Decision Making for a Risk-Averse Dual-Channel Supply Chain with Customer Returns

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Abstract. An optimal mathematic model is presented in consideration of customers' returns in a dual-channel supply chain consisting of a risk-averse manufacturer and a risk-averse retailer under the stochastic market requirement which supports the decision-making process for participants. Closed-form decisions are achieved in the centralized scenario. In the decentralized scenario, mean-variance analysis is used to conduct risk analysis. This study also delves into the influence of the degree of risk aversion, demand fluctuation and return rates on optimal decisions with the help of sensitivity analysis and numerical experimentation. Sensitivity analysis also indicates that the optimal solutions are robust. The model is a real expansion of the model library in the decision support system for dual-channel supply chains.

Keywords: Dual-channel supply chain · Risk-averse · Mean-variance · Pricing decision

1 Introduction

The Internet provides high-speed communication and close connection and serves as a new trading floor for enterprises, which can sell or purchase directly online through electronic marketplaces [1]. When e-commerce is used in a downside supply chain, the direct online channel and the traditional retail channel form a dual-channel supply chain. (A new retail channel and original direct online channel also form a dual-channel supply chain, such as Dell.) In this century, many well-known international enterprises have had dual channels, such as IBM, Dell, Cisco, Nike, Nestle and Estee Lauder. Reports from the Dell website [2] stated that the Dell retail presence amounted to more than 30,000 stores prior to 16 Jun 2009. According to IDC's worldwide quarterly tracking of PC sales statistics, in the first quarter of 2009, Dell's retail shipments rose by nearly 4 % compared with the same period last year. The total retail market share reached 7 %, which means that the dual-channel supply chain is now at the center stage of the business performance of manufacturing enterprises.

The decision-making process of a dual-channel supply chain is complicated because of its dynamic and large-scale nature, hierarchical decisions and random inputs. The decision-making process provides important technology support to the supply chain in terms of enterprise location, information integration, performance

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management, etc. Almost every enterprise (e.g., Nestle) has its own decision support system. A contract has been signed between Nestle and SAP to purchase $200 million worth of software to be accessed by all its employees. The applications, which are both internal and external, will be in the following areas: e-commerce, product life cycles, financial and cost management, marketing, customer relationships, and knowledge management. In addition, Nestle USA has signed a contract with IBM Corp to build its direct-to-customer B2B website, nestleezorder.com. Nestle is now one of the enterprises possessing a dual-channel supply chain.

Although dual-channel supply chains make profits for enterprises, problems also arise. Customer returns are so common that they become a very important factor influencing decision-making processes because the inherent characteristics of the direct online channel mean that customers cannot touch the physical commodities when the purchasing behavior occurs. In addition, profit is always accompanied with risk, and supply-chain participants have different attitudes toward risk. In fact, many factors should be considered in a dual-channel supply chain's decision-making process, and we want to make some contribution to this topic from the point of risk management. The principal contribution of this paper is the development of a model based on the consideration of participants' risk aversion attitude and costumer returns, which could support decision-making processes well.

2 Literature Review

The emergence of dual channels has caught the attention of academic circles, and conflict and coordination problems have been investigated by many scholars. In spite of the wide public concern and several academic research results on dual-channel supply chains, not much attention has been paid to dual-channel risk issues.

Currently, the study of supply chain risk issues focuses mainly on single traditional retail channels, and considering risk factor as a model parameter has gradually become the main method in supply chain research. Lau and Lau [3] used variance to measure retailers' risk and optimized the expected revenue of the manufacture and the retailer to obtain a counter-intuitive conclusion: it was not always good for the retailer to obtain return permission from the manufacturer. Gan et al. [4] proposed the coordinated study of risk-averse supply chains early. Recently, Choi et al. [5] and Choi and Chow [6] studied the return problem and fast response problem in supply chains using the mean-variance method. Chen et al. [7] analyzed the risk-averse newsvendor problem using an exponential utility function and found that the difference between the risk-averse case and risk-natural case was not very large. Chen et al. [8] took advantage of CVaR[1] to analyze the newsvendor problem and created an inventory model with additive stochastic demand and multiplicative stochastic demand. Wu et al. [9] adopted two

[1] VaR: Abbreviation for value at risk, which is a widely used risk measure of the risk of loss for a specific portfolio of financial assets in financial mathematics and financial risk management. CVaR: Abbreviation for conditional value at risk, also called Expected Shortfall (ES), which is an alternative to VaR that is more sensitive to the shape of the loss distribution in the tail of the distribution. —— Wikipedia. Both of them are also now used in supply chain risk management.

different risk measures, VaR (see Footnote 1) and CVaR, to studied the impact of uncertainty on the inventory strategy of a risk-averse newsvendor and found that different risk measures had a large effect on the inventory strategy. Chiu and Choi [10] reviewed the mean-variance model of supply chain risk issues, dividing the existing literatures into three types: single cycle problems, multiple cycle problems and information updating problems. All of these stated that the mean-variance model had become an important method for researching supply chain risk issues. The literatures above did not cover the optimal problem where both the supplier and the retailer are risk averse in dual-channel supply chains.

Today, market competition is becoming increasingly fierce, and accepting customer returns has proven to be an important means of enterprise marketing. Some scholars' research has suggested that customer returns are related to the price of the good and higher prices lead to more returns [11]. Anderson et al. [12] studied the online sales of women's fashion clothing and found that demand and customer returns were strongly positive correlated. Mostard and Teunter [13] studied the impact of customer returns on online retailer's strategies, but their research was restricted to the given price newsboy problem in a single cycle. Chen and Bell [14] studied pricing and ordering strategies in consideration of customer returns and presented the optimal retail price and order quantity under additive stochastic demand. Ghoreishi et al. [15] studied perishable goods' pricing and ordering strategies when there are currency inflation and customer returns. None of the literature refers to dual-channel supply chain strategies in which all of the supply chain participants are risk averse and customer returns exist.

Because of the inherent complexity of supply chains, especially dual-channel supply chains, modeling is not easy, and the management of supply chain systems requires not only rigid computer control but also human knowledge. A decision support system (DSS) can guarantee analysis. Decision making is easily understood with the help of a computer. Some research refers to DSS for Supply chain management (SCM). Audimoolam and Dutta [16] applied for a United States Patent for a DSS regarding SCM that collaborates forecasting, ordering, replenishment and inventory. Biswas and Narahari [17] disclosed a DSS called DESSCOM (decision support for supply chains through object modeling), the two major components of which are DESSCOM-MODEL (model library) and DESSCOM-WORKBENCH (decision workbench). Blackhurst et al. [18] proposed a decision support modeling methodology called a Product Chain Decision Model (PCDM), which can assist a manager in decision making by modeling both the operation of a supply chain design and the effects of product and process design decisions. Sarkis [19] discussed the decision framework for a green supply chain by exploring the applicability of a dynamic non-linear multi-attribute decision model. Few studies refer to decision support systems for dual-channel supply chains. This paper tries to build a decision-making model for a risk-averse dual-channel supply chain to support a better understanding of the system complexity and expand the model library.

In summary, few pieces of research refer to the decision-making process in a dual-channel supply chain in which both of the supply chain participants are risk averse. Although the customer returns problem has been studied many times, it mostly focuses on a single-channel supply chain. This paper analyzes the decision-making process in consideration of direct-channel consumers' returns under the stochastic market requirement and tries to provide references for practice in reality.

3 The Model

We consider a dual-channel supply chain in which a risk-averse manufacturer sells to a risk-averse retailer and to consumers directly. There is only one commodity. D_d, p_d, c_d, D_r, p_r and c_r indicate the demand, the price, and the production cost of the direct and retail channels, respectively. We assume that the manufacturer's wholesale price is w, and the unsold goods' salvage is zero. To obtain the demand functions (D_d and D_r), we adopt the customer utility function in Ingene and Parry [20]

$$U \equiv \sum_{i=d,r} (\alpha_i D_i - \frac{bD_i^2}{2}) - \theta D_d D_r - \sum_{i=d,r} p_i D_i. \tag{1}$$

α_i denotes the basic demand in channel i ($i = d, r$), b denotes the rate of change of marginal utility and is normalized to 1 in the sequel for brevity and θ ($0 \le \theta < 1$) denotes channel substitutability. The channels are demand interdependent (unless $\theta = 0$). Maximization of Eq. (1) yields the demand functions for each channel, as follows:

$$D_d = \frac{\alpha_d - \theta\alpha_r - p_d + \theta p_r}{1-\theta^2} \quad \text{and} \quad D_r = \frac{\alpha_r - \theta\alpha_d - p_r + \theta p_d}{1-\theta^2}. \tag{2}$$

The actual demand is often stochastic; we adopt the thought in Petruzzi and Dada [21], and assume that the stochastic demand in each channel is $X_i = D_i + \varepsilon$, $\varepsilon \sim N(0, \sigma^2)$, ($i = d, r$).

Based on the inherent characteristic that customers cannot touch the physical commodities when purchasing behavior occurs, we consider customer returns in the direct channel. We assume that customer returns can obtain full compensation. The returns function is $R_d = \beta_d X_d$ according to literature reviews, where β_d is the return rate in the direct channel. Manufacturers can always meet the needs of retailers in single cycle sales. The objective of the manufacturer and retailer is maximizing the expected revenue. We first discuss the optimal strategy under a centralized decision scenario and then discuss the optimal strategy under a decentralized decision scenario. After, we compare the results for each scenario.

3.1 Decision Making in Centralized Dual-Channel Supply Chain

In line with the model description, the stochastic demand in each channel is $X_d = D_d + \varepsilon$, $X_r = D_r + \varepsilon$, $\varepsilon \sim N(0,\sigma^2)$, and the customer return function in a single cycle is $R_d = \beta_d X_d$. Given the above, the manufacturer's revenue is $\Pi_d = (D_r + \varepsilon)w + (D_d + \varepsilon)(p_d - c_d) - p_d\beta_d(D_d + \varepsilon)$. Because we assume $E(\varepsilon) = 0$, the manufacturer's expected revenue is

$$E(\Pi_d) = D_r w + D_d(p_d(1-\beta_d) - c_d). \tag{3}$$

The retailer's revenue is $\Pi_r = (D_r + \varepsilon)(p_r - w - c_r)$, and its expected revenue is

$$E(\Pi_r) = D_r(p_r - w - c_r). \tag{4}$$

The dual-channel supply chain's revenue under a decentralized decision is

$$E(\Pi_{sc}) = D_r(p_r - c_r) + D_d(p_d(1-\beta_d) - c_d). \tag{5}$$

The first optimal conditions are as follows,

$$\frac{\partial E(\Pi_{sc})}{\partial p_d} = (-\frac{1}{1-\theta^2})(p_d(1-\beta_d) - c_d) + (1-\beta_d)D_d + \frac{\theta}{1-\theta^2}(p_r - c_r). \tag{6}$$

$$\frac{\partial E(\Pi_{sc})}{\partial p_r} = (-\frac{1}{1-\theta^2})(p_r - c_r) + D_r + \frac{\theta}{1-\theta^2}(p_d(1-\beta_d) - c_d). \tag{7}$$

Because the second optimal conditions are $\frac{\partial^2 E(\Pi_{sc})}{\partial p_d^2} = -\frac{2(1-\beta_d)}{1-\theta^2} < 0$, $\frac{\partial^2 E(\Pi_{sc})}{\partial p_r^2} = -\frac{2}{1-\theta^2} < 0$, the dual-channel supply chain's revenue is strictly a concave function with respect to p_d and p_r under a centralized decision. Combining Eqs. (6) and (7) gives proposition 1. Then, we can obtain the optimal expected revenue $E(\Pi^*_{sci})$ according to Eq. (5).

Proposition 1. The optimal prices of the manufacturer and the retailer under a centralized decision are as follows:

$$p_{di}{}^* = \frac{2A_d + \theta(2-\beta_d)\cdot A_r}{B} \quad \text{and} \quad p_{ri}{}^* = \frac{2(1-\beta_d)\cdot A_r + \theta(2-\beta_d)\cdot A_d}{B},$$

where $A_d = c_d - \theta c_r + (1-\beta_d)(\alpha_d - \theta\alpha_r)$, $A_r = c_r - \theta c_d + \alpha_r - \theta\alpha_d$ and $B = 4(1-\beta_d) - \theta^2(2-\beta_d)^2$.

3.2 Decision Making in a Decentralized Dual-Channel Supply Chain

The stochastic fluctuation of market demand gives risk to supply chain participants. We use mean-variance analysis to evaluate the expected utility in consideration of the risk aversion of the manufacturer and the retailer. We assume that there is a Stackelberg game between the manufacturer, who is the leader, and the retailer, who is the follower. The expected utility function is $U(\Pi) = E(\Pi) - k\sqrt{Var(\Pi)}$, which is presented in Lau [22]. The following are the expected revenue and variance of the manufacturer and the retailer.

The revenue, expected revenue and revenue's variance of the manufacturer and retailer are as follows:

$$\Pi_d = (D_r + \varepsilon)w + (D_d + \varepsilon)(p_d(1-\beta_d) - c_d), \Pi_r = (D_r + \varepsilon)(p_r - w - c_r),$$

$$E(\Pi_d) = D_r w + D_d(p_d(1-\beta_d) - c_d), E(\Pi_r) = D_r(p_r - w - c_r),$$

$$Var(\Pi_d) = E[(\Pi_d - E(\Pi_d))^2] = [w + p_d(1-\beta_d) - c_d]^2\sigma^2 \text{ and}$$

$$Var(\Pi_r) = E[(\Pi_r - E(\Pi_r))^2] = [p_r - w - c_r]^2\sigma^2.$$

3.2.1 Decision Making of the Retailer

With the reverse recursive method, the retailer decides the retail price in the case of having known the wholesale price and direct channel price of the manufacturer in the second stage of the Stackelberg game. The expected utility function of the retailer is

$$U(\Pi_r) = E(\Pi_r) - k\sqrt{Var(\Pi_r)} = (p_r - w - c_r)(D_r - k_r\sigma). \tag{8}$$

k_r is the degree of risk aversion; $k_r > 0$ means the retailer is risk averse, and $k_r = 0$ means the retailer is risk neutral.

Taking the first and second derivatives of $U(\Pi_r)$ with respect of p_r yields the following:

$$\frac{\partial U(\Pi_r)}{\partial p_r} = D_r - k_r\sigma + (p_r - w - c_r)(-\frac{1}{1-\theta^2}), \frac{\partial^2 U(\Pi_r)}{\partial p_r^2} = -\frac{2}{1-\theta^2} < 0.$$

$U(\Pi_r)$ is concave function about p_r. Therefore, we can obtain the optimal retail price:

$$p_r{}^* = \frac{1}{2}[\alpha_r - \theta\alpha_d + \theta p_d - k_r\sigma(1-\theta^2) + w + c_r]. \tag{9}$$

3.2.2 Decision Making of the Manufacturer

In the first stage of the game, the manufacturer decides the optimal wholesale price and direct channel price. The expected utility function of the manufacturer is

$$U(\Pi_d) = E(\Pi_d) - k_d\sqrt{Var(\Pi_d)} = (D_r - k_d\sigma)w + [p_d(1-\beta_d) - c_d](D_d - k_d\sigma). \tag{10}$$

The manufacturer will take into account the retailer's action in the first stage. Therefore, p_r^* is substituted into Eq. (10). Taking the first and second derivatives of $U(\Pi_d)$ with respect of p_d and w yields the following:

$$\frac{\partial U(\Pi_d)}{\partial p_d} = \frac{\theta}{2(1-\theta^2)}w + (1-\beta_d)(D_d - k_d\sigma) + \frac{\theta^2 - 2}{2(1-\theta^2)}[p_d(1-\beta_d) - c_d] \tag{11}$$

and

$$\frac{\partial U(\Pi_d)}{\partial w} = -\frac{w}{2(1-\theta^2)} + (D_r - k_d\sigma), \tag{12}$$

$\frac{\partial^2 U(\Pi_d)}{\partial p_d^2} = \frac{(1-\beta_d)(\theta^2-2)}{1-\theta^2} < 0, \quad \frac{\partial^2 U(\Pi_d)}{\partial p_d \partial w} = \frac{\theta(2-\beta_d)}{2(1-\theta^2)}, \quad \frac{\partial^2 U(\Pi_d)}{\partial w^2} = -\frac{1}{1-\theta^2} < 0, \quad \frac{\partial^2 U(\Pi_d)}{\partial w \partial p_d} = \frac{\theta}{2(1-\theta^2)}$.
The Hesse matrix of the manufacturer's expected utility function is as follows:

$$H(U(\Pi_d)) = \begin{bmatrix} \frac{(1-\beta_d)(\theta^2-2)}{1-\theta^2} & \frac{\theta(2-\beta_d)}{2(1-\theta^2)} \\ \frac{\theta}{2(1-\theta^2)} & -\frac{1}{1-\theta^2} \end{bmatrix}. \tag{13}$$

$|H(U(\Pi_d))| = \frac{(8-5\theta^2)(1-\beta_d)-\theta^2}{4(1-\theta^2)^2}$. When $(8-5\theta^2)(1-\beta_d) > \theta^2$ and $|H(U(\Pi_d))| > 0$, the objective function is at a minimum. Actually, the customer return rate that the supply chain participants can bear is less than 50 %, i.e., $\beta_d \le 0.5$; thus, the inequality above is usually set up. Combining Eqs. (11) and (13), we obtain the optimal direct channel price and wholesale price.

Proposition 2. The optimal direct channel price and wholesale price of the manufacturer under a decentralized decision are

$$p_d{}^* = \frac{2(2-\beta_d)\theta \cdot M_1 + 4(2-\theta^2)(1-\beta_d) \cdot M_2}{N} \quad \text{and}$$

$$w^* = \frac{2(2-\theta^2)(1-\beta_d)(2M_1 + (2-\beta_d)\theta M_2)}{N}.$$

Here,

$$N = 4(2-\theta^2)(1-\beta_d) - \theta^2(2-\beta_d)^2$$

$$M_1 = \frac{1}{2}[-\theta c_d - c_r + \alpha_r - \theta\alpha_d - \sigma(1-\theta^2)(2k_d - k_r)]$$

$$M_2 = \frac{1}{2(2-\theta^2)}[\frac{(2-\theta^2)c_d}{1-\beta_d} + \theta c_r + (2-\theta^2)\alpha_d - \theta\alpha_r - \sigma(1-\theta^2)(\theta k_r + 2k_d)].$$

Substituting p_d^* and w^* into p_r^* results in the following proposition.

Proposition 3. The optimal retail price under a decentralized decision is

$$p_r{}^* = \frac{1}{2}[\alpha_r - \theta\alpha_d + \theta p_d^* - k_r\sigma(1-\theta^2) + w^* + c_r].$$

We analyze the impact of k_d, k_r and σ on the optimal decision variables and obtain the following propositions.

Proposition 4. The degree of risk aversion of the manufacturer is negatively correlated with the optimal decisions of the manufacturer and the retailer under the decentralized decision.

Proposition 5. The degree of risk aversion of the retailer is positively correlated with the optimal direct channel price and wholesale price of the manufacturer and is negatively correlated with the retail price under the decentralized decision.

Proposition 6. The stochastic fluctuation of market demand is negatively correlated with the optimal decisions of the manufacturer and the retailer under the decentralized decision.

The proofs of Proposition 4, 5 and 6 can be obtained by emailing the authors.

4 Numerical Experimentation

We assume $\alpha_d = 100$, $\alpha_r = 100$, $c_d = 2$, $c_r = 2$, and $\theta = 0.3$ under a centralized decision scenario. When $\beta_d = 0.2$, the optimal direct channel price and retail price are $p^*_{di} = 52.7286$ and $p^*_{ri} = 49.9367$. The maximum expected revenue is $\Pi^*_{sci} = 3314.3$.

Next, we discuss the decentralized decision scenario.

(1) The impact of the customer return rate and demand fluctuation on optimal decision variables. Assume $k_d = 0.5$, $k_r = 0.5$ and $\sigma \in [0, 20]$. The results obtained by MATLAB are presented in the following four figures.

Based on Figs. 1, 2, 3 and 4, as the return rate increases, the wholesale price and the retail price first decrease and then increase, the direct channel price increases and the retailer's expected revenue increases. However, the manufacturer's expected revenue and the whole supply chain's expected revenue decrease until the return rate approaches 1. Actually, the customer return rate that the supply chain participants can bear is less than 50 %. By plotting between 0 and 1, observing the variation trend of each variable becomes more intuitive. We define $\Delta z / \Delta x$ as the *rate of change* of z. For the retailer, let $\sigma = 5$. When β_d changes from 0 to 0.5, the rate of change of the wholesale price is $(47.3750 - 44.5862)/0.5 = 5.5776$, and the rate of change of the retail price is $(65.9562 - 65.1714)/0.5 = 1.5696$, which is smaller than the return rate's rate of change, i.e., the main reason the retailer's revenue increases. For the manufacturer, the wholesale price decreases, and goodwill is damaged, as evidenced by the return rate increasing and sales dropping in the direct channel, resulting in revenue decreasing, despite the wholesale price increasing. Eventually, the manufacturer accounts for most of the revenue in terms of the supply chain revenue distribution.

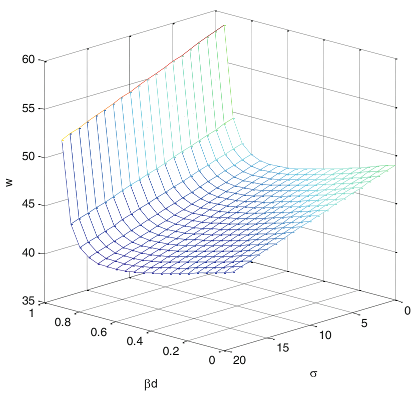

Fig. 1. Impact of β_d and σ on w

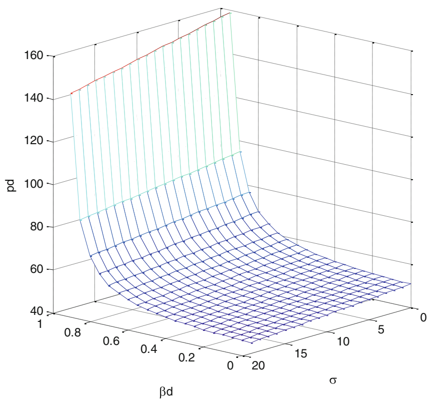

Fig. 2. Impact of β_d and σ on p_d

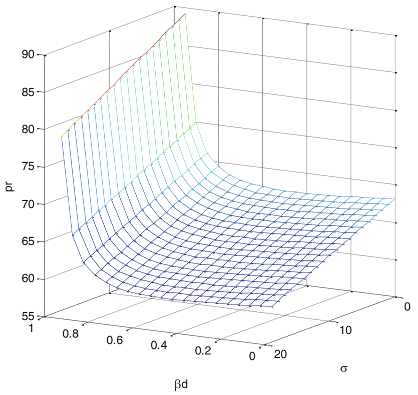

Fig. 3. Impact of β_d and σ on p_r

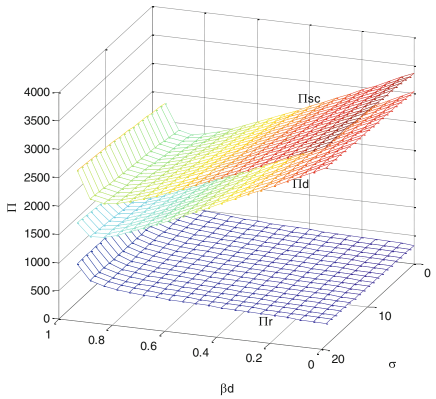

Fig. 4. Impact of β_d and σ on Π_d, Π_r and Π_{sc}

As demand fluctuation becomes more aggravated, the wholesale price, direct channel price and retail price decrease. Both of the channels' revenues increase.

When $k = 0$ and $\sigma = 0$ under decentralized decision, we obtain $p_d^*(\beta_d = 0.2) = 51.9889 < p_{di}^*$, $p_r^*(\beta_d = 0.2) = 67.6668 > p_{ri}^*$ and $\Pi_{sc}^*(\beta_d = 0.2) = 2960.6 < \Pi_{sci}^*$, indicating that the revenue under the decentralized decision is smaller than that under the centralized decision.

(2) The impact of the degree of risk aversion and demand fluctuation on optimal decision variables. Assume $k_d = k_r = k$, $k \in [0, 3]$ and $\sigma \in [0, 30]$. The results obtained by MATLAB are presented in Fig. 5.

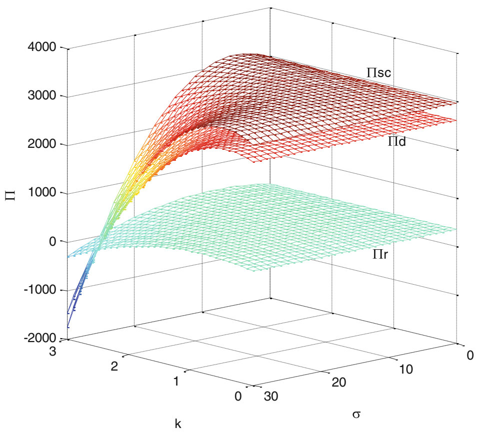

Fig. 5. Impact of k and σ on Π_d, Π_r, Π_{sc}

Based on Fig. 5, as the degree of risk aversion increases, the variation trends of the revenue of the manufacturer, the retailer and the whole supply chain change similarly, and all have close relations to the demand fluctuation. When demand fluctuation is small, revenue increases as the degree of risk aversion increases; as demand fluctuation becomes larger, revenue first increases and then decreases. The demand fluctuation directly depicts the risk that participants face. The above results suggest that participants' risk aversion favors high revenue when demand is relatively stable but may have a negative impact on revenue with demand volatility.

As the demand fluctuation becomes more aggravated, the variation trends of the revenue of the manufacturer, the retailer and the whole supply chain are closely related to the degree of risk aversion. When the degree of risk aversion is small, revenue increases as demand fluctuation increases; when the degree of risk aversion degree becomes larger, revenue first increases and then decreases.

Revenue under the decentralized decision is lower than that under the centralized decision when participants are risk neutral or demand is stable ($\Pi_{sc}^{*}(k = 0, \sigma = 0) = 2960.6 < \Pi_{sci}^{*}$). However, when participants are risk averse and demand is unstable, revenue under the decentralized decision could increase, but the maximum revenue is still lower (Π_{sc}^{*} $(k = 0.25, \sigma = 30) = 3161.4 < \Pi_{sci}^{*}$).

(3) Let us discuss the variation trends of the decision variables when the variance of the demand is confirmed and the degrees of risk aversion between the manufacturer and the retailer are different. Fixing $\beta_d = 0.2$ and $\sigma = 10$, the results are as follows:

Table 1. Optimal solutions when k_d is fixed and k_r changes

k_d	k_r	w^*	p_d^*	p_r^*	Π_d^*	Π_r^*	Π_{sc}^*	Π_{sci}^*
0.5	0	42.3	48.6	64.4	2587.0	446.4	3033.4	3314.3
0.5	1	46.9	48.7	62.2	2777.7	328.6	3106.3	3314.3
0.5	2	51.4	48.8	59.9	2991.2	176.7	3167.8	3314.3
0.5	3	56.0	48.9	57.7	3227.4	−9.4	3218.0	3314.3
0.5	4	60.6	49.0	55.4	3486.3	−229.6	3256.8	3314.3
0.5	5	65.2	49.1	53.2	3768.1	−483.9	3284.2	3314.3

Based on Table 1, when k_d is fixed and k_r increases, the optimal wholesale price and direct channel price increase, and the optimal retail price decreases. Meanwhile, the manufacturer's revenue increases, and the retailer's revenue decreases, which results in the whole supply chain's revenue increasing. This scenario is very bad for the retailer. The retailer decreases the retail price, but the manufacturer increases the wholesale price. The slight increase in the direct channel price has little impact on customers' transformation between the two channels. So, the retailer's revenue receives a large shock, but the manufacturer benefits.

Table 2. Optimal solutions when k_r is fixed and k_d changes

k_r	k_d	w^*	p_d^*	p_r^*	Π_d^*	Π_r^*	Π_{sc}^*	Π_{sci}^*
0.5	0	50.0	52.0	66.5	2699.9	304.2	3004.1	3314.3
0.5	1	39.1	45.3	60.1	2618.6	490.2	3108.7	3314.3
0.5	2	28.2	38.7	53.6	2374.7	719.7	3094.3	3314.3
0.5	3	17.3	32.0	47.2	1968.2	992.7	2960.9	3314.3
0.5	4	6.4	25.3	40.7	1399.1	1309.2	2708.3	3314.3
0.5	5	-4.5	18.6	34.3	667.3	1669.3	2336.6	3314.3

Based on Table 2, when k_r is fixed and k_d increases, the optimal wholesale price, direct channel price and optimal retail price decrease. Meanwhile, the manufacturer's revenue decreases, and the retailer's revenue increases, which results in the whole supply chain's revenue first increasing and then decreasing. The retail price decreases more slowly than the wholesale price and at the same rate as the direct channel price, which means that the price war has little impact on consumers' channel selection. Therefore, this scenario benefits the retailer, who obtains higher revenue.

5 Conclusions

The principal contribution of this paper is building a mathematic model that could support decision-making process in consideration of direct-channel consumers' returns under the stochastic market requirement. Optimum decisions are proposed in the centralized dual-channel supply chain. In terms of decentralized decisions, we use an analytical method and numerical simulation. The results show that a high direct channel return rate will reduce the revenue of the manufacturer and the whole supply chain, but it is beneficial for the retailer in obtaining high revenue, regardless of market demand fluctuations. The impact of the degree of risk aversion on revenue is closely related to demand fluctuation; when the market is stable, revenue increases with an increase in the degree of risk aversion, and when the market is unstable, revenue increases first and then decreases. When the manufacturer's risk aversion is fixed and the retailer's risk aversion increases, it is a nightmare for the retailer; however, when the retailer's risk aversion is fixed and the manufacturer's risk aversion increases, it is beneficial for the retailer. These conclusions could help supply chain participants adjust their risk aversion attitude to obtain maximum revenue through observing or predicting the market situation and other enterprises' risk attitude. The fact that the expected revenue under a decentralized decision is lower than that under a centralized decision shows that the decentralized decision will lead to double marginalization.

The model in this paper is not difficult to understand but is very useful for managers when making decisions. Parameters could be added or reduced or changed on the basis of our model, which means the model is flexible. As we know, the decision support system for a dual-channel supply chain is large scale and complex as a type of network information system that includes several modules, such as a problem analysis and information processing module, a decision analysis module, an electronic communication module, an electronic conference module, an information management module, a system management module and a human-computer interaction module. A little mistake may result in disastrous results in the complex system. The robust mathematic model in our paper could be used in the problem analysis and decision analysis module and will be good for the system. It is a real expansion of the model base in the decision support system for dual-channel supply chains.

There are some limitations in this paper. We did not consider the existence of substitute products in this paper. The contract problem of dual-channel supply chains in consideration of returns and risk aversion in both of the channels will be discussed in the future.

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