ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

Research on Coordination Contract of Three-Level Logistics Service Supply Chain under Competitive Environment

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Abstract

This paper examines how manufacturers can leverage new retail technologies to develop O2O (online-to-offline) markets and strengthen the coordination strategies of third-party logistics service supply chains in competitive market conditions. The first part of this paper introduces the research background and problem, and proposes the assumptions and symbols to be used. The latter part of the paper employs a backward induction method to solve the model and calculate the results. Based on the calculations, the study designs contracts and verifies the effectiveness of the proposed cost-sharing contract in addressing channel invasion by manufacturers. The paper concludes with management insights drawn from the research findings.

Keywords

E-commerce; Logistics service supply chain; Logistics Service Effort Level; Cost sharing contract; The competitive environment.

1. INTRODUCTION

In recent years, global digital technology and the digital economy have rapidly developed, vigorously promoting the digital transformation of various industries, significantly improving people's living standards, and continuously expanding the scale of e-commerce transactions. Taking China as an example, according to the "China E-commerce Report (2021)", the domestic e-commerce transaction volume in China reached 42.3 trillion yuan in 2021, a year-on-year increase of 19.6%. Innovative business models such as live streaming e-commerce and instant retail continuously stimulate consumer potential and drive the upgrading of network retail.

Logistics is an important component of e-commerce, and with the development of the times, e-commerce logistics operations have become more challenging. If merchants hope to gain more economic benefits through live streaming, they need to bear greater "explosive order" pressure. Some merchants even promise "buy one get N" in live streaming rooms to attract consumers to actively place orders. A large number of complex orders undoubtedly increase the difficulty of logistics distribution. Phenomena such as "out of stock", "delayed delivery", and "damaged goods" hinder consumers' repeat purchase behavior, and the logistics service level cannot keep up. "Explosive orders" can make merchants cry, and can also cause reputational damage to e-commerce platforms. Currently, e-commerce platforms mostly adopt light-asset operation models. This is mainly because self-built logistics requires huge capital investment. Therefore, this paper mainly conducts research on the three-level logistics service supply chain composed of e-commerce platforms-logistics service integrators-logistics service integrators.

In addition, the e-commerce industry is facing increasingly intense market competition. With the rapid development of global digital technology and digital economy, not only the e-commerce industry, but also the traditional manufacturing industry is actively promoting digital transformation, gradually connecting online and offline, and new retail and other

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

emerging formats are emerging, promoting market prosperity, but also increasing market competition. Brand owners open new retail stores offline, focus on mining sales data, meet consumers' personalized improvement needs, enhance their market share grabbing ability, and reduce their dependence on e-commerce platforms. In the context of increasingly fierce market competition and consumers' constantly increasing demands for logistics service levels, it is urgent to conduct research on e-commerce logistics service supply chain coordination strategies, provide low-cost and high-quality logistics services to consumers, improve the overall competitiveness of the supply chain, and cannot be delayed.

Some studies have already investigated the operation of e-commerce game systems under competitive environments. As manufacturers or brand owners gain more strength, they often choose to open up other sales channels and change the original sales structure, which is known as channel invasion. Chiang et al. [1]analyzed the impact of manufacturers opening up direct sales channels on the members of the supply chain and found that introducing direct sales channels can lead to a win-win situation. Arya et al. [2]conducted separate studies on the case of general manufacturers' invasion, considering direct sales costs, cost-reducing investments, and quality decisions. Jin et al. [3]established a supply chain consisting of an incumbent manufacturer, an entering manufacturer, and a retailer. They considered two manufacturers producing substitute products with brand differentiation and sold through the same retailer to the same market. They constructed a benchmark model before market invasion and a power structure model dominated by manufacturers and retailers respectively after market invasion, and obtained a unique equilibrium solution. Zhou et al. [4]modeled and analyzed the decision-making of manufacturers in a single (or dual) channel supply chain under incomplete information conditions, through adjusting entrance fees and wholesale prices to signal transmission. Zheng et al. [5]constructed a two-tier supply chain model consisting of manufacturers and retailers and established a channel invasion decision-making model for manufacturers under two situations: without remanufacturing and with remanufacturing. They analyzed the intrinsic relationship between product remanufacturing, channel competition, and manufacturer's channel invasion decision-making. They found that when the competition between channels is strong, the external effect of remanufacturing on retailers cannot offset the impact of channel conflict on retailers' profits, so channel invasion will harm retailers' interests. Jing et al. [6]considered the market situation where retailers obtain market uncertainty demand information through investigation, while manufacturers may establish direct sales channels to compete with retailers. They constructed a two-tier supply chain composed of retailers and manufacturers, characterized the optimal collection and disclosure strategies for retailers under centralized and decentralized decision-making, and the optimal invasion strategy for manufacturers. Based on this, they designed a fixed reward incentive mechanism to promote retailers to collect and disclose demand information. The research conducted by Sun et al.[7] demonstrates that channel intrusion by manufacturers erodes the profits of retailers. Hu et al.[8] establish static and dynamic evolutionary game models of manufacturer intrusion and non-intrusion under fair concern and fair neutrality of retailers, and point out that under static and fair neutrality, intrusion is harmful to retailers in most cases, while under dynamic and fair concern, manufacturers can achieve a win-win situation by considering the benefits of retailers from fair concern when intruding. Li et al.[9] study a two-stage supply chain evolutionary model before and after the intrusion of new retail channels, respectively, and compare the optimal prices of decision makers under decentralized and centralized decision models, and analyze the impact of various variables on channel pricing and participant profits before and after channel intrusion. Nie et al.[10] find that when both retailers and manufacturers choose channel strategies, the intrusion of manufacturers under the dual-channel sales channel strategy of retailers may increase the profits of both parties, achieving a win-win situation. However, as the acceptance of online channels by consumers increases, manufacturers will erode the profits of

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

retailers. From the above, it can be seen that in today's society, with the rapid development of 5G and logistics, competition among businesses is intensifying. However, there is little research on the three-level logistics service supply chain in a competitive environment. This article considers this situation and designs a contract optimization for the effectiveness of supply chain operations.

Another study related to this article is the research on supply chain coordination. Netessine and Rudi[11] studied cooperative contracts between suppliers and retailers for sharing promotion costs. Cachon and Lariviere[12] proved that revenue-sharing contracts can coordinate two-level supply chains that include one or more retailers. Giannoccaro and Pontrandolfo[13] extended the application of revenue-sharing mechanisms to multi-level supply chains. Wu and Dan[14] studied the decision problem of logistics outsourcing using a dynamic game model and achieved coordination of inventory levels and service levels through a contract that shares revenue and costs. Wang Yong and Li Liying[15] added endogenous pricing decisions based on this and used the same contract combination to achieve channel coordination. Cao Wei et al.[16] focused on a new logistics model that involves e-commerce enterprises, express delivery enterprises, and convenience stores. They used a Stackelberg model to solve for variable values and profit levels for centralized decision-making, decentralized decision-making, and three types of semi-centralized decision-making scenarios under the premise that price and logistics service levels jointly affect market demand. They also designed a revenue-sharing and cost-sharing contract to coordinate ordering and service level decisions in the system. Wang Daoping et al.[17] established a dynamic programming equation for network retailers and e-commerce platforms and provided methods for finding optimal pricing and optimal promotion decisions. They designed a cost-sharing contract to increase expected profits for both parties. Xiao Di[18] et al. studied the coordination effect of order quantity commitment contracts used by e-commerce enterprises in a supply chain consisting of a single e-commerce enterprise and a single supplier in a C2B e-commerce model. Xie Jiaping et al.[19] discussed supply chain coordination problems in the context of e-commerce shopping festivals under both complete and incomplete information scenarios, providing guidance for e-commerce platforms' ordering decisions during the shopping festival.

2. PROBLEM DESCRIPTION AND MODEL ASSUMPTIONS

This chapter explores the coordination strategies of the e-commerce logistics service supply chain under intensified competitive situations. A game model is constructed consisting of a single e-commerce platform, a logistics service integrator, and logistics service providers in the market. In the model, the e-commerce platform acts as the game leader and determines the sale price of the goods, and proposes the required level of logistics services based on market performance. The logistics service integrator acquires logistics service capabilities available in the market and sells them to the e-commerce platform. The integrator is responsible for determining the wholesale price of logistics services and the final level of logistics services.

The supply chain structure under investigation in this chapter is illustrated in Figure 1:

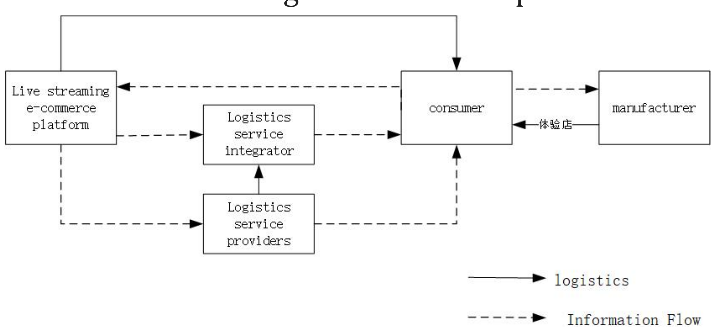


Figure 1. Game Structure of Logistics Service Supply Chain

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

Table 1. Shows the mathematical symbols and their meanings required in this chapter.

Table 1. Mathematical Symbols and Their Meanings

Symbols	Meaning
π_{e1}^{1}	Profit earned by the e-commerce platform under scenario i. (i=C,D,D-J1)
π_{e2}^{i}	Profit earned by the Logistics service integrator under scenario i. (i=C,D,D-J1)
π_{e3}^{i}	Profit earned by the Logistics service provider under scenario i. (i=C,D,D-J1)
π_{esc}^{i}	Profit earned by the logistics service supply chain under scenario i. (i=C,D,D-J1)
A	Basic market demand for goods
p_{ea}	e-commerce retail price
p_b	manufacturer's set retail price
p_{el}	logistics service retail price
w_e	logistics service wholesale price
s_{el}	logistics service effort level
α	consumer preference for live streaming e-commerce sales channels
β	channel price sensitivity coefficient
b	the impact of logistics service effort level on market demand coefficient
c	the cost per unit of goods
c_l	the basic cost per unit of logistics service
k	logistics service effort cost coefficient
m_e	e-commerce platform marginal revenue
m_{el}	logistics service integrator marginal revenue
η	cost sharing ratio
C	centralized system
D	decentralized system
$D-J1$	cost sharing contract

To ensure that each profit function can be optimized and has practical meaning, this study proposes the following assumptions regarding the range of variable values: $2k-b^2>0$, $4k-b^2>0$, $4k(1-\eta)-b^2>0$, and $\alpha A+\beta p_b-(c+c_l)>0$.

In addition, to focus the research on the main issues, this paper also makes the following assumptions:

1. The demand function is: $D=\alpha A-p_{\mathrm{a}}+\beta p_b+bs_l$, where $0<\alpha<1$, $A>0$, $0<\beta<1$, $\mathrm{b}>0$, $\mathrm{p}_a=m+m_l+w+c$.

2. All members of the logistics service supply chain make rational decisions. In the case of centralized decision-making, members of the logistics service supply chain are considered as a whole, with the goal of maximizing the supply chain's profit. In the case of decentralized decision-making, each member aims to maximize their own benefit.

3. The e-commerce platform is the leader in the Stackelberg game, while the logistics service integrators and logistics service providers are followers.

4. Logistics service costs consist of two parts. The first is the basic cost of logistics services, which is paid by the logistics service provider per unit. The second is the effort cost of logistics

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

services, which is mainly incurred by the logistics service integrator to improve the level of logistics services.

3. DECISION MODEL CONSTRUCTION AND COMPARISON

3.1. Centralized model

Based on the introduction of mathematical symbols and related research background above, it can be concluded that under centralized decision-making, market demand is affected by the retail price of goods and the effort level of logistics services. The demand function can be represented by symbols as follows:

$$D_e = \alpha A - p_{ea} + \beta p_b + b s_{el} \tag{1}$$

Under centralized decision-making, each member of the live e-commerce supply chain is regarded as a whole, so combined with the introduction of mathematical symbols and related research background, the profit function of the logistics service supply chain can be expressed as:

$$\pi_{esc}^{c} = (p_{ea} - c - c_l) \cdot D_e - \frac{1}{2} k s_{el}^2 \tag{2}$$

The optimal commodity pricing strategy and optimal service level under centralized decision-making can be obtained:

$$s_{el}^{c} = -\frac{b[(c + c_l) - (\alpha A + \beta p_b)]}{2k - b^2} \tag{3}$$

$$p_{ea}^{c} = \frac{k(\alpha A + \beta p_b) + (k - b^2)(c + c_l)}{2k - b^2} \tag{4}$$

The optimal profit under centralized decision-making is:

$$\pi_{esc}^{c} = \frac{k(b^2 + 2k)[(\alpha A + \beta p_b) - (c + c_l)]^2}{2(2k - b^2)^2} \tag{5}$$

3.2. Decentralized model

Under decentralized decision-making, each member of the live streaming e-commerce supply chain is a rational decision maker pursuing their own profit maximization. The live streaming e-commerce platform, logistics service integrators, and logistics service providers form a Stackelberg game, in which the live streaming e-commerce platform is the game leader and the logistics service integrators and logistics service providers are followers. The market demand function is the same as that under centralized decision-making, and the profit function is as follows:

$$\pi_{e1}^{D} = (p_{ea} - p_{el} - c) \cdot D_e \tag{6}$$

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

$$\pi_{e2}^{D}=(p_{el}-w_{e})\cdot D_{e}-\frac{1}{2}ks_{el}^{2} \tag{7}$$

$$\pi_{e3}^{D}=(w_{e}-c_{l})\cdot D_{e} \tag{8}$$

$$\pi_{esc}^{D}=(p_{ea}-c-c_{l})\cdot D_{e}-\frac{1}{2}ks_{el}^{2} \tag{9}$$

Based on the introduction of the symbols and modeling background in the previous text, it can be inferred that $p_{ea}=m_{e}+m_{el}+w_{e}+c$, Therefore, the profit function can be transformed as:

$$\pi_{e1}^{D}=m_{e}\cdot[\alpha A-(m_{e}+m_{el}+w_{e}+c)+\beta p_{b}+bs_{el}] \tag{10}$$

$$\pi_{e2}^{D}=m_{el}\cdot[\alpha A-(m_{e}+m_{el}+w_{e}+c)+\beta p_{b}+bs_{el}]-\frac{1}{2}ks_{el}^{2} \tag{11}$$

$$\pi_{e3}^{D}=(w_{e}-c_{l})\cdot[\alpha A-(m_{e}+m_{el}+w_{e}+c)+\beta p_{b}+bs_{el}] \tag{12}$$

$$\pi_{esc}^{D}=\pi_{e1}^{D}+\pi_{e2}^{D}+\pi_{e3}^{D} \tag{13}$$

By using backward induction, we can obtain:

The optimal marginal revenue of the e-commerce platform:

$$m_{e}^{D}=-\frac{c+c_{l}-(\alpha A+\beta p_{b})}{2} \tag{14}$$

The optimal logistics service decision and optimal marginal profit of the logistics service integrator are:

$$m_{l}^{D}=-\frac{k[c+c_{l}-(\alpha A+\beta p_{b})]}{4k-b^{2}} \tag{15}$$

$$s_{l}^{D}=-\frac{b[c+c_{l}-(\alpha A+\beta p_{b})]}{2(4k-b^{2})} \tag{16}$$

The optimal wholesale price of logistics services for the logistics service provider

$$w_{e}^{D}=\frac{k[7c_{l}-c+\alpha A+\beta p_{b}]-2c_{l}b^{2}}{2(4k-b^{2})} \tag{17}$$

Based on the above analysis, the optimal retail price strategy for the e-commerce platform can be obtained as follows:

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

$$p_{ea}^{D} = m_{e}^{D} + m_{el}^{D} + w_{e}^{D} + c = -\frac{(\alpha A + \beta p_{b})(b^{2} - 7k) + (c + c_{l})(b^{2} - k)}{2(4k - b^{2})} \tag{18}$$

Based on the equilibrium decisions obtained above, we can obtain the optimal profits of the e-commerce platform, logistics service integrator, and logistics service provider under decentralized decision-making as follows:

$$\pi_{e1}^{D} = \frac{k[c + c_{l} - (\alpha A + \beta p_{b})]^{2}}{4(4k - b^{2})} \tag{19}$$

$$\pi_{e2}^{D} = \frac{k[c + c_{l} - (\alpha A + \beta p_{b})]^{2}}{8(4k - b^{2})} \tag{20}$$

$$\pi_{e3}^{D} = \frac{k^{2}[c + c_{l} - (\alpha A + \beta p_{b})]^{2}}{4(4k - b^{2})^{2}} \tag{21}$$

The optimal profits of the logistics service supply chain:

$$\pi_{esc}^{D} = \frac{k(-3b^{2} + 14k)[c + c_{l} - (\alpha A + \beta p_{b})]^{2}}{8(4k - b^{2})^{2}} \tag{22}$$

3.3. Model comparative analysis

By comparing the centralized system with the decentralized system, we can obtain the following proposition:

proposition 1: By comparing centralized and decentralized decision-making, it can be concluded that when market competition intensifies, the optimal retail price of the logistics service supply chain under centralized decision-making is lower than that under decentralized decision-making. Moreover, the overall optimal profit of the supply chain under centralized decision-making is higher than that under decentralized decision-making, and the optimal effort level of logistics services under centralized decision-making is higher than the optimal profit level under decentralized decision-making. Which means $p_{ea}^{C} < p_{ea}^{D}$, $\pi_{esc}^{C} > \pi_{esc}^{D}$, $s_{el}^{C} > s_{el}^{D}$.

proposition 2: When market competition intensifies, under decentralized decision-making, the revenue of the e-commerce platform is twice that of the logistics service integrator. The profit of the logistics service integrator is greater than that of the logistics service provider. Which means $\pi_{e1}^{D} = 2\pi_{e2}^{D}$, $\pi_{e2}^{D} > \pi_{e3}^{D}$.

Proposition 1 and Proposition 2 imply that designing contracts for supply chain coordination is necessary.

4. CONTRACT COORDINATION DESIGN

This study explores the operational performance of the logistics service supply chain under the implementation of a cost-sharing contract (i.e., Model D-J1). The basic content of the contract is that the e-commerce platform agrees to bear a certain proportion of the logistics service effort cost of the logistics service integrator, in order to encourage the logistics service integrator to provide higher-level logistics services to customers.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

In Model D-J1, the e-commerce platform, the logistics service integrator, and the logistics service provider constitute a three-level Stackelberg game, in which the e-commerce platform is the game leader, and the logistics service integrator and the logistics service provider are followers. Therefore, the game sequence is as follows: the e-commerce platform first determines the retail price of the product, and then the logistics service integrator and the logistics service provider make their optimal decisions, respectively.

Based on the symbols introduced in the previous section and the problem background analysis, the profit functions of each member on the supply chain in Model D-J1 are as follows:

$$\pi_{e1}^{D-J1} = m_e[\alpha A - (m_e + m_{el} + w_e + c) + \beta p_b + bs_{el}] - \frac{1}{2}\eta k s_{el}^2 \tag{23}$$

$$\pi_{e2}^{D-J1} = m_{el}[\alpha A - (m_e + m_{el} + w_e + c) + \beta p_b + bs_{el}] - \frac{1}{2}(1-\eta) k s_{el}^2 \tag{24}$$

$$\pi_{e3}^{D-J1} = (w_e - c_l)\cdot[\alpha A - (m_e + m_{el} + w_e + c) + \beta p_b + bs_{el}] \tag{25}$$

$$\pi_{usc}^{D-J1} = \pi_{u1}^{D-J1} + \pi_{u2}^{D-J1} + \pi_{u3}^{D-J1} \tag{26}$$

Using the same mathematical solution method and steps as Model C and Model D, we can use backward induction to obtain a unique set of solutions that can achieve equilibrium in Model-DJ1. The optimal marginal revenue of the e-commerce platform, the optimal marginal revenue of the logistics service integrator, the optimal effort level of the logistics service, the optimal wholesale price of the logistics service, and the optimal retail price of the product are represented as follows:

$$m_e^{D-J1} = -\frac{[c + c_l - (\alpha A + \beta p_b)][b^2(2\eta - 1) + 4k(\eta - 1)^2]}{b^2(3\eta - 2) + 8k(\eta - 1)^2} \tag{27}$$

$$m_{el}^{D-J1} = -\frac{2k(\eta - 1)^2[c + c_l - (\alpha A + \beta p_b)]}{b^2(3\eta - 2) + 8k(\eta - 1)^2} \tag{28}$$

$$s_{el}^{D-J1} = \frac{b(\eta - 1)[c + c_l - (\alpha A + \beta p_b)]}{b^2(3\eta - 2) + 8k(\eta - 1)^2} \tag{29}$$

$$w_{el}^{D-J1} = \frac{b^2 c_l(3\eta - 2) - k(\eta - 1)^2[c - 7c_l + (\alpha A + \beta p_b)]}{b^2(3\eta - 2) + 8k(\eta - 1)^2} \tag{30}$$

$$P_{ea}^{D-J1} = \frac{(\alpha A + \beta P_b)[(2\eta - 1)(b^2 - 7k) + 7k\eta^2] + (\eta - 1)(c + c_l)[b^2 - k(1-\eta)]}{b^2(3\eta - 2) + 8k(\eta - 1)^2} \tag{31}$$

Based on the above, we can obtain the optimal profits of the e-commerce platform, logistics service integrator, and logistics service provider, which are as follows:

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

$$\pi_{e1}^{D-J1}=\frac{k(\eta-1)^2[c+c_l-(\alpha A+\beta p_b)]^2}{2[b^2(3\eta-2)+8k(\eta-1)^2]} \tag{32}$$

$$\pi_{e2}^{D-J1}=\frac{k(\eta-1)^3[c+c_l-(\alpha A+\beta p_b)]^2[b^2+4k(\eta-1)]}{2[b^2(3\eta-2)+8k(\eta-1)^2]^2} \tag{33}$$

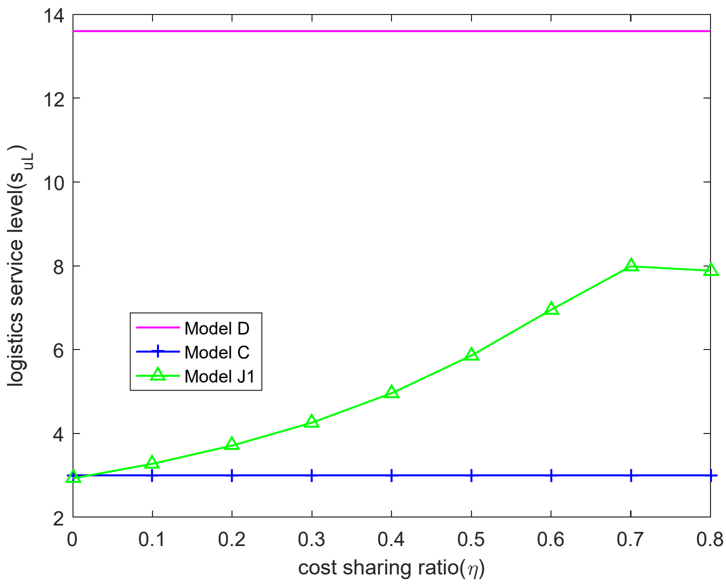
$$\pi_{e3}^{D-J1}=\frac{k^2(\eta-1)^4[c+c_l-(\alpha A+\beta p_b)]^2}{[b^2(3\eta-2)+8k(\eta-1)^2]^2} \tag{34}$$

$$\pi_{esc}^{D-J1}=\frac{k(\eta-1)^2[b^2(4\eta-3)+14k(\eta-1)^2][c+c_l-(\alpha A+\beta p_b)]^2}{2[b^2(3\eta-2)+8k(\eta-1)^2]^2} \tag{35}$$

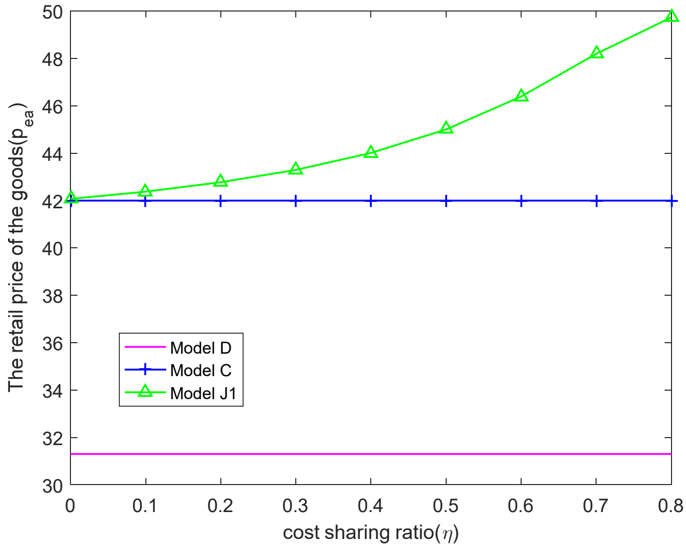
After comparison, it was found that when implementing the cost-sharing contract, the expected profits of each decision-maker in the logistics service supply chain can be improved as long as the cost-sharing ratio does not exceed a certain level. In addition, the optimal level of logistics service effort will also increase, but the price of the product will also rise. This indicates that consumers will have to pay more to purchase higher quality services.

5. NUMERICAL SIMULATION ANALYSIS

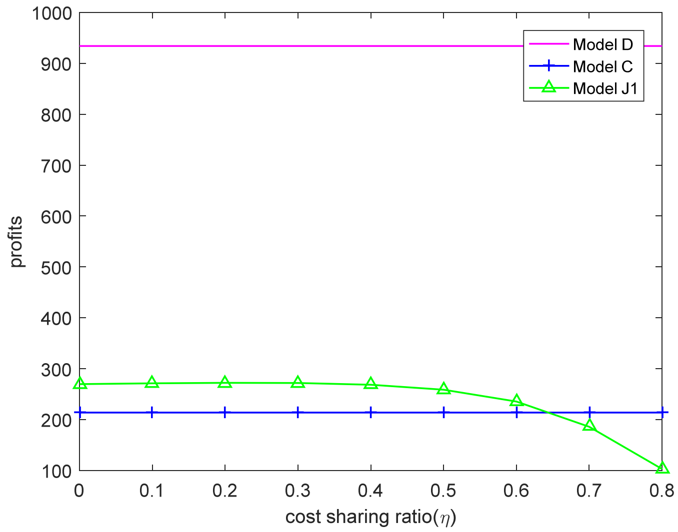
The following figure illustrates the coordination of logistics service effort level under the cost-sharing contract. It is evident that the logistics service effort level can be improved when the cost-sharing contract is implemented in the system.



The following figure illustrates the coordination effect of cost-sharing contracts on retail prices. It can be observed that when the system implements a cost-sharing contract, the retail price of goods will increase due to the improvement of logistics service effort level.



The figure below illustrates the coordination of optimal revenue under the cost-sharing contract. It can be observed that when the cost-sharing contract is implemented, the cost-sharing ratio should not be too high, otherwise it will damage the system revenue.



6. SUMMARY AND ENLIGHTENMENT

Based on the above research, the following managerial implications can be drawn.

In the fiercely competitive e-commerce platform market, the quality and price of logistics services have become the focal point of the game between the platform, logistics service integrators, and logistics service providers. In this three-level game system, the quality and price of logistics services directly affect consumers' purchasing decisions and the platform's market position. Therefore, in this game system, each participant has different pricing strategies and choices of logistics service quality.

Firstly, for e-commerce platforms, platforms will try to provide higher quality logistics services to attract consumers, gain better prices through technological and scale advantages, and maintain market share through pricing strategies. For example, the platform may provide fast, accurate, and traceable logistics services to enhance consumers' shopping experience and attract more consumers through discounts and promotions.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202304_9(4).0033

Secondly, when e-commerce platforms seek to cooperate with logistics service providers, they can offer higher quality logistics services to attract consumers and increase market share. Platforms can reach cooperation agreements with logistics service providers, requiring them to provide on-time, accurate, safe, and traceable logistics services and evaluate and supervise service quality. Platforms can also negotiate with logistics service providers to obtain better prices to reduce costs and improve market competitiveness.

Finally, both parties need to establish appropriate cooperation models and agreements to ensure the balance of logistics service quality and price. Both parties can clarify the service quality that logistics service providers should provide, the price that e-commerce platforms should pay, and solve the problems and disputes that may arise in their cooperation through cost-sharing contracts and other means.

In summary, the balance between logistics service quality and price is critical. The three-level logistics service supply chain needs to meet consumers' needs and maintain market competitiveness through cooperation agreements and pricing strategies.

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