Study on Dynamic Joint Optimization of Inventory and Transportation Processes of Online Shopping Supply Chains Based on Shared-Savings Contracts

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**Abstract.** In this paper, inventory and transportation joint optimization can help reduce the logistics costs and improve logistics efficiency, and realize the optimal efficiency of the whole supply chain; shared-savings contracts is an effective way to achieve dynamic optimization between inventory and transportation, which is conducive to achieve mutual benefits for the participating parties and mobilize the enthusiasm of cooperation. This paper successively constructs a benefit model of policy-making bodies under inventory and transportation integrated optimization and an income distribution model of policy-making bodies under revenue sharing and a bargaining game process of inventory and transportation under the dynamic environment, and also verify its feasibility by numerical examples analysis.

**Introduction**

With the rapid development of e-commerce, online shopping is playing a more and more important role in people's daily life. It has become an important way to stimulate the consumption and promote the integration development between real economy and online sales. According to the 2015 (up) the Chinese network retailers market data monitoring report (hereinafter referred as the report), the transaction size of China's online retail market reaches RMB 16140 in the first half of 2015 which increased 48.7 percent; the transaction size of China's online retail market accounts for 11.4 percent of total retail sales of social consumer goods in the first half of 2015 which increased 31 percent. However, the rapid development of online shopping expose many problems in the development of express delivery industry at the same time. Survey shows that there are 81.7% satisfaction and 18.3% dissatisfaction among the online retailers who use the third party logistic. To sum up, the dissatisfied reasons are mainly because of the inefficient and improper coordination of transport management and inventory control. On the process of online shopping, the cost of inventory and transportation is the mainly part of the total cost, accounted for more than 80%. Therefore, the dynamic joint optimization between inventory and transportation is necessary for seek the best solution. It not only has important theoretical value, but also has great practical significance.

Scholars at home and abroad have carried out some researches on the inventory and transportation optimization. Bertazzi etc.(2002), Campbel and Savelbergh(2004) showed that considering both inventory control and transportation decision can greatly reduce the costs of logistics system. Shukla etc.(2013)based on the combined optimization problem of uncertain customer demand, with car delivery frequency as the breakthrough point, designed and improved genetic algorithm to solve the problem. In China, Guiqing Liu and Yongwu Zhou (2009) studied how to coordinate the supply chain through the profit distribution strategy when the retailer undertaking the cost of transportation. Fuchang Li(2012) pointed out that distribution of profits related to the joint optimization which can be carried out and whether the supply chain can open up a new profit growth point in the study of joint optimization of profit distribution. Xiaoming Wu etc. (2016) designed a hybrid heuristic algorithm to solve the problem of inventory and transportation,
applied to the fresh agricultural product distribution in practice, and constructed the optimal distribution solution to effectively reduce logistics costs by determining the balance of inventory and transportation mileage.

Although the scholars at home and abroad studied on both shared-savings contract and joint optimization, it hasn’t applied to the dynamic online shopping supply chain. This article constructs a dynamic optimization model of online shopping supply chain based on the shared-savings contract, explores the dynamic cooperation mechanism of supply chain parties involved in online shopping, and helps the online retailers and logistics service providers achieve a win-win situation.

**Problem Descriptions**

Supposing the online shopping supply chain is composed of a supplier, an online retailer and a logistics service provider. Hereinto, the online retailer and logistics service provider are both risk neutral and fully rational. Online retailer is dominant in the supply chain, which faces the market demand for D and inventory for zero. Supplier does not exist the shortage situation, and online retailer is always provided with the needed quantity in constant price, and the numbers of distribution are in line with the market demand D. D is a function of price P and logistics service provider’s effort level \( x \) \((0 < x < 1)\), and online retailer has complete information. Unit purchase cost and service cost of online retailer are respectively \( f_1 \)、\( f_2 \). The logistic service provider charge by the number of distribution quantity, each billing for \( g_1 \), and its distribution cost of unit commodity are \( g_2 \) \((g_1 > g_2)\). \( G(x) \) is the effort cost function, hereinto, \( f_1 \)、\( f_2 \)、\( g_1 \) and \( g_2 \) all are constant.

To facilitate the collaboration between online retailer and logistic service provider, we shall establish a sharing contract, namely the one whose incomes have increased transfers \( \varphi \) times of the profits to the one whose incomes have reduced, only reserve \((1 - \varphi)\) times of its profit, so that the profits of both are higher than which under the decentralized decision-making. \( \varphi \) is a decision variable and related to the smoothly cooperation and profits distribution of joint optimization between the shop retailer and logistics service provider.

**Research on the Dynamic Joint Optimization Model of Inventory and Transportation in Online Shop Supply Chain Based on Shared-savings contract**

**Analysis for each participant’s benefit when joint optimization of inventory and transportation**

In order to compare the total profits when joint optimizing with the one under decentralized optimizing, we need to calculate and analyze the profit of each decision subject.

We hypothesis that the market demand function of online retailer faces is as follows:

\[
D(P, x) = a - bP + Lx
\]  
(1)

Hereinto, \( a \)、\( b \) and \( L \) are some constants which greater than zero. \( a \) is the largest market demand for sales price \( P \); \( b \) is the sensitivity of the market demand to the sales price \( P \); \( L \) is the sensitivity coefficient of the market demand to the effort degree \( x \) of logistic service provider.

The effort cost function of logistic service provider is as follows:

\[
G(x) = \varepsilon x^2
\]  
(2)

Hereinto, \( \varepsilon > 0 \) and it is a constant. \( \varepsilon \) is the sensitivity coefficient of the effort cost of logistic service provider for its effort level.

The profit function of online shop retailer is as follows:
\[ \pi_1 (P, x) = PD(P, x) - (f_1 + f_2 + g_1)D(P, x) \]  
Equation (3)

The profit function of logistic service provider is as follows:

\[ \pi_2 (P, x) = (g_1 - g_2)D(P, x) - G(x) \]  
Equation (4)

When online shop retailer and logistics service provider making decisions respectively, the online shop retailer sets price \( P \) firstly according to its dominant position and the principle of profit maximization. Logistic service provider is a price follower and sets its own effort level to achieve profit maximization according to the price of online retailer. Online retailer determines the sales price based on the expected effort level when logistic service provider achieving profit maximization, so as to achieve its maximum profit.

To maximizing the profit of logistic service provider under the established price \( P \), we need to seek the maximum value of eq.(5), and calculate the effort level \( x \). Online retailer calculates the maximum value of eq.(6) based on the effort level \( x \) that we got, and gets the sale price \( P \) to obtain the maximum profit of online shop retailer. We calculate the first derivative of \( x \) in eq.(7) and \( P \) in eq.(8), and make them equal to zero respectively. So we can get that:

\[ x_1 = \frac{L(g_1 - g_2)}{2b}, \quad P_1 = \frac{1}{2} \left( \frac{a}{b} + f_1 + f_2 + g_1 \right) + \frac{L^2(g_1 - g_2)}{4be} \]  
Equation (9)

Because that \( d^2\pi_2(P,x)/dx^2 = -2b < 0 \), logistic service provider and online supplier achieve the maximum profit \( \pi_1^* \) \( \pi_2^* \) respectively under the conditions of \( x_1 \) and \( P_1 \). Put the eq.(10) into eq.(11) and eq.(12), we can get the biggest profits of online shop retailer and logistic service provider are as follow:

\[ \pi_1^* = b \left( \frac{1}{2} \left( \frac{a}{b} - r_1 \right) + \frac{L^2(g_1 - g_2)}{4be} \right)^2, \quad \pi_2^* = \frac{(g_1 - g_2)(a - br_1)}{2} \]  
Equation (13)

Here \( r_1 = f_1 + f_2 + g_1 \). The total profit of the supply chain is \( \pi^* \) when the online retailer and the logistics service provider make decision dispersed, and then \( \pi^* = \pi_1^* + \pi_2^* \).

When online shop supply chain has ITIO joint optimized, online retailer and logistics service provider begin with the interests of the whole supply chain, considering both inventory cost and transportation cost to achieve the profit maximization of the whole supply chain.

The total profit function of the online supply chain is as follow:

\[ \pi(P, x) = PD(P, x) - (f_1 + f_2 + g_2)D(P, x) - G(x) \]  
Equation (14)

Put the eq.(15) and eq.(16) into eq.(17), we can get that:

\[ \pi(P, x) = (P - r_2)(a - bP + Lx) - \varepsilon x^2 \]  
Equation (18)

Here \( r_2 = f_1 + f_2 + g_2 \). In order to maximize the overall profit of ITIO, we need to seek out the first order partial derivative, two partial derivative and mixed partial guide of \( P \) \( x \) in eq.(19) respectively. We work out the first order partial derivative of \( P \) \( x \) in eq.(20) and make them equal to zero, and get that:

\[ x_2 = \frac{(a - br_2)L}{4eb - L^2}, \quad P_2 = \frac{2\varepsilon(a - br_2)}{4eb - L^2} + r_2 \]  
Equation (21)

Here \( A = 2b > 0, C = 2\varepsilon > 0, B = -L/2b < 0 \), namely \( AC - B^2 > 0 \). At this point, the optimal solution is meaningful and the supply chain achieve the maximum profit. We can record this maximum profit as \( \pi_{ITIO} \).
We compare the total profit of the supply chain under joint optimizing with that under the single
decision making. It is easy to know that \( g_1 - g_2 = r_1 - r_2 \). In order to simplify it further, we make
\( L^2 \) close to zero, namely \( L \) close to zero, and the result can be expressed as:

\[
\pi_{ITIO} - \pi^* = \frac{e(a - br_1)^2(2 - e) + 2be^2(r_1 - r_2)(a - rb)}{4be} \tag{22}
\]

Because of \( 2be^2(r_1 - r_2)(a - rb) > 0, e(a - br_1)^2 > 0, 4be > 0 \), in order to make the upper formula
greater than zero, we must make the eq.(23) greater than zero, namely equal to \( 2 - e > 0 \).
Because of \( e > 0 \), we work out that \( 0 < e < 2 \). So, when \( 0 < e < 2 \), \( L \) closing to zero, and
formula \( \pi_{ITIO} - \pi^* > 0 \) is set up. That is, under this condition, the overall profit of online shop retailer and logistics service provider of ITIO joint optimization is greater than that of decentralized decision-making. \( L \) closes to zero and that means the change of logistics service provider's effort level has very little influence on market demand. The smaller of the \( e \) means the less impact of the change in the effort level of the logistics service provider on its effort cost.

We record that \( \pi_{ITIO} \) and \( \pi_{ITIO} \) are respectively delegate the profit of online shop retailer and logistics service provider when \( P = P_2 \) and \( x = x_2 \).

\[
\pi_{ITIO} = \left( P_2 - r_1 \right)(a - bP_2 + Lx) \quad \pi_{ITIO} = \left( g_1 - g_2 \right)(a - bP_2 + Lx) - \varepsilon x^2 \tag{24}
\]

In the case of restrained total profits of this online shop supply chain, the profit distribution of all parties involved in the supply chain has inversely proportional relationship. This paper discusses the situation that one party’s profit increase and another decrease. There we give a numerical example to calculate the numerical operation in order to verify that the profit of online retailer has decreased and the profit of logistics service provider has increased when inventory and transportation integrated optimizing compared to that they are under decentralized decision making. Here, \( a = 1\,100, b = 13, L = 15, \varepsilon = 100, f_1 = 40, f_2 = 20, g_1 = 10, g_2 = 6 \), so that \( r_1 = 70, r_2 = 66 \). Put these numerical value into these upper formulas and we get that \( \pi^{\ast}_{ITIO} = 724.51 \), \( \pi^{\ast}_{ITIO} = 452.65 \), \( \pi^i = 727.51 \), \( \pi^j = 380 \). \( \pi_{ITIO} - \pi^i = -3 < 0, \pi_{ITIO} - \pi^j = 72.65 > 0 \), we know that after participating in inventory and transportation integrated optimization, the profit of online retailer has decreased but the profit of logistics service provider has increased compared to they are under decentralized decision making. That is to say, ITIO joint optimization makes the total profit of online shop supply chain and the profit of logistics service provider increase, but it also damages the profit of the online retailer, so it is very important to introduce the shared-savings contract. Logistics service provider can share a part of its revenue to the online retailer, so that the profit of online shop retailer under ITIO joint optimization is greater than that under decentralized decision-making, and ensure the smooth progress of cooperation.

**Income analysis of participating parties in shared-savings contract**

Under the shared-savings contract, logistics service provider transfers \( \varphi \) times of its profit \( \pi_{ITIO} \) when ITIO joint optimizing to online shop retailer. By this time, we record the profits of online shop retailer and logistics service provider respectively are \( \pi^i, \pi^j \). In order to make the benefits of two sides greater than that under the dispersed optimization, it is necessary to meet that \( \pi^i = (1 - \varphi)\pi_{ITIO} \), \( \pi^j = \varphi \pi_{ITIO} \), \( \pi^i > \pi^j \). The upper conditions are simplified and can be expressed as:

\[
\frac{\left( P_1 - \gamma \right)(a - bP_1 + Lx_1) - \left( P_2 - \gamma \right)(a - bP_2 + Lx_2)}{(g_1 - g_2)(a - bP_2 + Lx_2) - \varepsilon x^2} < \varphi \left( g_1 - g_2 \right)(a - bP_2 + Lx_2) - \varepsilon x^2 \tag{25}
\]
As long as $\phi$ content with the eq.(26), the online retailer and logistics service provider can have a cordial working relationship. At this time, the overall profit of the whole supply chain has increased after the inventory and transportation joint optimization, and the profit of the online retailer and the logistics service provider are respectively greater than that of the decentralized decision making. From the above eq.(27), we know that the greater effort level $\epsilon$ of the logistics service provider, the greater range of contract parameter $\phi$ can be taken. It means that the harder the logistics service provider, the greater changes of the contract share can be provided. In addition, the smaller the unit commodity distribution of logistics service provider, the greater scopes of the contract parameter can be used. It means that the closer unit distribution price of logistics service provider to the unit distribution cost, the greater scopes of the contract parameter can be provided with online shop retailer. The different share of profit distribution will lead to different incomes of the online retailer and the logistics service provider, so it has very important practical significance to bargaining analyze the joint optimization of profit distribution in dynamic environment.

Bargaining analysis of inventory and transportation optimization of profit distribution under dynamic environment

One of the key problem to be solved in the joint optimization of inventory and transportation is how to distribute the profits of logistics provider in shared-savings contract. Bargaining model is an effective way to solve this problem. After the joint optimization, online retailer and logistics service provider need to bargain on contractual terms of the logistics service provider's profit distribution. First of all, the parties involved in the contract quoted price according to their own costs is the requirement of profit distribution. Then, they can reach a cooperation agreement after the bargaining process, which make the profit of the two sides and the supply chain increase, compared with that under decentralized optimization. The two sides obtain the distribution according to the cooperation agreement. At this point, the online shop retailer and logistics service provider complete the first cooperation, and enter to the next round of cooperation negotiation.

In this case, we only take the two phases of the bargaining game as an example, and it can be such a push to the $n$ phase. In this paper, we analysis the profit distribution of logistics service provider from the second phase based on the idea of backward induction. At the second phase, the logistics service provider offers first and this is the last chance for online shop retailer to choose in the profit distribution phase of the bargaining game. The online shop retailer will get the benefit $\partial_s \pi_{ITIO}$ if he refuses this quotation. As long as the income of online shop retailer is greater than the income $\pi_{ITIO}$ of dispersed optimization when accept the price, online retailers will accept this quotation. That means we does not take the offer of online shop retailer into account in the first phase, and the online shop retailer will accept the offer as long as the next type is establishing.

$$
\partial_s (\beta_s^w \pi_{ITIO} + \pi_{ITIO}) \geq \partial_s \pi_{ITIO}^s
$$

The solution is as follows:

$$
\beta_s^w \geq \frac{2 \epsilon (a-bn_r) + L^2 (g_1 - g_2)^2 - 16b^2(\pi_{ITIO} - \pi_{ITIO}^s) (a-bP_2 + Lx_2)}{16b^2 (g_1 - g_2)^2 (a-bP_2 + Lx_2) - \epsilon x_2^s}
$$

Then we analysis the quotation of the logistics service provider at the second phase. The logistics service provider's strategy is to maximize its profits at this stage. Because the logistics service provider knows that the online shop retailer will make decisions according to the eq.(30) in the second phase, he will offer $(1-\beta_s^w)\pi_{ITIO}$ to maximize his income expectation in this stage.

$$
\text{Max} \partial_s (1-\beta_s^w) \pi_{ITIO} P \left( \beta_s^w \geq \frac{\pi_{ITIO}^s - \pi_{ITIO}^s}{\pi_{ITIO}^s} \right) + \partial_s \pi_{ITIO} P \left( \beta_s^w \leq \frac{\pi_{ITIO}^s - \pi_{ITIO}^s}{\pi_{ITIO}^s} \right)
$$

$$
\beta_s^w \geq \frac{\pi_{ITIO}^s - \pi_{ITIO}^s}{\pi_{ITIO}^s}
$$

(28)
There $\partial_w (1 - \beta^w) \pi_{itio2} P \left( \beta^w \geq \frac{\pi^*_i - \pi_{itio1}}{\pi_{itio2}} \right)$ is the income expectation of the logistics service provider when the online shop retailer accepts this quotation, and $\partial_w (1 - \beta^w) \pi_{itio2} P \left( \beta^w \geq \frac{\pi^*_i - \pi_{itio1}}{\pi_{itio2}} \right)$ is the income expectation of the logistics service provider when the online shop retailer refuses this quotation. By the uniform distribution properties of $\pi^*_i \pi_{itio1} \pi_{itio2}$ we can get that:

$$P \left( \beta^w \geq \frac{\pi^*_i - \pi_{itio1}}{\pi_{itio2}} \right) = \frac{\beta^w \pi_{itio2} + \pi_{itio1} - c}{d - c}$$

(32)

$$P \left( \beta^w \leq \frac{\pi^*_i - \pi_{itio1}}{\pi_{itio2}} \right) = \frac{d - \beta^w \pi_{itio2} - \pi_{itio1}}{d - c}$$

(33)

There $d - c$ is the range of changes in $\pi^*_i$, then we verify the eq.(34) and it can be expressed as:

$$\text{Max} \partial_w (1 - \beta^w) \pi_{itio2} \frac{\beta^w \pi_{itio2} + \pi_{itio1} - c}{d - c} + \partial_w \pi_{itio2} \frac{d - \beta^w \pi_{itio2} - \pi_{itio1}}{d - c}$$

(35)

We work out the first order derivative of $\beta^w$ in the upper formula and make it equal to zero, we can get the optimum condition of $\beta^w$.

$$\beta^w = \frac{c - \pi_{itio1}}{2 \pi_{itio2}}$$

(36)

After we get the quotation of logistics service provider at the second phase, we can work out the incomes between the logistics service provider and the online shop retailer when the online shop retailer accepts the quotation.

$$\pi_{2w} = \partial_w (1 - \beta^w) \pi_{itio2} = \partial_w \frac{2 \pi_{itio2} + \pi_{itio1} - c}{2}$$

$$\pi_{2s} = \partial s (\beta^w \pi_{itio2} + \pi_{itio1}) = \partial s \frac{c + \pi_{itio1}}{2}$$

(37)

If the online shop retailer refuses the quotation of the logistics service provider at the second phase, the incomes of the online shop retailer and the logistics service provider respectively are $(\partial_{itio1} \pi_{itio1}, \partial_{itio2} \pi_{itio2})$. Then we come back to the first phase that the logistics service provider knows that once he chooses to refuse the quotation of the online shop retailer at this phase, the game will enter the second phase. The maximum payment that the logistics service provider may get is $\pi_{2w}$ at the second phase. So as long as the income of the logistics service provider at the first phase is not less than $\pi_{2w}$, he will choose to accept the shop retailer’s offer. As soon as the next formula is set up, the logistics service provider will accept the quotation of the online shop retailer at the first phase.

$$\left(1 - \beta^*_i \right) \pi_{itio2} \geq \partial_w \frac{2 \pi_{itio2} + \pi_{itio1} - c}{2}$$

(38)

At the first phase, the online shop retailer offers $\beta^*_i \pi_{itio2}$ according to the decision-making ideas of the logistics service provider that he grasps at these two phases to maximize his income at the
first phase. That is to choose the quotation $\beta_{s}^{*} \pi_{\text{ITIO}}$ to maximize the value of the next formula:

$$\text{Max} \beta_{s}^{*} \pi_{\text{ITIO}} P(A) + \pi_{s}^{*} P(B) + \partial_{s} \pi_{\text{ITIO}} P(C)$$

(39)

Where A says that the logistics service provider accepts the offer of online retailer at the first stage; B says that the logistics service provider refuses the offer of the online shop retailer at the first phase and the online shop retailer accepts the offer of the logistics service provider at the second phase; C says that the logistics service provider refuses the offer of the online shop retailer at the first phase and the online shop retailer refuses the offer of the logistics service provider at the second phase.

We verify the eq. (40) and work out the optimum conditions of this formula about $\beta_{s}^{*}$, and we can know the optimum quotation of online shop retailer at the first phase that is as follow:

$$\beta_{s}^{*} = \frac{2(c-n) + \partial_{s} (c \beta_{s}^{*} \pi_{\text{ITIO}} - c^{2} + 2d \pi_{\text{ITIO}} - \beta_{s}^{*} \pi_{\text{ITIO}} - \pi_{\text{ITIO}}^{2})}{8 \pi_{\text{ITIO}}^{2}}$$

(41)

Put $\beta_{s}^{*} = \frac{c - \pi_{\text{ITIO}}}{2 \pi_{\text{ITIO}}^{2}}$ into $\beta_{s}^{*}$, and the upper formula can be verified to that:

$$\beta_{s}^{*} = \frac{(c-n) + \partial_{s} (d \pi_{\text{ITIO}} - (\pi_{\text{ITIO}} + c)^{2})}{4 \pi_{\text{ITIO}}^{2}}$$

(42)

From the above formula, we can know that the quotation of the shop retailer at the first phase is influenced by the discount factor of the two sides. The quotation is influenced not only by the patience level of himself, but also by the logistics service provider.

We work out the first order derivative of $\beta_{s}^{*}$ in the eq.(43) about the discount factor and verify it, so we can get that:

$$\frac{d \beta_{s}^{*}}{d \partial_{s}} = \frac{d \left( P_{2} - r_{1} \right) (a - bP_{2} + Lx_{2}) - \left( P_{2} - r_{1} \right) (a - bP_{2} + Lx_{2}) + c}{4 \left( (g_{1} - g_{2}) (a - bP_{2} + Lx_{2}) - \epsilon x_{2}^{2} \right)} (d - c)$$

(44)

The upper formula can be positive or negative. When it is greater than zero, the more of the patient logistics service provider quotes the higher price at the first phase. At this time if the shop retailer accepts his offer, the logistics service provider can get a higher share of income distribution. But when it is smaller than zero, the more patient of the logistics service provider quotes the lower price at the first phase. At this time if the shop retailer accepts his offer, the logistics service provider can get a smaller share of income distribution.

The Conclusions

This paper firstly establishes the model of the joint optimization of inventory and transportation based on the common decision of the online retailer and the logistics service provider. The maximum profit and total profit of the online retailer and logistics service provider in the joint optimization is worked out, and then compare it with the profit which is made in decentralized decision-making. It finds that the total profit of the online shop supply chain in the ITIO joint optimization is greater than that of the decentralized decision-making, but the profit of online shop retailer is damaged. Then, a joint optimization model of inventory and transportation based on shared-savings contract is established in order to increase the profits of online retailer, logistics service provider and online shop supply chain. Finally, we build a bargaining model of profit distribution under the dynamic environment of inventory and transportation integrated optimization, and point out in the case of bargaining the quotation of one side will not only be influenced by their
degree of patience, but also by the degree of others’ patience and the distribution of income share will also be affected by the degree of patience. Therefore, in the online shop supply chain, the total profit of the online retailer and logistics service provider and online shopping supply chain can be optimized based on the shared-savings contract through the optimization of inventory and transportation and bargaining.

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