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Inventory Strategy of Dual Channel Supply Chain of Channel Preference under Fuzzy Demand Circumstance

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Abstract

This paper takes fuzzy demand and consumers' channel preference into serious consideration so as to construct the decision-making model of dual channel supply chain inventory under the circumstance of dual channel supply chain system made up of one manufacturer and retailers for the sales of a single product. It carries out the optimum analysis, obtains the optimal inventory strategy of manufacturer and retailer and further analyzes the inventory decision making of both sides in the supply chain and variation of fuzzy expected profit with channel sales price, fuzzy demand and consumers' online channel preference rate. The result shows that the selling price of dual channel has a definite impact on the inventory decision making of supply chain and fuzzy expected profit. With great fuzzy demand, manufacturers and retailers tend to increase inventory. Fuzzy expected profit of both sides on the supply chain and total fuzzy expected profit of the supply chain will fall down, and the fuzzy expected profits of the retailers decrease significantly. The increase of consumers' online channel preference rate will lead to the increase of manufacturer's inventory and the decrease of retailer's inventory. The total inventory of supply chain will increase slightly. At the same time, the manufacturer's fuzzy expected profit will increase while the fuzzy expected profit of retailer and sully chain will decrease.

Keywords: *Fuzzy demand, channel preference, dual channel, inventory strategy*

1. Introduction

With the increasing popularity of Internet technology and rapid development of e-commerce, many enterprises introduce the network marketing channel while retaining traditional retail channels at the same time. On the one hand, this dual-channel marketing model enlarges the market demand. However, there are competitions between network marketing channel and traditional retail channel, resulting in channel conflicts. Many scholars have studied the pricing strategy and coordination mechanism of dual channel supply chain. On the basis of manufacturer's marketing channel, Kong Zaojie[1]et al have studied the influence of retailer open electric channel on the supply chain. This paper respectively studies centralized decision making and optimal pricing and profit problem of retailers and manufacturers under the Stackelberg game scatter decision model. Yongwei Zhou [2] has studied the pricing strategy of dual channel supply chain under the altruistic behavior and channel preference. The research shows that the channel preference coefficient of consumers, the loyalty of consumer retail channel and the altruistic behavior

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of manufacturers and retailers have definite impact on the pricing decision of supply chain. The impact of manufacturers' altruistic behavior on the pricing decision of supply chain is greater than the impact of retailers' altruistic behavior on the pricing decision of supply chain. Wang Xianjia [3] et al have discussed the coordination strategy of dual channel supply chain of uneconomical scale of production characteristics and proposed the product pricing and overall profit of dual channel supply chain under centralized decision making and design proposal of wholesale price and gain sharing contract under scatter decision model. Zhou Jianheng [4] et al have set up the three channel structures of single online marketing channel, perfect competition between retailers and manufacturers and joint production between retailer and manufacturer and discussed product experience based supply chain channel operation combination and cooperation conditions on the basis of the differences between traditional channel and online channel caused by product experience. However, there are few researches on logistics conflicts of dual channel by scholars. Logistics conflicts in dual-channel supply chain are mainly reflected in the warehouse problem of online marketing and traditional distribution. Fuzzy demand and channel preference directly affect the inventory and revenue of manufacturers and retailers. Therefore, it is particularly important for manufacturers and retailers to adjust inventory levels under the circumstance of fuzzy demand. On this basis, this paper studies the inventory control optimization strategy of dual-channel supply chain under the circumstance of fuzzy demand.

Some scholars have studied the inventory problem of the dual-channel supply chain. Based on the study subject of dual channel supply chain system, Li Li [5] et al set up relevant inventory decision model for the optimum solution while taking into account of consumers' preferences for channel selection. The research shows that the greater demand uncertainty is, the more likely manufacturers and retailers trend to increase inventory and the greater the profit losses. However, increase of online channel preference rate will lead to the increase of manufacturer inventory and the loss of profits of retailers and supply chains. Bai Qingguo [6] et al have studied the optimal inventory strategy under these two distribution channels in dual channel supply chain and the combination of traditional marketing and online marketing for customers' demand by distributors. Mixed integer optimization model of non-perishable products and perishable products are set up when the ordering cost in the system is of certain learning effect. Research shows that this system can gain more profit when there is learning effect in supply chain system. Panda S [7] et al have studied the pricing and replenishment strategy of dual channel supply chain of a certain high-tech product. The product cost is reduced with the time. Optimal pricing and replenishment strategy for supply chain system is calculated if the manufacturer is the leader of Stackelberg. It then proposes the coordination mechanism to alleviate the channel conflicts. Based on the dual channel supply chain system in the online marketing channel, Yang J Q[8] et al have studied the channel transfer behavior of consumers in the shortage of goods supply, inventory competition of perishable products and expanded the classic newsvendor model so as to obtain the optimal order quantity of the retailer and the optimal inventory level of the manufacturer. Tao F [9] et al have introduced carbon emission constraints into the dual-channel supply chain and studied the influence of carbon emission constraints on supply chain inventory strategy and coordination mechanism by setting up multicycle dynamic plan model. Fan Chen [10] et al have proposed the contract design of VMI supply chain of ownership supplier according to the two inventory replenishment strategies (r, Q) and (s, S) and provided two feasible risk sharing contract form by using risk sharing idea. Due to the uncertainty of demand of supply chain system in dual channel competition, Liu Zheng [11] et al construct the inventory mode and shortage model of dual channel supply chain and analyze the influence of shortage loss cost and demand fluctuation on the supply chain as well as the cost of these two modes

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while taking into account of demand fluctuation in the early stage. The result shows that the cost under independent inventory mode is higher than the cost of dual channel under the joint mode. In terms of the inventory decision problem of the two stage supply chain under the restricts of three carbon policies, Yi Dongbo et al. [12] explore how to achieve the minimum target of the total cost under the different carbon policies from the perspective of enterprise and study the modes under the different carbon policies. It is proved that enterprise can reduce the carbon emissions without increasing the total cost significantly under the reasonable carbon policies of two stage supply chain. At the same time, under the carbon quota and trading policy, enterprises play incentive role in reducing carbon emissions with the increase of carbon price.

It can be found that the centralized management of most of the assumed supply chain inventory is inconsistent with management inventory on the actual supply chain without considering the influence of consumers' channel preference on supply chain. In addition, most of the above studies regard market demand as a random variable of a certain distribution. In fact, due to the insufficient historical data and information, it is difficult to describe the high-tech products with short life cycle and changing market demand by using accurate data and probability theory. Instead, we only have a vague understanding of the changing demand situation. Therefore, fuzzy mathematical theory is suitable for uncertainty modeling. It has set up single stage supply chain model in literature [13-18] under fuzzy demand circumstance. Variable market demand is shown in triangle fuzzy number and its parameter is determined by experts. However, most of their researches focus on fuzzy pricing and coordination mechanism of supply chain and there are few researches on the fuzzy inventory in dual channel supply chain. Based on the previous research results, this paper regards market demand as a fuzzy variable, sets up decision-making model of dual channel supply chain inventory under the circumstance of fuzzy demand and consumer channel preference and analyzes the fuzzy demand and the influence of channel preference on manufacturer, retailer optimal inventory level and fuzzy expected profit, thus providing preference basis for inventory decision making of relevant enterprises..

2. The Fuzzy Set Theory and Model Description

2.1. The Triangular Fuzzy Numbers and Their Properties

Definition 1. Called the triadic array $\tilde{A}=(\underline{d},\, d, \bar{d})$ as triangular fuzzy number, if and only if its membership function $\mu_{\tilde{A}(x)}: x \to [0,\, 1]$ satisfies:

$$\mu_{\tilde{A}(x)}=\begin{cases}\dfrac{x-\underline{d}}{d-\underline{d}}, & x\in[\underline{d},\, d]\\ 0, & x\notin[\underline{d},\, \bar{d}]\\ \dfrac{\bar{d}-x}{\bar{d}-d}, & x\in(d,\, \bar{d}]\end{cases} \tag{1}$$

Here d is called the center point of triangular fuzzy number, $\underline{d}$ and $\bar{d}$ are called the lower and upper infimum of $\tilde{A}$, if $\underline{d}>0$, $\tilde{A}$ is called positive triangular fuzzy number, when $x\in[\underline{d},\, d]$, $L(x)=\dfrac{x-\underline{d}}{d-\underline{d}}$ is a strict increasing function of x, when $x\in(d,\, \bar{d}]$, $R(x)=\dfrac{\bar{d}-x}{\bar{d}-d}$ is a strict decreasing function of x.

Definition 2. Let $\tilde{A}$ be a fuzzy subset of the domain, let' s call $\lambda\in[0,\, 1]$, let's call it $\tilde{A}_\lambda=\{x|\mu_{\tilde{A}(x)}\ge\lambda\}$, let's call it the λ intercept of $\tilde{A}$, where λ is the confidence level. $\tilde{A}_\lambda$ can be expressed as $\tilde{A}_\lambda=[L^{-1}(\lambda), R^{-1}(\lambda)]$, where $L^{-1}(\lambda)$ and $R^{-1}(\lambda)$ are the left and right boundaries of $\tilde{A}_\lambda$, here $L^{-1}(\lambda)=\inf\{x\in R: \mu_{\tilde{A}(x)}\ge\lambda\}$ and $R^{-1}(\lambda)=\sup\{x\in R: \mu_{\tilde{A}(x)}\ge\lambda\}$.

For any $\lambda\in[0,\, 1]$, the λ intercept set of triangular fuzzy number $\tilde{A}=(\underline{d},\, d, \bar{d})$ can be expressed as $L^{-1}(\lambda)=\underline{d}+(d-\underline{d})\lambda$, $R^{-1}(\lambda)=\bar{d}-(\bar{d}-d)\lambda$.

According to the expansion principle of fuzzy set, it

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can be obtained:

Property 1. If $\tilde{A}$ is a positive triangular fuzzy number, for any $\lambda \in [0, 1]$, there is

$$k\tilde{A}_\lambda = \begin{cases} [kL^{-1}(\lambda),\ kR^{-1}(\lambda)], & k \in R^+ \\ [kR^{-1}(\lambda),\ kL^{-1}(\lambda)], & k \in R^- \end{cases}. \tag{2}$$

Property 2. Note that $\tilde{B}_\lambda = [L_{\tilde{B}}^{-1}(\lambda), R_{\tilde{B}}^{-1}(\lambda)]$ and $\tilde{C}_\lambda = [L_{\tilde{C}}^{-1}(\lambda), R_{\tilde{C}}^{-1}(\lambda)]$ are the λ intercept sets of triangular fuzzy Numbers $\tilde{B}$ and $\tilde{C}$ respectively, then

$$\begin{cases} \tilde{B}_\lambda + \tilde{C}_\lambda = [L_{\tilde{B}}^{-1}(\lambda) + L_{\tilde{C}}^{-1}(\lambda),\ R_{\tilde{B}}^{-1}(\lambda) + R_{\tilde{C}}^{-1}(\lambda)] \\ \tilde{B}_\lambda - \tilde{C}_\lambda = [L_{\tilde{B}}^{-1}(\lambda) - R_{\tilde{C}}^{-1}(\lambda),\ R_{\tilde{B}}^{-1}(\lambda) - L_{\tilde{C}}^{-1}(\lambda)] \end{cases} \tag{3}$$

Property 3. If $\tilde{A}$ is a triangular fuzzy number, the expected value can be expressed as

$$E[\tilde{A}] = \frac{1}{2}\int_0^1 [L^{-1}(\lambda) + R^{-1}(\lambda)] d\lambda \tag{4}$$

2.2. Symbol Description and Model Description

This paper studies the dual channel supply chain system made up of manufacturer and retailer as well as the joint sales of a kind of high-tech product with short life cycle. Due to the insufficient data information for high-tech products, the decision makers can only have a vague understanding of the changes in market demand. Therefore, this paper regards the total market demand of manufacturer and retailer as triangle fuzzy variables $\tilde{D}$, $\tilde{D} = (\underline{d},\ d, \overline{d})$, and $0 < \underline{d} < d < \overline{d}$. Among them, d is the center point of fuzzy demand $\tilde{D}$. $\tilde{D}$ is market demand. $\underline{d}$ and $\overline{d}$ are respectively the minimum demand value and maximum demand value. The value of $\underline{d}$, d and $\overline{d}$ are determined by experts. In the supply chain system, retailers are responsible for traditional sales channel while manufacturers are responsible for online sales channel. Consumers will take into account of product price, spend time, travel cost and other factors in product purchasing. Therefore, two types of consumers, preference retail channel and preference online channel come into being. It is assumed that these two types of consumer demand are independent random variables. Manufacturers and retailers in the supply chain hold inventory. The inventory of manufacturers is used to meet the demand of online marketing channel while the inventory of retailers is used to meet the demand of offline channel.

This system focuses on the optimal inventory strategy of manufacturers and retailers. Therefore, the wholesale price and retail price of the products are regarded as the external variables. The revenues of manufacturers mainly come from sales revenue of online marketing channel, retail revenue of wholesale sales and residual value of residual products and the manufacturers' costs consist of production cost of the product, stockholding cost, product distribution cost of network marketing channel and shortage cost. The revenues of retailers are the sales revenue of traditional retail channel and residual value of residual products and the retailers' costs include product ordering cost, stockholding cost and shortage cost of traditional retail channel. The symbol and significance of model is shown in Table 1.

Table 1. Symbols and Their Meanings

Symbol	Meaning
α	The preference rate of consumers for internet channels indicates the proportion of consumers who prefer shopping internet channels to the total demand
$\tilde{D}_r$	Demand for retail channels($\tilde{D}_r = (1-\alpha)\tilde{D}$)
$\tilde{D}_d$	Demand for manufacturers' internet channels($\tilde{D}_d = \alpha\tilde{D}$)
p_r	Retail price of products in traditional retail channels
p_d	The price of the manufacturer's internet channel products
w	The wholesale price at which a retailer purchases a product from a manufacturer

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c	Cost per unit of production
s	The unit residual value of surplus stock(Satisfy $s < c < w < p_d < p_r$)
l_r	The out-of-stock cost of retail channel unit products
l_d	The cost of out-of-stock of a manufacturer's internet channel unit product
t_d	Unit product distribution costs for the manufacturer's internet channels
Q_r	Retailer inventory
Q_d	Manufacturer inventory
Q	Total supply chain inventory($Q = Q_r + Q_d$)
a_r	Retailer's fixed carrying cost of inventory
a_d	Manufacturer's fixed carrying cost of inventory
b_r	The carrying cost of a retailer as a function of inventory
b_d	The carrying cost of a manufacturer as a function of inventory
$\tilde{\pi}_R$	Fuzzy profit of retailer
$\tilde{\pi}_M$	Fuzzy profit of manufacturer
$\tilde{\pi}$	Fuzzy profit of supply chain

3. Model Solution

Suppose that both retailers and manufacturers aim to maximize their own fuzzy profit expectations. The fuzzy expected profit of supply chain is closely related to the optimal inventory of manufacturer and retailer, both of which are risk neutral, that is, the basis of their inventory decisions is to maximize their fuzzy expected profit.

To do this, fuzzy profit of retailer:

$$\tilde{\pi}_R = p_r \min(Q_r, \tilde{D}_r) + s\max(Q_r - \tilde{D}_r, 0) - l_r \max(\tilde{D}_r - Q_r, 0) - wQ_r - (a_r + b_r Q_r) \tag{5}$$

The problem to be solved can be expressed as:

$$\max E[\tilde{\pi}_R] = E[p_r \min(Q_r, \tilde{D}_r) + s\max(Q_r - \tilde{D}_r, 0) - l_r \max(\tilde{D}_r - Q_r, 0) - wQ_r - (a_r + b_r Q_r)] \tag{6}$$

s. t. $(1-\alpha)\underline{d} < Q_r < (1-\alpha)\bar{d}$

Thus there are

Theorem 1. Retailer's fuzzy expected profit $E[\tilde{\pi}_R]$ is a strict concave function of its inventory Q_r.

Proof: Due to $Q_r \in ((1-\alpha)\underline{d},\ (1-\alpha)\bar{d})$,

when $Q_r \in ((1-\alpha)\underline{d},\ (1-\alpha)d)$,

The λ intercept of $\min(Q_r, \tilde{D}_r)$ is:

$$[\min(Q_r, \tilde{D}_r)]_\lambda = \begin{cases} [L^{-1}(\lambda),\ Q_r], & \lambda \in (0,\ L(Q_r)] \\ [Q_r,\ Q_r], & \lambda \in (L(Q_r),\ 1] \end{cases} \tag{7}$$

$\max(Q_r - \tilde{D}_r, 0) = Q_r - \min(Q_r, \tilde{D}_r)$, its λ intercept is:

$$[\max(Q_r - \tilde{D}_r, 0)]_\lambda = \begin{cases} [0,\ Q_r - L^{-1}(\lambda)], & \lambda \in (0,\ L(Q_r)] \\ [0,\ 0], & \lambda \in (L(Q_r),\ 1] \end{cases} \tag{8}$$

$\max(\tilde{D}_r - Q_r, 0) = -\min(Q_r - \tilde{D}_r, 0)$, its λ intercept is:

$$[\max(\tilde{D}_r - Q_r, 0)]_\lambda = \begin{cases} [0,\ R^{-1}(\lambda) - Q_r], & \lambda \in (0,\ L(Q_r)] \\ [L^{-1}(\lambda) - Q_r,\ R^{-1}(\lambda) - Q_r], & \lambda \in (L(Q_r),\ 1] \end{cases} \tag{9}$$

If $\lambda \in (0,\ L(Q_r)]$, the λ intercept set of $\tilde{\pi}_R$ can be known from (5), (7), (8) and (9):

$$\begin{aligned}[\tilde{\pi}_R]_\lambda &= p_r[\min(Q_r,\tilde{D}_r)]_\lambda + s[\max(Q_r-\tilde{D}_r,0)]_\lambda - l_r[\max(\tilde{D}_r-Q_r,0)]_\lambda - [wQ_r+(a_r+b_rQ_r)]_\lambda \\ &= p_r[L^{-1}(\lambda),\ Q_r] + s[0,\ Q_r-L^{-1}(\lambda)] - l_r[0,\ R^{-1}(\lambda)-Q_r] - [wQ_r+(a_r+b_rQ_r), wQ_r+(a_r+b_rQ_r)] \\ &= [\,p_rL^{-1}(\lambda)-l_rR^{-1}(\lambda)+l_rQ_r-wQ_r-(a_r+b_rQ_r)\,,\ (p_r+s)Q_r-sL^{-1}(\lambda)-wQ_r-(a_r+b_rQ_r)]\end{aligned} \tag{10}$$

If $\lambda \in (L(Q_r),\ 1]$, the λ intercept set of $\tilde{\pi}_R$ can be known:

$$\begin{aligned}[\tilde{\pi}_R]_\lambda &= p_r[\min(Q_r,\tilde{D}_r)]_\lambda + s[\max(Q_r-\tilde{D}_r,0)]_\lambda - l_r[\max(\tilde{D}_r-Q_r,0)]_\lambda - [wQ_r+(a_r+b_rQ_r)]_\lambda \\ &= p_r[Q_r,\ Q_r] + s[0,\ 0] - l_r[L^{-1}(\lambda)-Q_r,\ R^{-1}(\lambda)-Q_r] - [wQ_r+(a_r+b_rQ_r), wQ_r+(a_r+b_rQ_r)] \\ &= [\,p_rQ_r-l_rR^{-1}(\lambda)+l_rQ_r-wQ_r-(a_r+b_rQ_r)\,,\ p_rQ_r-l_rL^{-1}(\lambda)+l_rQ_r-wQ_r-(a_r+b_rQ_r)]\end{aligned} \tag{11}$$

The retailer's fuzzy expected profit can be obtained from (4), (10) and (11)

$$\begin{aligned}E[\tilde{\pi}_R] &= \frac{1}{2}\int_0^{L(Q_r)}[\,p_rL^{-1}(\lambda)-l_rR^{-1}(\lambda)+l_rQ_r-wQ_r-(a_r+b_rQ_r)+(p_r+s)Q_r-sL^{-1}(\lambda)-wQ_r-(a_r+b_rQ_r)]d\lambda + \\ &\quad \frac{1}{2}\int_{L(Q_r)}^{1}[\,p_rQ_r-l_rR^{-1}(\lambda)+l_rQ_r-wQ_r-(a_r+b_rQ_r)+p_rQ_r-l_rL^{-1}(\lambda)+l_rQ_r-wQ_r-(a_r+b_rQ_r)]d\lambda \\ &= \frac{p_r+l_r-s}{2}\int_0^{L(Q_r)}L^{-1}(\lambda)d\lambda - \frac{(1-\alpha)l_r}{2}E[\tilde{A}] + (p_r+l_r)Q_r - \frac{p_r+l_r-s}{2}Q_rL(Q_r) - wQ_r-(a_r+b_rQ_r)\end{aligned} \tag{12}$$

Take the second derivative of Q_r with respect to $E[\tilde{\pi}_R]$, and get:

$$\frac{d^2E[\tilde{\pi}_R]}{dQ_r^{\ 2}} = -\frac{p_r+l_r-s}{2}L'(Q_r)$$

Clearly, $p_r+l_r-s>0$, $L'(Q_r)>0$, $\frac{d^2E[\tilde{\pi}_R]}{dQ_r^{\ 2}}<0$, So when $Q_r \in ((1-\alpha)\underline{d},\ (1-\alpha)d)$, $E[\tilde{\pi}_R]$ is a strictly concave function of its inventory Q_r.

When $Q_r \in ((1-\alpha)d,\ (1-\alpha)\bar{d})$,

The λ intercept of $\min(Q_r,\tilde{D}_r)$ is:

$$[\min(Q_r,\tilde{D}_r)]_\lambda = \begin{cases}[L^{-1}(\lambda),\ Q_r], & \lambda\in(0,\ R(Q_r)] \\ [L^{-1}(\lambda),\ R^{-1}(\lambda)], & \lambda\in(R(Q_r),\ 1]\end{cases} \tag{13}$$

$\max(Q_r-\tilde{D}_r,0) = Q_r - \min(Q_r,\tilde{D}_r)$, its λ intercept is:

$$[\max(Q_r-\tilde{D}_r,0)]_\lambda = \begin{cases}[0,\ Q_r-L^{-1}(\lambda)], & \lambda\in(0,\ R(Q_r)] \\ [Q_r-R^{-1}(\lambda),\ Q_r-L^{-1}(\lambda)], & \lambda\in(R(Q_r),\ 1]\end{cases} \tag{14}$$

$\max(\tilde{D}_r-Q_r,0) = -\min(Q_r-\tilde{D}_r,0)$, its λ intercept is:

$$[\max(\tilde{D}_r-Q_r,0)]_\lambda = \begin{cases}[0,\ R^{-1}(\lambda)-Q_r], & \lambda\in(0,\ R(Q_r)] \\ [0,\ 0], & \lambda\in(R(Q_r),\ 1]\end{cases} \tag{15}$$

If $\lambda \in (0,\ R(Q_r)]$, the λ intercept set of $\tilde{\pi}_R$ can be known from (5), (13), (14) and (15):

$$\begin{aligned}[\tilde{\pi}_R]_\lambda &= p_r[\min(Q_r,\tilde{D}_r)]_\lambda + s[\max(Q_r-\tilde{D}_r,0)]_\lambda - l_r[\max(\tilde{D}_r-Q_r,0)]_\lambda - [wQ_r+(a_r+b_rQ_r)]_\lambda \\ &= p_r[L^{-1}(\lambda),\ Q_r] + s[0,\ Q_r-L^{-1}(\lambda)] - l_r[0,\ R^{-1}(\lambda)-Q_r] - [wQ_r+(a_r+b_rQ_r), wQ_r+(a_r+b_rQ_r)] \\ &= [\,p_rL^{-1}(\lambda)-l_rR^{-1}(\lambda)+l_rQ_r-wQ_r-(a_r+b_rQ_r)\,,\ (p_r+s)Q_r-sL^{-1}(\lambda)-wQ_r-(a_r+b_rQ_r)]\end{aligned} \tag{16}$$

If $\lambda \in (L(Q_r),\ 1]$, the λ intercept set of $\tilde{\pi}_R$ can be known:

$$\begin{aligned}[\tilde{\pi}_R]_\lambda &= p_r[\min(Q_r,\tilde{D}_r)]_\lambda + s[\max(Q_r-\tilde{D}_r,0)]_\lambda - l_r[\max(\tilde{D}_r-Q_r,0)]_\lambda - [wQ_r+(a_r+b_rQ_r)]_\lambda \\ &= p_r[L^{-1}(\lambda),\ R^{-1}(\lambda)] + s[Q_r-R^{-1}(\lambda),\ Q_r-L^{-1}(\lambda)] - l_r[0,\ 0] - [wQ_r+(a_r+b_rQ_r), wQ_r+(a_r+b_rQ_r)] \\ &= [\,p_rL^{-1}(\lambda)+sQ_r-sR^{-1}(\lambda)-wQ_r-(a_r+b_rQ_r)\,,\ p_rR^{-1}(\lambda)+sQ_r-sL^{-1}(\lambda)-wQ_r-(a_r+b_rQ_r)]\end{aligned} \tag{17}$$

The retailer's fuzzy expected profit can be obtained from (4), (16) and (17)

$$E[\tilde{\pi}_R]=\frac{1}{2}\int_0^{R(Q_r)}[p_rL^{-1}(\lambda)-l_rR^{-1}(\lambda)+l_rQ_r-wQ_r-(a_r+b_rQ_r)+(p_r+s)Q_r-sL^{-1}(\lambda)-wQ_r-(a_r+b_rQ_r)]d\lambda+$$
$$\frac{1}{2}\int_{R(Q_r)}^{1}[p_rL^{-1}(\lambda)+sQ_r-sR^{-1}(\lambda)-wQ_r-(a_r+b_rQ_r)+p_rR^{-1}(\lambda)+sQ_r-sL^{-1}(\lambda)-wQ_r-(a_r+b_rQ_r)]d\lambda \quad (18)$$
$$=(p_r-s)(1-\alpha)E[\tilde{A}]+sQ_r+\frac{p_r+l_r-s}{2}Q_rR(Q_r)-\frac{p_r+l_r-s}{2}\int_0^{R(Q_r)}R^{-1}(\lambda)d\lambda-wQ_r-(a_r+b_rQ_r)$$

Take the second derivative of Q_r with respect to $E[\tilde{\pi}_R]$, and get:

$$\frac{d^2E[\tilde{\pi}_R]}{dQ_r^{\,2}}=\frac{p_r+l_r-s}{2}R'(Q_r)$$

Clearly, $p_r+l_r-s>0$, $R'(Q_r)<0$, $\frac{d^2E[\tilde{\pi}_R]}{dQ_r^{\,2}}<0$, So when $Q_r\in((1-\alpha)d,\ (1-\alpha)\bar{d})$, $E[\tilde{\pi}_R]$ is a strictly concave function of its inventory Q_r.

Based on the above two cases, when $Q_r\in((1-\alpha)\underline{d},\ (1-\alpha)\bar{d})$, the retailer's fuzzy expected profit $E[\tilde{\pi}_R]$ is a strict concave function of its inventory Q_r.

Theorem 2. Under the fuzzy demand environment, the optimal inventory Q_r^* of retailer is

$$Q_r^*=\begin{cases}L^{-1}\left(\dfrac{2(p_r+l_r-w-b_r)}{p_r+l_r-s}\right), & p_r\le 2(w+b_r)-(l_r+s)\\ R^{-1}\left(\dfrac{2(w+b_r-s)}{p_r+l_r-s}\right), & p_r>2(w+b_r)-(l_r+s)\end{cases} \quad (19)$$

Proof: When $Q_r\in((1-\alpha)\underline{d},\ (1-\alpha)d)$, by (12):

$$\frac{dE[\tilde{\pi}_R]}{dQ_r}=p_r+l_r-w-b_r-\frac{p_r+l_r-s}{2}L(Q_r) \quad (20)$$

Let $\frac{dE[\tilde{\pi}_R]}{dQ_r}=0$, $L(Q_r^*)=\frac{2(p_r+l_r-w-b_r)}{p_r+l_r-s}$, so $Q_r^*=L^{-1}\left(\frac{2(p_r+l_r-w-b_r)}{p_r+l_r-s}\right)$, and then from $\frac{2(p_r+l_r-w-b_r)}{p_r+l_r-s}\le 1$, getting $p_r\le 2(w+b_r)-(l_r+s)$.

When $Q_r\in((1-\alpha)d,\ (1-\alpha)\bar{d})$, by (18):

$$\frac{dE[\tilde{\pi}_R]}{dQ_r}=\frac{p_r+l_r-s}{2}R(Q_r)-w-b_r+s \quad (21)$$

Let $\frac{dE[\tilde{\pi}_R]}{dQ_r}=0$, $R(Q_r^*)=\frac{2(w+b_r-s)}{p_r+l_r-s}$, so $Q_r^*=R^{-1}\left(\frac{2(w+b_r-s)}{p_r+l_r-s}\right)$, and then from $\frac{2(w+b_r-s)}{p_r+l_r-s}<1$, getting $p_r\le 2(w+b_r)-(l_r+s)$.

Based on the above two cases, so theorem 2 is true.

Fuzzy profit of manufacturer:

$$\tilde{\pi}_M=p_d\min(Q_d,\tilde{D}_d)+s\max(Q_d-\tilde{D}_d,0)-l_d\max(\tilde{D}_d-Q_d,0)-t_d\min(Q_d,\tilde{D}_d)+wQ_r-c(Q_r+Q_d)-(a_d+b_rQ_d) \quad (22)$$

The problem to be solved can be expressed as:

$$\max E[\tilde{\pi}_M]$$
$$\text{s. t.}\quad \alpha\underline{d}<Q_d<\alpha\bar{d} \quad (23)$$

Thus there are

Theorem 3. Manufacturer 's fuzzy expected profit $E[\tilde{\pi}_M]$ is a strict concave function of its inventory Q_d.

Proof: Similar theorem proving process, when $Q_d\in(\alpha\underline{d},\ \alpha d)$,

If $\lambda\in(0,\ L(Q_d)]$, the λ intercept set of $\tilde{\pi}_M$ can be known:

$$[\tilde{\pi}_M]_\lambda=[(p_d-t_d)L^{-1}(\lambda)-l_dR^{-1}(\lambda)+l_dQ_d+wQ_r-c(Q_r+Q_d)-(a_d+b_dQ_d),$$
$$(p_d-t_d)Q_d+sQ_d-sL^{-1}(\lambda)+wQ_r-c(Q_r+Q_d)-(a_d+b_dQ_d)].$$

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If $\lambda \in (L(Q_d),1]$, the λ intercept set of $\tilde{\pi}_M$ can be known:

$$[\tilde{\pi}_M]_\lambda = [(p_d - t_d)Q_d - l_d R^{-1}(\lambda) + l_d Q_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d),$$
$$(p_d - t_d)Q_d - l_d L^{-1}(\lambda) + l_d Q_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)].$$

So the manufacturer 's fuzzy expected profit

$$\begin{aligned}
E[\tilde{\pi}_M] = {} & \frac{1}{2}\int_0^{L(Q_d)} [(p_d - t_d)L^{-1}(\lambda) - l_d R^{-1}(\lambda) + l_d Q_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d) + \\
& (p_d - t_d)Q_d + sQ_d - sL^{-1}(\lambda) + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)]d\lambda + \\
& \frac{1}{2}\int_{L(Q_d)}^{1} [(p_d - t_d)Q_d - l_d R^{-1}(\lambda) + l_d Q_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d) + \\
& (p_d - t_d)Q_d - l_d L^{-1}(\lambda) + l_d Q_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)]d\lambda \\
= {} & (p_d + l_d - t_d)Q_d - \frac{p_d + l_d - t_d - s}{2} Q_d L(Q_d) - l_d \alpha E[\tilde{A}] + \frac{p_d + l_d - t_d - s}{2}\int_0^{L(Q_d)} L^{-1}(\lambda)d\lambda + \\
& wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)
\end{aligned} \tag{24}$$

Take the second derivative of Q_d with respect to (24), and get:

$$\frac{d^2 E[\tilde{\pi}_M]}{dQ_d^{\,2}} = -\frac{p_d + l_d - t_d - s}{2} L'(Q_d)$$

Clearly, $p_d + l_d - t_d - s > 0$, $L'(Q_d) > 0$, $\frac{d^2 E[\tilde{\pi}_M]}{dQ_d^{\,2}} < 0$, So when $Q_d \in (\alpha \underline{d},\ \alpha d)$, $E[\tilde{\pi}_M]$ is a strictly concave function of its inventory Q_d.

When $Q_d \in (\alpha d,\ \alpha \bar{d})$,

If $\lambda \in (0,\ R(Q_d)]$, the λ intercept set of $\tilde{\pi}_M$:

$$[\tilde{\pi}_M]_\lambda = [p_d L^{-1}(\lambda) - l_d R^{-1}(\lambda) + l_d Q_d - t_d Q_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d),$$
$$(p_d + s)Q_d - sL^{-1}(\lambda) - t_d L^{-1}(\lambda) + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)].$$

If $\lambda \in (L(Q_d),1]$, the λ intercept set of $\tilde{\pi}_R$:

$$[\tilde{\pi}_M]_\lambda = [p_d L^{-1}(\lambda) + sQ_d - sR^{-1}(\lambda) - t_d R^{-1}(\lambda) + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d),$$
$$p_d R^{-1}(\lambda) - sL^{-1}(\lambda) - t_d L^{-1}(\lambda) + sQ_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)].$$

So the manufacturer 's fuzzy expected profit

$$\begin{aligned}
E[\tilde{\pi}_M] = {} & \frac{1}{2}\int_0^{R(Q_d)} [p_d L^{-1}(\lambda) - l_d R^{-1}(\lambda) + l_d Q_d - t_d Q_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d) + \\
& (p_d + s)Q_d - sL^{-1}(\lambda) - t_d L^{-1}(\lambda) + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)]d\lambda + \\
& \frac{1}{2}\int_{R(Q_d)}^{1} [p_d L^{-1}(\lambda) + sQ_d - sR^{-1}(\lambda) - t_d R^{-1}(\lambda) + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d) + \\
& p_d R^{-1}(\lambda) - sL^{-1}(\lambda) - t_d L^{-1}(\lambda) + sQ_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)]d\lambda \\
= {} & \frac{p_d - t_d - s}{2}\alpha E[\tilde{A}] - \frac{p_d + l_d - t_d - s}{2}\int_0^{R(Q_d)} R^{-1}(\lambda)d\lambda + \frac{p_d + l_d - s - t_d}{2} Q_d R(Q_d) + \\
& sQ_d + wQ_r - c(Q_r + Q_d) - (a_d + b_d Q_d)
\end{aligned} \tag{25}$$

Take the second derivative of Q_d with respect to(21), and get:

$$\frac{d^2 E[\tilde{\pi}_M]}{dQ_d^{\,2}} = \frac{p_d + l_d - t_d - s}{2} R'(Q_d)$$

Clearly, $p_d + l_d - t_d - s > 0$, $R'(Q_d) < 0$, $\frac{d^2 E[\tilde{\pi}_M]}{dQ_d^{\,2}} < 0$, So when $Q_d \in (\alpha d,\ \alpha \bar{d})$, $E[\tilde{\pi}_M]$ is a strictly concave function of its inventory Q_d.

Based on the above two cases, when $Q_d \in (\alpha \underline{d},\ \alpha \bar{d})$, the manufacturer 's fuzzy expected profit $E[\tilde{\pi}_M]$ is a strict concave function of its inventory Q_d.

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Theorem 4. Under the fuzzy demand environment, the optimal inventory Q_d^* of manufacturer is

$$Q_d^* = \begin{cases} L^{-1}\left(\dfrac{2(p_d + l_d - t_d - c - b_d)}{p_d + l_d - t_d - s}\right), & p_d \le 2(c+b_d) + t_d - (l_d + s) \\ R^{-1}\left(\dfrac{2(c+b_d - s)}{p_d + l_d - t_d - s}\right), & p_d > 2(c+b_d) + t_d - (l_d + s) \end{cases} \tag{26}$$

Proof: When $Q_d \in (\alpha \underline{d},\ \alpha d)$, by (24):

$$\frac{dE[\tilde{\pi}_M]}{dQ_d} = p_d + l_d - t_d - c - b_d - \frac{p_d + l_d - t_d - s}{2} L(Q_d) \tag{27}$$

Let $\dfrac{dE[\tilde{\pi}_M]}{dQ_d} = 0$, $L(Q_d^*) = \dfrac{2(p_d + l_d - t_d - c - b_d)}{p_d + l_d - t_d - s}$, so $Q_d^* = L^{-1}\left(\dfrac{2(p_d + l_d - t_d - c - b_d)}{p_d + l_d - t_d - s}\right)$, and then from $\dfrac{2(p_d + l_d - t_d - c - b_d)}{p_d + l_d - t_d - s} \le 1$, getting $p_d \le 2(c+b_d) + t_d - (l_d + s)$.

When $Q_d \in (\alpha d,\ \alpha \bar{d})$, by (25):

$$\frac{dE[\tilde{\pi}_M]}{dQ_d} = s - c - b_d - \frac{p_d + l_d - t_d - s}{2} R(Q_d) \tag{28}$$

Let $\dfrac{dE[\tilde{\pi}_M]}{dQ_d} = 0$, $R(Q_d^*) = \dfrac{2(c+b_d - s)}{p_d + l_d - t_d - s}$, so $Q_d^* = R^{-1}\left(\dfrac{2(c+b_d - s)}{p_d + l_d - t_d - s}\right)$, and then from $\dfrac{2(c+b_d - s)}{p_d + l_d - t_d - s} < 1$, getting $p_d > 2(c+b_d) + t_d - (l_d + s)$.

Based on the above two cases, so theorem 4 is true.

4. Numerical experiments

It is assumed that market demand $\tilde{D} = (100,\ 200, 300)$, and the various parameters in the model are $p_r = 16$; $p_d = 12$; $l_d = 0.5$; $l_r = 1$; $c = 2.5$; $w = 4$; $s = 1.5$; $t_d = 1$; $a_d = 0$; $a_r = 0$; $b_d = 0.5$; $b_r = 0.5$; $\alpha = 0.5$. In order to better illustrate the impact of parametric variation on supply chain inventory decision making and supply chain fuzzy expected profit.

This paper first analyzes the impact of retailers' traditional channel marketing price on the inventory of manufacturers and retailers, total inventory in the supply chain and supply chain fuzzy expected profit as shown in Table 2. It can be seen from Table 2 that with the increase of retailers' traditional channel marketing price, the increase of retailers' inventory and fuzzy expected profit, the increase of manufacturers' fuzzy expected profit and the increase of supply chain total inventory and fuzzy expected profit, the manufacturers' inventory still keeps unchanged.

Table2. Supply chain inventory decision and fuzzy expected profit vary with retailer's price

p_r	Q_r^*	Q_d^*	Q^*	$E[\tilde{\pi}_R]$	$E[\tilde{\pi}_M]$	$E[\tilde{\pi}]$
14	127.7778	135	262.7778	833.3	452.9	1286.2
16	130.6452	135	265.6452	1029.0	457.2	1486.2
18	132.8571	135	267.8571	1225.7	460.5	1686.2
20	134.6154	135	269.6154	1423.1	463.2	1886.3

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22	136.0465	135	271.0465	1620.9	465.3	2086.2
24	137.2340	135	272.2340	1819.1	467.1	2286.2
26	138.2353	135	273.2353	2017.6	468.6	2486.2

It then analyzes the impact of manufacturers' marketing channel price on supply chain inventory and fuzzy expected profit as shown in Table 3.

Table3. Supply chain inventory decision and fuzzy expected profit vary with manufacturer's price

p_d	Q_r^*	Q_d^*	Q^*	$E[\tilde{\pi}_R]$	$E[\tilde{\pi}_M]$	$E[\tilde{\pi}]$
12	138.2353	135.0000	273.2353	2017.6	468.6	2486.2
14	138.2353	137.5000	275.7353	2017.6	566.7	2584.4
16	138.2353	139.2857	277.5210	2017.6	665.4	2683.0
18	138.2353	140.6250	278.8603	2017.6	764.4	2782.0
20	138.2353	141.6667	279.9020	2017.6	863.6	2881.3
22	138.2353	142.5000	280.7353	2017.6	963.0	2980.6
24	138.2353	143.1818	281.4171	2017.6	1062.5	3080.1

It can be seen from Table 3 that with the increase of marketing channel price, retailers' inventory and fuzzy expected profit keep unchanged. However, the manufacturers' inventory, fuzzy expected profit, total inventory of supply chain and fuzzy expected profit are on the increase.

Table4. The influence of demand fuzziness on supply chain inventory decision and fuzzy expected profit

$\tilde{D}$	Q_r^*	Q_d^*	Q^*	$E[\tilde{\pi}_R]$	$E[\tilde{\pi}_M]$	$E[\tilde{\pi}]$
(190, 200, 210)	103.0645	103.5000	206.5645	1137.9	473.2	1611.1
(170, 200, 230)	109.1935	110.5000	219.6935	1113.7	469.7	1583.4
(150, 200, 250)	115.3226	117.5000	232.8226	1089.5	466.1	1555.6
(130, 200, 270)	121.4516	124.5000	245.9516	1065.3	462.6	1527.9
(110, 200, 290)	127.5806	131.5000	259.0806	1041.1	459.0	1500.1

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(100, 200, 300)	130.6452	135.0000	265.6452	1029.0	457.2	1486.3

It then analyzes the impact of demand fuzzy variation on supply chain inventory and fuzzy expected profit as shown in Table 4. It can be seen that with the increase of fuzzy demand, manufacturers and retailers trend to increase inventory. The manufacturers' inventory has a larger range of increase. However, the manufacturers' and retailers' fuzzy expected profit and supply chain total profit decrease and retailers' fuzzy expected profit has a smaller range of decrease. It has put forward requirements for manufacturers and retailers to have accurate estimation of the market demand in the early stage of inventory decision making so as to avoid the profit losses.

It can be seen from Table 2 and Table 4 that when consumer preference rate $\alpha = 0.5$, the manufacturers' fuzzy expected profit is smaller than the retailers' fuzzy expected profit due to the existence of price differences of two channel marketing and manufacturers' distribution cost.

Figure 1 and Figure 2 reflect the impact of consumers' online channel preference rate variation on supply chain inventory and fuzzy expected profit. It can be seen from Figure 1 that with the increase of consumers' network channel preference rate and small increase of supply chain total inventory, the retailers' inventory decreases rapidly to 0 and the manufacturers' inventory increases until it is equal to supply chain total inventory. It can be seen from Figure 2 that with the increase of consumers' online channel preference, retailers' fuzzy expected profit drops rapidly to 0 and manufacturers' fuzzy expected profit increases until it reaches the supply chain fuzzy expected total profit. It can be seen that with the increase of online channel preference, manufacturers' inventory variation and fuzzy expected profit do not exactly coincide. The reason is that with the increase of consumers' network marketing channel preference rate, manufacturers need to pay higher costs for accurate market demand information, which causes great losses to retailers' interest. The total two aspects are higher than the manufacturers' revenue. Therefore, manufacturers and retailers should consider to set up an cooperative contract so as to gain win-win situation.

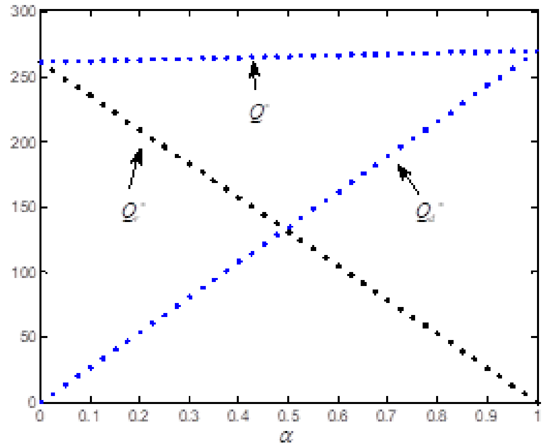

Fig.1. Impact of changes in consumers' internet channel preference rate on supply chain inventory

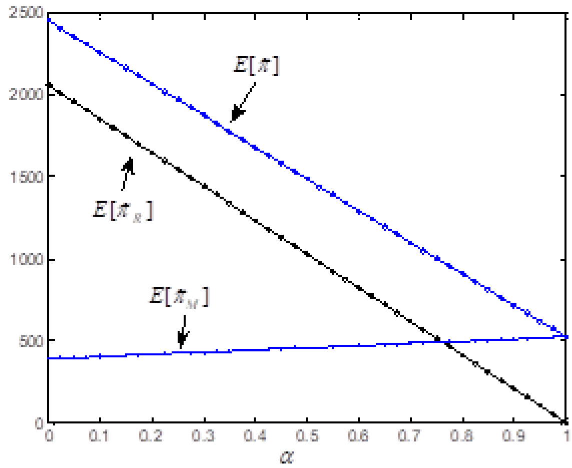

Fig.2. Impact of changes in consumers' internet channel preference rate on the fuzzy expected profit of supply chain

5. Conclusions

This paper discusses the channel preference dual channel supply chain inventory strategy under the circumstance of fuzzy demand. Manufacturers adopt

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sales modes of network marketing channel and traditional sale. The consumers in the market can be divided into network marketing channel preference and traditional retail channel preference. Based on the optimal inventory strategy model of manufacturers and retailers, this paper analyzes these two channel preference rate and sales price of these two channels, the impact of fuzzy demand on the optimal inventory level of manufacturers and retailers and their separate fuzzy expected profit increase. It is found that with the increase of retailers' traditional channel sales price, increase of retailers' inventory and fuzzy expected profit, the increase of manufacturers' fuzzy expected profit, increase of supply chain total inventory and fuzzy expected profit and the increase of manufacturers' fuzzy expected profit, the manufacturers' inventory keeps unchanged. With the increase of marketing channel price, the retailers' inventory and fuzzy expected profit keeps unchanged while manufacturers' inventory, supply chain total inventory and fuzzy expected profit increase. When consumers' channel preference rate $\alpha = 0.5$, the manufacturers' fuzzy expected profit is lower than the retailers' fuzzy expected profit due to the channel price differences and manufacturers' product distribution cost. At the same time, we also take the impact of consumers' online channel preference rate on supply chain into serious consideration. The result shows that with the increase of consumers' online channel preference, the manufacturers' inventory variation and fuzzy expected profit variation do not totally coincide. The reason is that with the increase of consumers' network marketing channel preference rate, manufacturers need to pay higher costs for accurate market demand information, which causes great losses to retailers' interest. The total two aspects are higher than the manufacturers' revenue. Therefore, manufacturers and retailers should consider setting up a cooperative contract so as to gain win-win situation. It will be one of the research areas in the future.

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