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RESEARCH ON THE MARITIME LOGISTICS PRICING MODEL OF RISK-AVERSE RETAILER-DOMINATED DUAL-CHANNEL SUPPLY CHAIN

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ABSTRACT

Price decision is studied in a risk-averse retailer-dominated dual-channel supply chain, which consisting of one manufacturers and one retailer with both off-line and on-line channels. Firstly, two mean-variance models in centralized and decentralized supply chain are established. Secondly, the optimal solutions under the two decision modes are compared and analyzed. The results shows that the price of dual-channel of retailer decreased with the increase of retailers' risk- aversion coefficient and the standard deviation of the fluctuation of market demand, while the wholesale price changes is on the contrary; in addition, when the market demand is greater than a certain value, the prices of dual channel are correspondingly higher in decentralized supply chain than in centralized supply chain, and vice versa. In addition, when the retailer's risk aversion is in a certain interval, the expected utility of the whole supply chain is greater in centralized supply chain than in decentralized decision, and vice versa. Finally, a numerical example is given to verify the above conclusions.

Keywords: Dual channel; Risk-averse; Retailer-dominated; Supply chain

INTRODUCTION

Internet network has created a new consumer market and a growing network of user groups, enterprises which sale products through e-commerce can quickly obtain new competitive advantage. Especially in recent years, e-commerce and online retail are rapidly growing. While under the background of slowdown of economic growth and the impact of e-commerce the traditional physical retail enterprises are facing serious challenges, for example, high operating costs, consumer loss and reduced profits, and even many of the traditional retail closed. In this case, the traditional retail enterprises began to seek changes in sales patterns and have turned their attention to e-commerce business model. So many of the traditional retail giant enterprises, such as WAL-MART, Suning, Gome and other enterprises which in addition to continue to retain the traditional physical stores have opened a network of sales channels, namely the dual channel sales model. The implementation of dual channel will often lead to channel conflict, such as the conflict between the manufacturer and the retailer, the conflict between offline channel and online channel, and the main means to alleviate channel conflict is to determine the reasonable price of the dual channel, so the study on pricing strategy of retailer dual channel is significant.

At present, the research on pricing of dual channel supply chain mainly focuses on the manufacturer-dominated dual channel supply chain. Such as Brynjolfsson through the empirical research on two kinds of homogeneous products, books and CDs that these two types of products in the online price cheaper than the store price of books on the Internet 9–16%, an average difference of 33% CD, the average price is 25% [1]. Chiang et al. point out that the direct selling channel is beneficial to the manufacturer and the whole supply chain, which reduces the double marginal effect of the price, while the direct selling channel is not always harmful to the retailer, because it can reduce the wholesale price of the product [2]. Hsieh et al. consider the pricing and order quantity decision making problem for multiple manufacturers and a common retailer in supply chain with uncertain demand [3]. Panda et al. discusses the pricing and replenishment decision making of a dual channel supply chain consisting of a manufacturer and a network channel Stackelberg [4]. Yao and other to build Bertrand model and Stackelberg model, the equilibrium pricing strategy [5]. Khouja et al. studies the channel choice and price strategy of the manufacturer based on the consumer preference [6].

However, at present not much research on the problem of retailers in dual channel supply chain pricing, such as Wang proposed a model of the problem of sharing in the retailer dominated option contract coordination of supply chain channels and risk [7]. Pan construct a two cycle model to study the retailer dominated multi period ordering decision problem [8]. Huang et al. studies the pricing strategy of retailer's dual channel under the condition of determining demand [9]. Zhang in a study by two manufacturers and two retailers in the supply chain, are discussed in the manufacturer Stackelberg, retailer Stackelberg and vertical Nash in three cases with alternative products in the case of deterministic demand pricing strategy [10]. Wang et al. studied the pricing strategy of a supply chain consisting of two manufacturers and a common dominant retailer [11]. Zhang mainly study the dual channel coordination problem in short life cycle [12]. With the increase of uncertainty of market demand, enterprises must consider the risk bearing capacity of enterprises in the pursuit of maximum profits.

There are fewer literatures about the risk of supply chain participants in the dual channel pricing, such as Xiao etc., and studies the influence of the retailer's risk sensitivity on the service level and price under uncertain demand [13]. Xie studied the risk aversion behavior in three different supply chain structures in the supply chain participants, results show that the structure of supply chain and supply chain risk attitude of the participants had a significant effect on the quality of investment and pricing [14]. Xu et al. studied the supply chain participants as a risk averse manufacturer's dual channel pricing strategy, and proposed a two-way profit sharing contract coordination mechanism [15]. The influence of the degree of risk aversion on the price and profit of the manufacturer's dual channel supply chain under the condition of complete information and asymmetric information by Liu and [16]. Kim et al. studied the impact of risk averse participants on the price in a decentralized dual channel supply chain [17]. Li et al. studied the effect of risk averse retailers on Pricing in the dual channel of manufacturer under uncertain demand [18].

The reminder of this paper is organized as follows. Section 2 introduces the notations, assumptions and the model. In Section 3, we examine the optimal pricing policies for the manufacturer and the retailer in both centralized and decentralized dual-channel supply chains. The theoretical results and comparisons of these results are presented in Section 4. We illustrate some managerial insights through numerical experiments in Section 5. Section 6 gives conclusions and directions for future research.

PROBLEM DESCRIPTION

In this paper, the dual channel supply chain is composed of one manufacturer and one retailer, in which the retailer is the dominant, the manufacturer is the follower. In the dual channel supply chain, the manufacturer produces a single product at a unit cost c and distribution it through the retailer at the wholesale price w, and the retailer will resell the product through his own offline channel at price p_r and online channel at price p_e. Where $p_i > w > c$ $(i=r, e)$, accordingly, the customers will migrate between two channel if they perceive the price difference. as shown in figure 1.

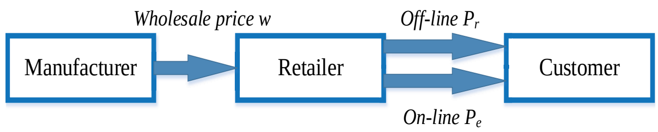

Fig.1. retailer dual-channel

Let D_r denote the consumer demand from the off-line channel and D_e denote the consumer demand from the on-line channel, respectively. we assume that the market demand is stochastic, therefore $\tilde{a}(\tilde{a}>0)$ is assumed to be a random variable, and $\tilde{a}=a+\varepsilon$, a is a positive constant and denote the potential gross market demand, whereas ε is a random variable and $\varepsilon \sim N(0,\sigma^2)$. Let s $(0<s<1)$represent the degree of customer loyalty to the offline channel, Correspondingly, $1-s$ represent the degree of customer loyalty to the online channel. The parameter $\theta(\theta>0)$is the coefficient of price elasticity of D_r and D_e. The parameter b $(\theta>0)$ is the coefficient of cross-price sensitivity, $\theta>b$ means that the effect of the cross-channel price is lower than that of the self-channel price.

Given the uncertainty of market demand, participants of supply chain have different attitude on market risk. There are a lot of risk measurement methods on risk attitude, according to the Choi on the risk aversion model summary [19], this paper adopts the mean variance theory to measure risk attitude of participants of supply chain. we consider the manufacturer as risk neutral and the retailer as risk averse. We use their risk tolerance level to measure their risk aversion. A higher tolerance for risk indicates a lower degree of risk aversion in which they are less scared of uncertainty and are more adventurous. Let k_m $(k_m>0)$ and k_r $(k_r>0)$ measure the degree of risk aversion of manufacture and retailer respectively. $k_r \geqslant 0$ denotes the retailer's risk tolerance (or degree of risk aversion), whereas $k_r > 0$ represents the retailer's aversion to risk. is used to signify the risk-neutralretailer. A larger implies that the retailer's degree of risk aversion is high. Similarly, $k_m (k_m \geqslant 0)$ refers to the manufacturer's risk tolerance or degree of risk aversion.

In model, the superscript *c* and *d* denote centralized decision and decentralized decision respectively, superscript * means optimal solution; the subscript *r* denotes the retailer or offline channels, the subscript *e* represents online channels; the subscript m represents the manufacturer, the subscript sc represents the entire supply chain.

Linear demand functions have been adopted in Chiang et al. [2], Yue and Liu [20], Huang and Swaminathan [9], and many others. The corresponding demand functions to the manufacturer and the retailer are described as follows:

$$d_r = s\tilde{a} - \theta p_r + bp_e \quad (1)$$

$$d_e = (1-s)\tilde{a} - \theta p_e + bp_r \quad (2)$$

With the above assumption and notion, expected profit functions of manufacturer and retailer is as follows:

$$E(\pi_m) = (w-c)(sa - \theta p_r + bp_e) + (w-c)[(1-s)a - \theta p_e + bp_r)] \quad (3)$$

$$E(\pi_r) = (p_r - w)(sa - \theta p_r + bp_e) + (p_e - w)[(1-s)a - \theta p_e + bp_r)] \quad (4)$$

The variance profit of manufacturer and retailer is as follows:

$$Var(\pi_m) = E\left[\pi_m - E(\pi_m)\right]^2 = (w-c)^2 \sigma^2 \quad (1)$$

$$Var(\pi_r) = E\left[\pi_r - E(\pi_r)\right]^2 = [\Delta w_r * s + \Delta w_e * (1-s)]^2 \sigma^2 \quad (2)$$

Expected utility functions of manufacturer and retailer is as follows:

$$U_m(\pi_m) = E(\pi_m) - k_m \sqrt{Var(\pi_m)} = (w-c)[a - (\theta - b)(2w + \Delta w_r + \Delta w_e) - k_m \sigma] \quad (3)$$

$$\begin{aligned} U_r(\pi_r) &= E(\pi_r) - k_r \sqrt{Var(\pi_r)} \\ &= (p_r - w_m)(sa - \theta p_r + bp_e) \\ &+ (p_e - w_m)[(1-s)a - \theta p_e + bp_r] \\ &- k_r[(p_r - w_m)s + (p_e - w_m)(1-s)]\sigma \end{aligned} \quad (4)$$

MODEL BUILDING AND SOLVING

In the dual channel supply chain of retailers, it is assumed that the retailer is risk averse and the leader in the supply chain. In order to analyze the influence of the retailer's risk aversion on the price and profit of the supply chain, the retailer and the manufacturer's decision making behavior are considered separately under the centralized decision-making and decentralized decision-making.

CENTRALIZED DECISION-MAKING SITUATION

According to the known conditions, the retailer is the leader in the dual channel supply chain, that is to say, the decision of the price and output of the supply chain is mainly determined by the retailer. When the dual channel supply chain is controlled or managed by a decision maker, the system will pursue the maximization of the profit of the whole supply chain.Thus, the expected profit, variance and expected utility function of the whole dual channel supply chain are respectively:

$$E(\pi_{sc}^c) = (p_r^c - c)(sa - \theta p_r^c + bp_e^c) + (p_e^c - c)[(1-s)a - \theta p_e^c + bp_r^c] \quad (5)$$

$$Var(\pi_{sc}^c) = E\left[\pi_{sc}^c - E(\pi_{sc}^c)\right]^2 = [(p_r^c - c)s + (p_e^c - c)(1-s)]^2 \sigma^2 \quad (6)$$

$$\begin{aligned} U_{sc}(\pi_{sc}^c) &= E(\pi_{sc}^c) - k_r \sqrt{Var(\pi_{sc}^c)} \\ &= (p_r^c - c)(sa - \theta p_r^c + bp_e^c) \\ &+ (p_e^c - c)[(1-s)a - \theta p_e^c + bp_r^c] \\ &- k_r[(p_r^c - c)s + (p_e^c - c)(1-s)]\sigma \end{aligned} \quad (7)$$

Proposition 1: In a centralized retailer dual channel supply chain with a risk-averse retailer and a risk-neutral manufacturer, assuming that the demand uncertainty ε follows a normal distribution, the optimal off-line price and on-line price are

$$p_r^{C*} = \frac{(2s-1)(a - k_r\sigma)}{4(\theta + b)} + \frac{(a - k_r\sigma)}{4(\theta - b)} + \frac{c}{2} \quad (8)$$

$$p_e^{C*} = -\frac{(2s-1)(a-k_r\sigma)}{4(\theta+b)} + \frac{(a-k_r\sigma)}{4(\theta-b)} + \frac{c}{2} \quad (9)$$

Proof of Proposition 1: From Eq.(11), it is easily known that the expected utility function of the dual channel supply chain is concave function, therefore make the Eq.(11) for first-order partial derivatives on offline-price and online-price respectively. Then make them equal to 0, the above equations are solved simultaneously, proposition 1 can be obtained. From the Eq.(12) and Eq.(13),we can know:

1) In centralized decision model, the price of retailer dual channel decreases with the increase of the retailer risk aversion coefficient and the standard deviation of the market demand.
2) In centralized decision model, dual channel retailer off-line price increases with the increase of market share of off-line channels, the on-line price is on the contrary; the offline price and online price of retailer dual channel increase with the increase of potential market volume.

Proposition 2: In a centralized retailer dual channel supply chain with a risk-averse retailer and a risk-neutral manufacturer, assuming that the demand uncertainty ε follows a normal distribution, the maximum expect profit and expect utility are

$$E_{max}(\pi_{sc}^c) = \frac{(2s-1)^2[a^2-(k_r\sigma)^2]}{8(\theta+b)} + \frac{[a^2-(k_r\sigma)^2]}{8(\theta-b)} + \frac{(\theta-b)c^2}{2} - \frac{ac}{2} \quad (10)$$

$$_{max}(\quad _{sc}) \quad \frac{(2s-1)^2(a-k\quad)^2}{8(\quad+\quad)} + \frac{(a-k_r\sigma)}{8(\qquad)} + \frac{(\qquad b)c}{2} \quad \frac{(a-k_r\sigma)c}{2} \quad (11)$$

Properties 1: In centralized decision scenario, the relation between expected utility $U_{max}(\pi_{sc}^c)$ and the degree of retailer risk averse k_r in the supply chain is as follow: if satisfy 1), then expected utility $U_{max}(\pi_{sc}^c)$ increase with the increase of the degree of retailer risk averse k_r; if satisfy 2), then expected utility $U_{max}(\pi_{sc}^c)$ decrease with the increase of the degree of retailer risk averse k_r.

1) If $k_r \geq \frac{a}{\sigma} - \frac{2(\theta^2-b^2)c}{[(2s-1)^2(\theta-b)+(\theta+b)]\sigma}$, then $\frac{\partial U_{max}\left(\pi_{sc}^c\right)}{\partial k_r} \geq 0$;

2) If $k_r < \frac{a}{\sigma} - \frac{2(\theta^2-b^2)c}{[(2s-1)^2(\theta-b)+(\theta+b)]\sigma}$, then $\frac{\partial U_{max}\left(\pi_{sc}^c\right)}{\partial k_r} < 0$;

Proof of Properties 1: In centralized decision scenario, taking the first-order partial derivatives of expected utility $U_{max}(\pi_{sc}^c)$ with respect to k_r, we have:

$$\frac{\partial U_{max}\left(\pi_{sc}^c\right)}{\partial k_r} = -\frac{(2s-1)^2(a^2-k_r\sigma)\sigma}{4(\theta+b)} - \frac{(a^2-k_r\sigma)\sigma}{4(\theta-b)} + \frac{\sigma c}{2}$$

1) Let $\frac{\partial U_{max}\left(\pi_{sc}^c\right)}{\partial k_r} \geq 0$, then $k_r \geq \frac{a}{\sigma} - \frac{2(\theta^2-b^2)c}{[(2s-1)^2(\theta-b)+(\theta+b)]\sigma}$;

2) Let $\frac{\partial U_{max}\left(\pi_{sc}^c\right)}{\partial k_r} < 0$, then $k_r < \frac{a}{\sigma} - \frac{2(\theta^2-b^2)c}{[(2s-1)^2(\theta-b)+(\theta+b)]\sigma}$.

Properties 2: In centralized decision scenario, the relation between expected utility $U_{max}(\pi_{sc}^c)$ and the market share of off-line channels s in the supply chain is as follow: (1) if satisfy $s \in (0, 0.5]$,then expected utility $U_{max}(\pi_{sc}^c)$ decrease with the increase of the market share of off-line channels s; (2) if satisfy $s \in [0.5, 1)$,then expected utility $U_{max}(\pi_{sc}^c)$ increase with the increase of the market share of off-line channels s.

Proof of Properties 2: In centralized decision scenario, taking the first-order partial derivatives of expected utility $U_{max}(\pi_{sc}^c)$ with respect to s and let it equal 0, we have:

$$\frac{\partial U_{sc}\left(\pi_{sc}^c\right)}{\partial s} = \frac{2(2s-1)(a-k_r\sigma)^2}{8(\theta+b)} = 0, \text{ then } s = 0.5.$$

therefore, if $s \in (0, 0.5]$, then $\frac{\partial U_{sc}\left(\pi_{sc}^c\right)}{\partial s} < 0$; if $s \in [0.5, 1)$, then $\frac{\partial U_{sc}\left(\pi_{sc}^c\right)}{\partial s} > 0$

DECENTRALIZED DECISION-MAKING SITUATION

In decentralized decision-making situation, manufacturer and retailer will make their own profit maximization as the goal of decision-making. Because of the assumption that the retailer is the leader of the supply chain and the manufacturer is the follower, the game between the manufacturer and the retailer belongs to Stackelberg. It is noted that when the retailer is the leader of the supply chain, we can't get the optimal solution when we substitute the demand function with respect to w into the profit function. Therefore, the sales price must be expressed as a function of the wholesale price, the retailer decision variables p_i are converted to the add-value of wholesale price Δw_i and expressed in the wholesale price, that is $p_i = w + \Delta w_i, i = r, e$.

In decentralized decision-making situation, according to Eq.(7), Eq.(8) and above assumption, the decision functions of manufacturer and retailer are respectively as follow:

$$\begin{aligned} U_m(\pi_m^d) &= E(\pi_m^d) - k_m\sqrt{Var(\pi_m^d)} \\ &= (w_m^d - c)[a - (\theta - b)(2w + \Delta w_r + \Delta w_e)] \end{aligned} \quad (12)$$

$$\begin{aligned} U_r(\pi_r^d) &= E(\pi_r^d) - k_r\sqrt{Var(\pi_r^d)} \\ &= (p_r^d - w_m^d)(sa - \theta p_r^d + bp_e^d) \\ &+ (p_e^d - w_m^d)[(1-s)a - \theta p_e^d + bp_r^d] \\ &- k_r[(p_r^d - w_m^d)s + (p_e^d - w_m^d)(1-s)]\sigma \end{aligned} \quad (13)$$

Game between retailer and manufacturer is divided into two steps: the first step, as the leader, the retailer first determines the premium Δw_r and Δw_e of wholesale price to maximize own expected utility; the second step, as the follower, the manufacturer determines the wholesale price to maximize expected utility after observing the decisions of retailer.

Proposition 3: In a decentralized retailer dual channel supply chain with a risk-averse retailer and a risk-neutral manufacturer, assuming that the demand uncertainty ε follows a normal distribution, the optimal off-line price and on-line price are

$$p_r^{d*} = \frac{(2s-1)(a-k_r\sigma)}{4(\theta+b)} + \frac{3a-2k_r\sigma}{8(\theta-b)} + \frac{c}{4} \quad (14)$$

$$p_e^{d*} = -\frac{(2s-1)(a-k_r\sigma)}{4(\theta+b)} + \frac{3a-2k_r\sigma}{8(\theta-b)} + \frac{c}{4} \quad (15)$$

$$w_m^{d*} = \frac{a+2k_r\sigma}{8(\theta-b)} + \frac{3}{4}c \quad (16)$$

Proof of Proposition 3: The proof is solved by backward induction. In the second stage of the game, the manufacturer takes its expect utility maximization as the goal, after the retailer determines the Δw_r and Δw_e, Manufacturer determines a wholesale price to maximize expected utility. The decision variable of the manufacturer is w_m^d, therefore make the Eq.(16) for first-order partial derivatives on w_m^d and make it equal to 0, then we can obtain response function w_m^d with respect to Δw_r and Δw_e.

$$w = \frac{a}{4(\theta-b)} + \frac{c}{2} - \frac{\Delta w_r + \Delta w_e}{4} \quad (17)$$

In the first stage of the game, the retailer makes decision with the goal of maximizing expected utility, his decision variable are the premium Δw_r and Δw_e of wholesale price, substitute Eq.(21) into Eq.(17), then taking the first-order partial derivatives of expected utility $U_{max}(\pi_r^d)$ with respect to Δw_r and Δw_e, and let them equal 0, we have:

$$\frac{\partial U(\pi_r^d)}{\partial \Delta w_r} = -2\theta\Delta w_r + sa - \frac{a}{4} - \frac{\theta-b}{2}c + \frac{(\theta-b)(\Delta w_r + \Delta w_e)}{2} + 2b\Delta w_e - k_r s\sigma = 0$$

$$\frac{\partial U(\pi_r^d)}{\partial \Delta w_e} = -2\theta\Delta w_e + (1-s)a - \frac{a}{4} - \frac{\theta-b}{2}c + \frac{(\theta-b)(\Delta w_r + \Delta w_e)}{2} + 2b\Delta w_r - k_r(1-s)\sigma = 0$$

To solve the above two equations, we have:

$$\Delta w_r = \frac{(2s-1)(a-k_r\sigma)}{4(\theta+b)} + \frac{a-2k_r\sigma}{4(\theta-b)} - \frac{c}{2}$$

$$\Delta w_e = -\frac{(2s-1)(a-k_r\sigma)}{4(\theta+b)} + \frac{a-2k_r\sigma}{4(\theta-b)} - \frac{c}{2}$$

Substitute above solutions into Eq.(21), then according to $p_i = w + \Delta w_i$, we can obtain Proposition 3.

From Eq. (18-20), it is easily known:

Properties 3: In decentralized decision scenario, the p_r^{d*} and p_e^{d*} decrease with the increase of the degree of retailer risk averse k_r and standard deviation σ of market demand fluctuation; the wholesale price increase with the increase of the degree of retailer risk averse k_r and standard deviation σ of market demand fluctuation.

Properties 4: In decentralized decision scenario, the p_r^{d*} and p_e^{d*} increase with the increase of the potential market demand a .The off-line price p_r^{d*} of retailer increase with the increase of the market share of off-line channel of retailer, but The on-line price p_e^{d*} of retailer decrease with the increase of the market share of off-line channel of retailer.

Proposition 4: In a decentralized retailer dual channel supply chain with a risk-averse retailer and a risk-neutral manufacturer, assuming that the demand uncertainty ε follows a normal distribution, the maximum expect utility of retailer, manufacturer and the whole supply chain respectively are

$$\begin{aligned} U_{max}^d(\pi_r^d) &= \frac{(2s-1)^2(a-k_r\sigma)^2}{8(\theta+b)} \\ &+ \frac{(a-2k_r\sigma)^2}{16(\theta-b)} - \frac{(a-2k_r\sigma)c}{4} + \frac{(\theta-b)c^2}{4} \end{aligned} \quad (18)$$

$$U_{max}^{d}(\pi_{m}^{d})=\frac{(a+2k_r\sigma)^2}{32(\theta-b)}-\frac{(a+2k_r\sigma)c}{8}+\frac{(\theta-b)c^2}{8} \quad (19)$$

$$U_{max}^{d}(\pi_{sc}^{d})=\frac{(2s-1)^2(a-k_r\sigma)^2}{8(\theta+b)}+\frac{(a-2k_r\sigma)^2}{16(\theta-b)}-\frac{(3a-2k_r\sigma)c}{4}+\frac{(a+2k_r\sigma)^2}{32(\theta-b)}+\frac{3(\theta-b)c^2}{8} \quad (20)$$

Properties 5: In decentralized decision scenario, the relation between expected utility $U_{max}(\pi_{sc}^{d})$ and the degree of retailer risk averse k_r in the supply chain is as follow: if satisfy 1), then expected utility $U_{max}(\pi_{sc}^{d})$ increase with the increase of the degree of retailer risk averse k_r ; if satisfy 2), then expected utility $U_{max}(\pi_{sc}^{d})$ decrease with the increase of the degree of retailer risk averse k_r .

1) $k_r \geq \frac{2(2s-1)^2(\theta-b)a+(\theta+b)a-4(\theta^2-b^2)c}{2\sigma[(2s-1)^2(\theta-b)+3(\theta+b)]}$;

2) $k_r < \frac{2(2s-1)^2(\theta-b)a+(\theta+b)a-4(\theta^2-b^2)c}{2\sigma[(2s-1)^2(\theta-b)+3(\theta+b)]}$.

Proof of Properties 5: In decentralized decision scenario, taking the first-order partial derivatives of expected utility $U_{max}(\pi_{sc}^{d})$ with respect to k_r , we have:

$$\frac{\partial U_{sc}\left(\pi_{sc}^{d}\right)}{\partial k_r}=-\frac{(2s-1)^2a\sigma}{4(\theta+b)}-\frac{a\sigma}{8(\theta-b)}+\frac{k_r\sigma^2(2s-1)^2}{4(\theta+b)}+\frac{3k_r\sigma^2}{4(\theta-b)}+\frac{\sigma c}{2}$$

1) Let $\frac{\partial U_{sc}\left(\pi_{sc}^{d}\right)}{\partial k_r}\geq 0$, then

$$k_r \geq \frac{2(2s-1)^2(\theta-b)a+(\theta+b)a-4(\theta^2-b^2)c}{2\sigma[(2s-1)^2(\theta-b)+3(\theta+b)]};$$

2) Let $\frac{\partial U_{sc}\left(\pi_{sc}^{d}\right)}{\partial k_r}< 0$, then

$$k_r < \frac{2(2s-1)^2(\theta-b)a+(\theta+b)a-4(\theta^2-b^2)c}{2\sigma[(2s-1)^2(\theta-b)+3(\theta+b)]}.$$

Properties 6: In decentralized decision scenario, the relation between expected utility $U_{max}(\pi_{sc}^{d})$ of the whole supply chain and the market share of off-line channels s is as follow: (1) If satisfy $s\in(0,0.5]$, then expected utility $U_{max}(\pi_{sc}^{d})$ decrease with the increase of the market share of off-line channels s ; (2) If satisfy $s\in[0.5,1)$, then expected utility $U_{max}(\pi_{sc}^{d})$ increase with the increase of the market share of off-line channel s .

Proof of Properties 6: In decentralized decision scenario, taking the first-order partial derivatives of expected utility $U_{max}(\pi_{sc}^{d})$ with respect to s and let it equal 0, we have:

$\frac{\partial U_{sc}\left(\pi_{sc}^{d}\right)}{\partial s}=\frac{2(2s-1)(a-k_r\sigma)^2}{8(\theta+b)}=0$, then $s=0.5$.

therefore, if $s\in(0,0.5]$, then $\frac{\partial U_{sc}\left(\pi_{sc}^{d}\right)}{\partial s}<0$; if $s\in[0.5,1)$, then $\frac{\partial U_{sc}\left(\pi_{sc}^{d}\right)}{\partial s}>0$.

COMPARATIVE ANALYSIS

PRICE COMPARISON UNDER TWO DECISION MODELS

(1) Price comparison under the same decision models

According to Eq.(12-13) and Eq.(17-18), let:

$\Delta p^{c}=p_r^{c*}-p_e^{c*}$, $\Delta p^{d}=p_r^{d*}-p_e^{d*}$, then

$$\Delta p^{c}=p_r^{c*}-p_e^{c*}=\Delta p^{d}=p_r^{d*}-p_e^{d*}=\frac{(2s-1)(a-k_r\sigma)}{2(\theta+b)}$$

(1) If $s>\frac{1}{2}, k_r<\frac{a}{\sigma}$, then $p_r^{c*}>p_e^{c*}, p_r^{d*}>p_e^{d*}$;

(2) If $s<\frac{1}{2}, k_r>\frac{a}{\sigma}$, then $p_r^{c*}<p_e^{c*}, p_r^{d*}<p_e^{d*}$;

(3) If $s=\frac{1}{2}$ or $k_r=\frac{a}{\sigma}$, then $p_r^{c*}=p_e^{c*}, p_r^{d*}=p_e^{d*}$.

From above analysis we can easily know: In the same decision mode, when the marker share of off-line channel is greater than that of the online channel, and the degree of the retailer risk aversion is less than a certain value, the price of off-line channel is higher than that of the online channel; when the marker share of off-line channel is less than that of the online channel, and the degree of the retailer risk aversion is greater than a certain value, the price of off-line channel is less than that of the online channel; when the marker share of off-line channel is equal to that of the online channel, and the degree of the retailer risk aversion is equal to a certain value, the price of off-line channel is equal to that of the online channel;

(2) Price comparison under the different decision models

According to Eq.(12–13) and Eq.(17–18), let $\Delta p_r = p_r^{d*} - p_r^{c*}$, $\Delta p_e = p_e^{d*} - p_e^{c*}$, then

$$\Delta p_r = p_r^{d*} - p_r^{c*} = \Delta p_e = p_e^{d*} - p_e^{c*} = \frac{a}{8(\theta - b)} - \frac{c}{4}$$

Further analysis:

(1)If $a > 2(\theta - b)c$, and $\theta > b > 0$, then $p_r^{d*} > p_r^{c*}$, $p_e^{d*} > p_e^{c*}$;

(2)If $a < 2(\theta - b)c$,then $p_r^{d*} < p_r^{c*}$, $p_e^{d*} < p_e^{c*}$.

Above analysis shows: when the market demand is greater than a certain value, the prices in decentralized dual channel are higher than that in centralized decision; when the market demand is less than a certain value, the prices in decentralized dual channel are less than that in centralized decision; when the market demand is equal to a certain value, the prices in decentralized dual channel are equal to than that in centralized decision.

EXPECT UTILITY COMPARISON UNDER TWO DECISION MODELS

According to Eq.(15) and Eq.(24), let $\Delta U(\pi_{sc}) = U_{sc}^c(\pi_{sc}^c) - U_{sc}^d(\pi_{sc}^d)$, then

$$\Delta U(\pi_{sc}) = U_{sc}^c(\pi_{sc}^c) - U_{sc}^d(\pi_{sc}^d)$$
$$= \frac{(a - 2k_r\sigma)^2 - 12(k_r\sigma)^2}{32(\theta - b)} + \frac{(\theta - b)c^2}{8} + \frac{ac}{4}$$

It is easy to know that:

1) If

$$0 \le k_r \le \frac{-a + \sqrt{3a^2 + 8(\theta - b)^2 c^2 + 16(\theta - b)ac}}{4\sigma},$$

then $U_{sc}^c(\pi_{sc}^c) \ge U_{sc}^d(\pi_{sc}^d)$;

2) If

$$k_r > \frac{-a + \sqrt{3a^2 + 8(\theta - b)^2 c^2 + 16(\theta - b)ac}}{4\sigma},$$

then $U_{sc}^c(\pi_{sc}^c) < U_{sc}^d(\pi_{sc}^d)$.

Proof: Let $\Delta U(\pi_{sc}) \ge 0$, we can get inequality: $8(k_r\sigma)^2 + 4ak_r\sigma - a^2 - 4(\theta - b)^2 c^2 - 8(\theta - b)ac \le 0$, and $k_r \ge 0$, through solving above inequality, it is easy to obtain:

$$0 \le k_r \le \frac{-a + \sqrt{3a^2 + 8(\theta - b)^2 c^2 + 16(\theta - b)ac}}{4\sigma}$$

Similarity, let $\Delta U(\pi_{sc}) < 0$, we can obtain

$$k_r > \frac{-a + \sqrt{3a^2 + 8(\theta - b)^2 c^2 + 16(\theta - b)ac}}{4\sigma}.$$

Above analysis show that only when the degree of retailer risk aversion is in a range of a certain interval, the expected utility of whole supply chain is greater in centralized decision than in decentralized decision; when the degree of retailer risk aversion exceeds a certain threshold, the expected utility of whole supply chain is less in centralized decision than in decentralized decision. This conclusion is different from that when the participants of supply chain are risk neutral.

NUMERICAL EXAMPLES

Because there are a lot of parameters in the model, the expression is more complex, to further analyze the effect of parameters on the optimal price and expected utility, the sensitivity analysis will be performed through numerical examples.

THE SENSITIVITY ANALYSIS OF PRICE

(1) The influence of k_r on the price of offline and online channel we assume that $a = 100$, $\theta = 0.6$, $b = 0.1$, $c = 2$, $s = 0.6$, $\sigma = 3$, $k_r \in [1,30]$, drawing using Matlab software. From Fig. 2 and Fig. 3, we know that the price of offline and online channel decrease with increase of the degree of retailer risk aversion both in centralized decision and in decentralized decision.

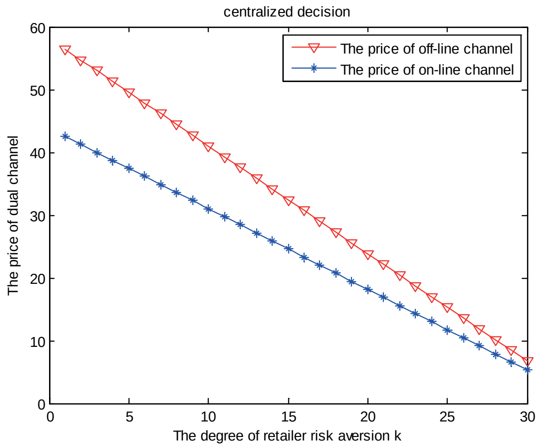

Fig.2. The influence of k_r on price in centralized decision

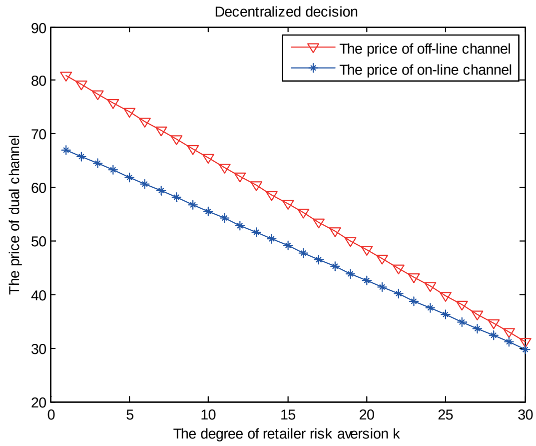

Fig.3. The influence of k_r on price in decentralized decision

(2) The influence of k_r and σ on the price of offline and online channel we assume that $a=100$, $\theta=0.6$, $b=0.1$, $c=2$, $s=0.6$, $k_r \in [0.1,1]$, $\sigma \in [1,20]$, drawing using Matlab software. From Fig.4, we know that the price of offline and online channel decrease with increase of the degree of retailer risk aversion and Standard deviation of demand fluctuation both in centralized decision and in decentralized decision.

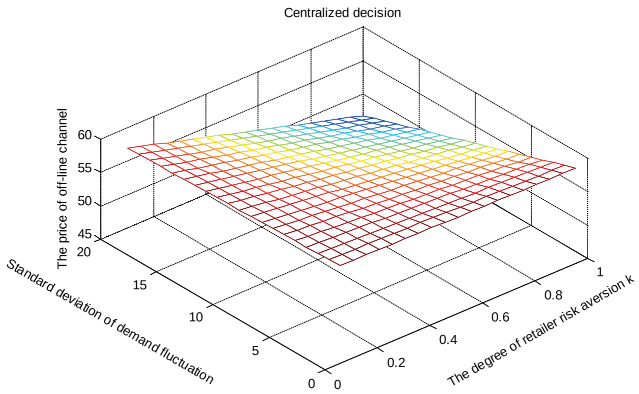

Fig.4. The influence of k_r and σ on offline price in centralized decision

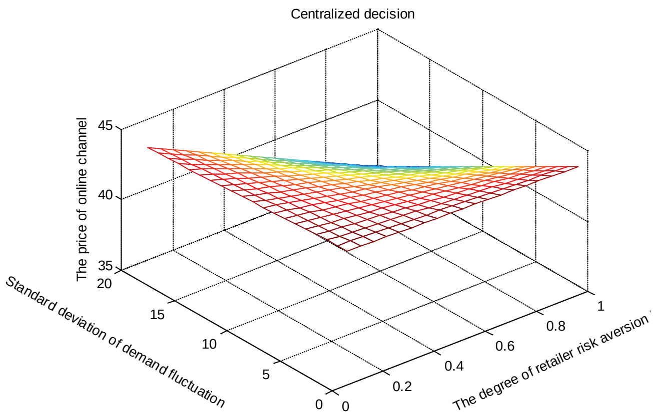

Fig.5. The influence of k_r and σ on online price in centralized decision

Similarly, in the case of the above parameters, the influence of k_r and σ on the price of offline and online channel in decentralized decision is as shown Fig.6 and Fig.7.

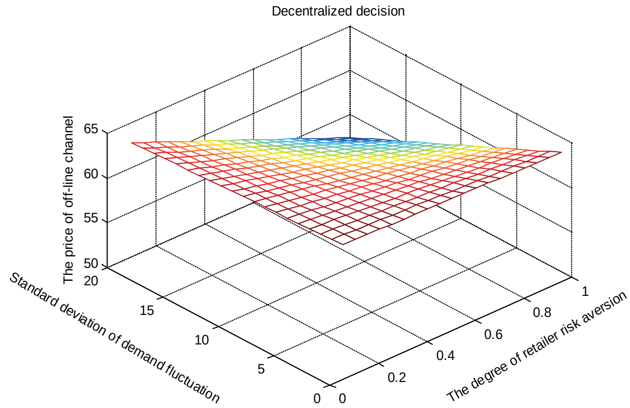

Fig.6. The influence of k_r and σ on offline price in decentralized decision

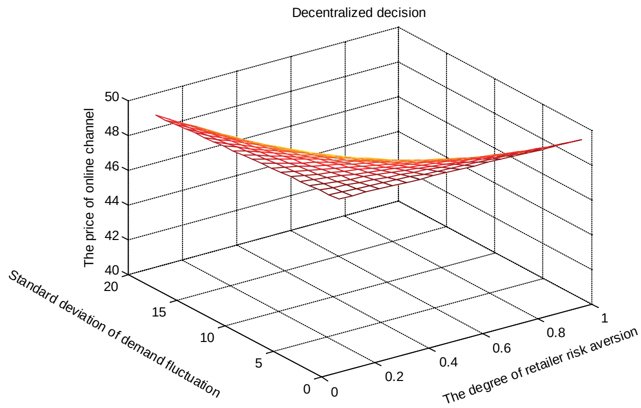

Fig.7. The influence of k_r and σ on online price in decentralized decision

THE SENSITIVITY ANALYSIS OF EXPECT UTILITY

(1) The influence of k_r on the expect utility of dual channel supply chain we assume that $a=100$, $\theta=0.6$, $b=0.1$, $c=2$, $s=0.6$, $\sigma=3$, $k_r \in [0,30]$, drawing using Matlab software. From Fig.8, we know that the expect utility of supply chain in centralized decision decrease with increase of the degree of retailer risk aversion, but the expect utility of supply chain in decentralized decision increase with increase of the degree of retailer risk aversion. From Fig.9, we know that the expect utility of retailer in centralized decision first decrease and then increase with increase of the degree of retailer risk aversion, but the expect utility of manufacturer in decentralized decision increase with increase of the degree of retailer risk aversion.

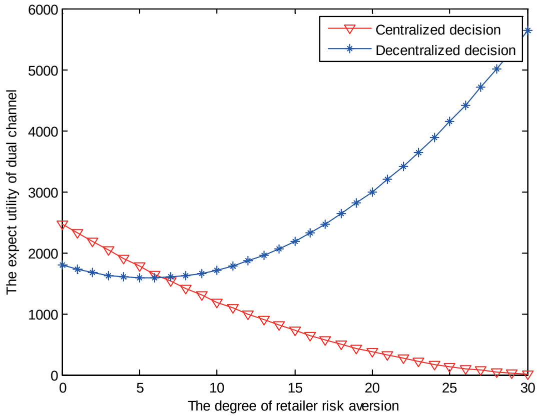

Fig.8. The influence of k_r on expect utility of supply chain in centralized and decentralized decision

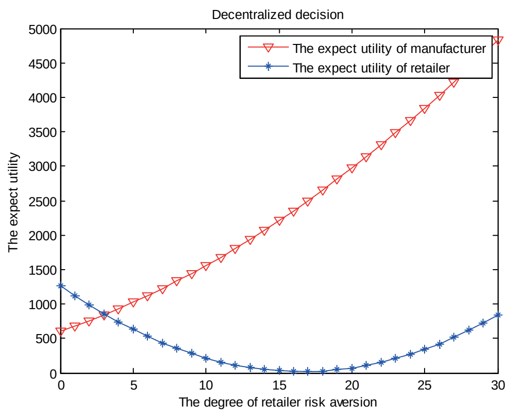

Fig.9. The influence of k_r on expect utility of retailer and manufacturer in decentralized decision

(2) The influence of k_r and σ on the expect utility of dual channel supply chain we assume that $a = 100$, $b = 0.1$, $c = 2$, $s = 0.6$, $\theta = 0.6$, $k_r \in [0.1,1]$, $\sigma \in [1,20]$ drawing using Matlab software. The influence of k_r and σ on the expect utility of dual channel supply chain in centralized and decentralized decision are as shown Fig. 10 and Fig. 11.

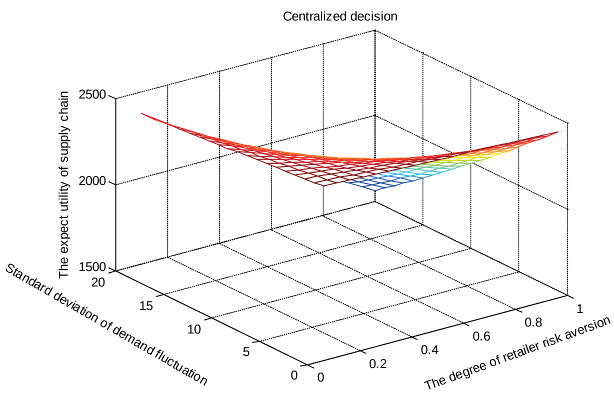

Fig.10. The influence of k_r and σ on expect utility of supply chain in centralized decision

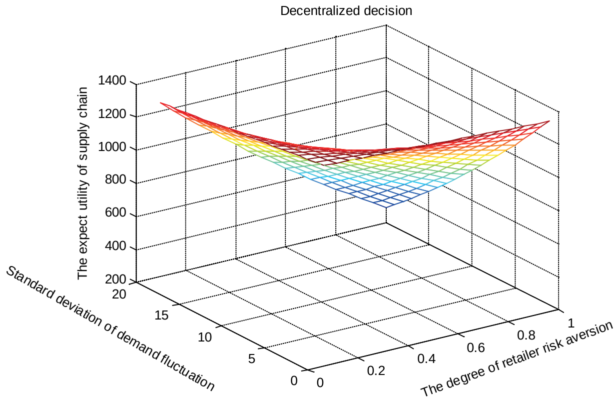

Fig.11. The influence of k_r and σ on expect utility of supply chain in decentralized decision

CONCLUSION

In a dual channel supply chain which composed of one manufacturer and one retailer with both off-line and on-line channels, considering the retailer is risk averse and the manufacturer is risk neutral, two mean-variance models in centralized and decentralized supply chain are established, Secondly, the optimal solutions under the two decision modes are compared and analyzed. analysis shows that the price of dual channel decreased with the increase of the degree of retailers risk aversion and the standard deviation of the fluctuation of market demand, while the wholesale price changes on the contrary; in addition, when the market demand is greater than a certain value, the prices are higher in decentralized decision than in centralized decision, and vice versa. Moreover, when the degree of retailer risk aversion vary in a certain interval, the expected utility of the whole supply chain is greater in centralized decision than in decentralized decision, and vice versa. Further analysis found that the price of online and offline channel decreases with the increase of price elasticity coefficient, but increased with the cross price elasticity coefficient; In addition, the off-line price increases with increase of market share, but changes of on-line price on the contrary. Finally, the numerical analysis verifies the correctness of the above conclusions.

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