \\ \Delta P_0 + \sum_{i=1}^n \Delta P_i = \Delta P \\ \theta_i \in [\alpha_i, \beta_i], 0 < \alpha_i \leq \beta_i \leq 1 \end{cases} \end{aligned} \quad (3)$$

In the formula: For the supplier i , the minimum share of the retailer's acceptable cost sharing is α_i ; for the supplier i , the maximum share of the retailer's cost sharing is β_i , and $0 < \alpha_i \leq \beta_i \leq 1$.

In order to simplify the calculation, we can make θ_i equal. The optimal cost sharing ratio θ can be obtained by solving equation (3), and the profit of retailers and suppliers after taking incentive measures can be obtained by substituting θ into equation (1) and equation (2).

3. Example Analysis

According to the collected data of the retailers and their suppliers, the least squares method can be used to estimate the relevant parameters and coefficients of a retailer and four suppliers about a product, as shown in table 1 and 2.

Table 1. Retailer related parameters.

r_0	a_0	b_0	c_0	f_0	e_0	h_0
1.6	21	28	50	20	0.48	2.5
	$\overline{a_0}$	$\overline{b_0}$	$\overline{c_0}$	$\overline{f_0}$	g_0	j_0
	22	44	45	21	0.5	2

Table 2. Supplier related parameters.

	r_i	C_{0i}	a_i	b_i	e_i	h_i	$\overline{a_i}$	$\overline{b_i}$	d_i
Supplier1	1.01	0.43	15	25	0.51	2.1	21	11	0.85
Supplier2	1.05	0.55	14.5	21	0.53	2.3	21.5	10	1.65
Supplier3	1.11	0.41	15.5	22	0.52	2.2	21.5	12	0.7
Supplier4	0.99	0.46	15.1	21	0.48	2.4	22.7	11.5	0.75

Table 3. Comparison of interests between retailers before and after incentives.

		Optimal coordination effort level	Optimal quality control effort level	Profit	Supply chain profit
No incentives	Retailer	0.3247	0.5195	40.3363	62.2222
	supplier1		0.2579	4.6861	
	supplier2		0.3575	5.9821	
	supplier3		0.2918	5.1421	
	supplier4		0.3398	6.0757	
incentives	Retailer	0.3598	0.7347	67.8711	115.2498
	supplier1		0.5340	10.2577	
	supplier2		0.6791	14.3850	
	supplier3		0.5087	10.0123	
	supplier4		0.5798	12.7236	

According to the parameter data, the profit values of retailers, suppliers and supply chains before and after taking the incentive measures can be obtained, as shown in table 3, and the formula can be used to obtain the optimal quality control effort level of retailers and suppliers before and after taking the incentive measures coordination and the optimal coordination effort level of retailers.

According to the constructed incentive model, the optimal quality control effort level and the optimal coordination effort level of retailers and suppliers who have adopted the incentive measures are substituted into equation (3), and then it is easy to get $\theta = 0.3097$ by Matlab. Substituting the parameter θ into the profit model of the retailer and supplier, the profit of all parties after taking the incentive measures are shown in table 3.

4. Conclusion

Aiming at the problem of incentives in the supply chain system, from the perspective of sharing costs, a retailer multi-supplier quality control cooperation incentive model is constructed by using game theory and optimization models with the threats of retailers and suppliers' non-incentive cooperation. Through the analysis of models and examples, it can be seen that the incentive mechanism designed in this paper can protect the interests of retailers and suppliers from being damaged. Retailers can mobilize the enthusiasm of suppliers by increasing the level of coordination efforts and using cost sharing contracts with suppliers, promote suppliers to invest more levels of quality control efforts, and

maximize profits throughout the supply chain, and ensure the relationship between retailers and suppliers. To some extent, it solves the problem of incentives for retailers and suppliers to improve quality in the supply chain.

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