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DECISION POLICIES ON PLAYERS' DIFFERENT RISK COMBINATION UNDER SUPPLIER ENCROACHMENT

Ping Chen, Bo Li* and Huafei Huang

Abstract. Literature concerning about the supply chain management problem is usually based on perfect rationality. However, risk preferences have been proved to be an important role which influences managers' decisions significantly. This paper investigates a risk combination problem under supplier encroachment with different risk preferences players. Assuming that the supply chain players may be risk-averse, risk-neutral and risk-taking, we build a Stackelberg game model to explore the optimal decisions and the impact of different risk combinations, respectively. We focus on two scenarios: the consumers perceive uniform quality between the two channels and perceive differentiated quality between the two channels. We find that the retailer always prefers a risk-averse supplier, while the supplier always prefers a risk-taking retailer. But the combination of a risk-averse supplier and a risk-taking retailer is not always beneficial to the whole supply chain. Further, we conduct numerical experiments to explore the risk combinations and the impacts of players' selfish, aggressive and altruistic behaviors on optimal decisions.

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1. Introduction

Nowadays, more and more upstream suppliers trend to invest in online channels to compete with traditional retailers. In these dual-channel supply chains, suppliers can distribute products through the traditional channels as well as directly to customers through their online channels. Under this circumstance, intensifying competition arises between the retailers and their suppliers, which is called supplier encroachment. Recently, the proliferation of online channels has made concerns about supplier encroachment a fever pitch [31]. It is shown that supplier encroachment has two effects on decision making, that is, it enables the supplier to control the selling price in the retail market, and consequently motivate him to reduce the wholesale price. Arya *et al.* [3] showed that double marginalization could be mitigated and both the supplier and the retailer could benefit from supplier encroachment if the latter effect is more efficient in the retail process. Although the existing literature has considered various elements that may influence the effects of supplier encroachment, the members in the supply chain are often assumed to be risk neutral. However, facing the volatile demand and fierce competition in the market, decision makers may show different risk preferences [11,28]. Therefore, a consideration of risk preferences is significantly important in setting a supplier encroachment problem.

Keywords. Supply chain management, supplier encroachment, risk preferences, Stackelberg game.

[1] College of Management and Economics, Tianjin University, 300072 Tianjin, PR China.
*Corresponding author: libo0410@tju.edu.cn

In fact, empirical and theoretical findings have shown that supply chain members' risk preferences may result in decisions deviating from the rational optimal decisions [11, 19, 28]. Schweitzer and Cachon [28] empirically found that newsvendors either ordered too low or too high depending on their risk preferences. Brown and Tang [6] showed that the subjects in the experiment tended to order less than the rational optimal quantity because they were concerned about potential profit loss. Although there were some studies addressing this problem in supply chain management models, most work paid more attention to risk-averse behavior rather than risk-taking behavior. Practically, empirical findings have shown that decision makers may show risk-taking behavior under certain circumstances [5, 28], but few researches have analytically addressed this problem. In addition, it is unclear that how the supply chain members' risk preferences influence their intention of choosing a partner. Therefore, this paper will explore how the supply chain members make ordering decisions and choose a partner when their opponent players show different risk preferences.

Above all, it motivates us to focus on the following questions:

(1) How do we characterize the different risk preferences of a decision maker and what are the optimal decisions with different risk preferences? (2) How do risk preferences affect the players' optimal decisions as well as their utilities? (3) For the supplier or the retailer, what kind of partner (risk averse, risk neutral and risk-taking) will he or she prefer to trade with? (4) How do players' selfish, aggressive and altruistic behaviors influence their preferences?

To address the above questions, we first propose a model to characterize the players' risk preferences with respect to two risk parameters including risk and pessimistic coefficients which can jointly model risk-neutral, risk-averse as well as risk-taking behavior in a unified framework [20]. It facilitates us to explore the impact of risk preferences on the optimal ordering quantities under supplier encroachment environment.

In this paper, we consider a supplier encroachment problem when players show different risk preferences (risk averse, risk neutral and risk prone) under the Mean Conditional Value at Risk (Mean-CVaR) formulation. To be specific, we consider a two-echelon supply chain consists of a supplier (he) and a retailer (she). The supplier acts as the leader and supplies the fashion product to the traditional retailer as well as directly to consumers through his online channel. We illustrate how to build the optimization models which can capture different risk preferences for individual decision makers. Notice that to our best knowledge, this paper is the first in the literature that addresses the risk preference choice problem in supply chains which includes risk neutral, risk averse and risk prone players together. We also explore the impacts of the supply chain players' selfish, aggressive and altruistic behaviors on the optimal decisions and partner choices. So, we are significantly different from all the other related works in the supply chain management literature.

The rest of the paper is organized as follows. Firstly, we take an overview of some related researches about risk preference behaviors in supply chain management in Section 2. Then we introduce a general supplier encroachment model with different risk preferences under uniform perceived quality based on Mean-CVaR criterion in Section 3. We analyze the impact of the players' risk preferences on optimal decisions, their utilities as well as their choices of selecting a partner. We also provide numerical examples to gain more managerial insights when players show selfish, aggressive and altruistic behaviors. In Section 4, we extend our model to capture the situation when consumers perceive differentiated quality between the two channels. Finally, we conclude with a summary and some future directions in Section 5.

2. Related literature

Papers on the supply chain management problem often assume that players are risk neutral. However, literature and practical experiences have shown that players' risk preferences have significant impacts on managers' decisions. For example, Qinghua [26] considered a supply chain coordination problem using revenue-sharing contract. Assuming that the supplier and the retailer had risk-averse attitudes, they explored how the optimal wholesale price, the order quantity, the quota of the revenue sharing and supply chain coordination were influenced by their risk-averse preferences. Xie *et al.* [34] studied quality investment and price decision of a make-to-order supply chain with uncertain demand. They analyzed three different supply chain strategies: Vertical

Integration, Manufacturer Stackelberg and Supplier Stackelberg, with considering the risk-averse behavior of the players. Demirag [14] pointed out that risk attitudes of retailers and buyers might play an important role on the effectiveness of weather-linked promotions in the presence of seasonal weather uncertainty. They investigated the performance of weather-conditional rebates incorporating the impact of the retailer's risk aversion behavior based on mean-variance framework. They found out that the rebate program could increase the mean profit and reduce the profit variance simultaneously. Liu and He [23] investigated the optimal order decision in a supply chain with risk-averse decision-makers when demand and consumer returns were uncertain. By using mean-variance objective framework, they illustrated the impacts of consumer returns and the supply chain members' risk attitudes on the optimal order decision. Wang and Hu [32] conducted the rational expectation (RE) equilibrium analysis for a risk-averse newsvendor facing strategic customers. They found out that a risk-averse newsvendor's equilibrium price was lower than that of a risk-neutral retailer and the equilibrium stocking quantity was higher than that of a risk-neutral one. Zhou [37] investigated the coordination of buyback policy in a supply chain with a risk-averse supplier and a risk-averse retailer, and adopted Conditional Value at Risk (CVaR) to estimate their risk attitude. Through establishing a Stackelberg game model, they showed that the optimal order quantity decreased as the players' risk aversion levels increased. Huynh and Pan [18] considered a vendor managed inventory problem with a risk-neutral manufacturer and a risk-averse retailer who maximized her expected utility. They made the conclusion that risk-averse retailer offered a lower price to the manufacturer than that of risk-neutral one. Li *et al.* [22] introduced the retailer's risk-averse behavior into a manufacturer encroachment problem under demand information asymmetry. Using mean-variance decision framework, they focused on revealing the influences brought by the retailer's risk-averse behavior and the manufacturer's selling cost on the optimal decisions. Dai and Chao [13] studied a pricing policy preference problem by assuming that the risk aversion coefficients of the agents were private information of the sales agents. They obtained the optimal compensation and pricing contracts under centralized pricing and delegated pricing settings. Then they found that either strong risk aversion or high effort valuation could drive the agents to favor centralized pricing over delegated pricing. Choi [10] adopted the mean-risk framework to uncover how the retailer's risk-averse behavior impacted its inventory decisions in a make-to-order quick response system. Cui *et al.* [12] studied a risk-averse retailer's optimal decision of introducing her store brand product under the mean-variance criterion. Xue *et al.* [36] considered the diversification strategy for a risk-sensitive manufacturer with unreliable suppliers under the mean-variance framework, and investigated the impact of the supplier's cost or reliability on the risk-averse manufacturer's ordering decisions and customer service level. Liu *et al.* [24] investigated the effect of risk aversion on the optimal policies of a dual-channel supply chain under symmetric information and asymmetric information cases. They found that if the manufacturer overestimated the retailers risk aversion value, the retailers' expected profit would be lower if she shared her risk aversion information with the manufacturer.

The above works all considered the risk-averse behaviors of the supply chain members, but there are some studies demonstrating that decision makers sometimes show risk taking behaviors. For example, Sitkin and Pablo [29] suggested that past successful experience of decision makers led to risk propensity, because the knowledge that decision makers accumulated from the past success was likely to make risk seem reasonable. Carpenter *et al.* [7] showed that when decision makers learned from their past experience and possessed sufficient knowledge about the decision domain, they were also more likely to convert their risk-taking incentives to the actual risk actions. Smith *et al.* [30] suggested that knowledge creation capability motivated organizations to take risk in innovative activities, such as new product development. Xue [35] showed that due to the risk return association of IT, organizations were likely to strategically take risk in adopting IT to pursue higher returns. These works gave examples in which situation did managers take risky behaviors, however, they did not incorporated this risk-taking behavior into supply chain management.

As risk-averse and risk-taking behaviors both exist in practice, some literature studies the combination of risk-neutral, risk-averse and risk-taking behaviors in a unified framework. He *et al.* [16] developed a model to determine optimal return policies for single-period products based on uncertain market demands and in the presence of risk preferences. The impacts of risk-preferences on the supplier's return policies and the retailer's order quantities were investigated. Hua *et al.* [17] studied how the risk attitude of the members affected decisions, profits and channel coordination. They proposed a Value-at-Risk formulation to capture the risk bias of each supply chain member and found that manufacturer could not coordinate the channel with a risk-prone or severely-risk-averse retailer by the traditional contracts. Choi *et al.* [11] proposed a mean-variance (MV) formulation to capture the risk preference of each individual supply chain agent. They found that a slightly risk averse supply chain coordinator can successfully coordinate with a slightly risk prone retailer but not a very risk averse retailer. Using the Mean-CVaR framework, Jammernegg and Kischka [20] constructed a newsvendor model to explore the optimal order quantity for an objective function when the inventory manager showed risk-neutral, risk-averse as well as risk-taking behaviors. Qin *et al.* [25] reviewed the contributions for analyzing the newsvendor problem and analyzed how the buyer's risk profile moderated the newsvendor order quantity decision. Arcelus *et al.* [1] evaluated the pricing and ordering policies of risk-neutral, risk-averse and risk-seeking newsvendor-type retailers facing price-dependent stochastic demand and several sales-promotion policies, namely pricing, rebates and advertising. They found that the more risk averse the retailer, the lower its profit and the more it favored multiple promotion policies. Avinadav *et al.* [4] investigated the revenue sharing contract used in the mobile applications (Apps) industry. They focused on how supply chain members' different attitudes toward risk: averse, neutral and seeking behaviors affected equilibrium strategies and chain performance. The above papers all have considered decision makers' different risk attitudes, however, they have not incorporated the supplier's encroachment behavior, nor have they considered the decision makers' choices of choosing partners. We are the first to study how risk preferences impact supply chain players' choices of choosing partners under supplier encroachment.

3. Encroachment with uniform perceived quality

We consider a supplier encroachment problem with a supplier (he) and a retailer (she), the supplier produces one product and sells to customers through the retailer and his own direct channel. To allow for the possibility that the retailer may be more efficient in retail operations than the supplier, we assume that the supplier incurs a per-unit selling cost c for each unit on direct channel and the selling cost of the retail channel is normalized to 0 [3, 15, 21]. On the demand side, we assume potential consumers with a total mass of one are heterogeneous in their valuation, δ, per unit of product quality, which we assume is uniformly distributed on $[0,1]$. Here, we outline the basic model and investigate a benchmark case that the consumers have the same recognition of network channel and traditional channel, namely, consumers have uniform perceived quality on both channels. In this case, for any given price p for the product, the net utility of a consumer with valuation δ is $\delta - p$. Therefore, all customers with $\delta \geq p$ would buy the product. Hence demand is $q = \delta - p$ [15]. Without loss of generality, we normalize that the product's quality $\delta = 1$. In order to characterize market uncertainty, we further assume that $q = 1 + \xi - p$, where the random variable ξ has a probability density function $g(\cdot)$ and a cumulative distribution function $G(\cdot)$ supported on $[-U, U]$, assuming $E[\xi] = 0$. Hence, we can yield the inverse demand function $p = 1 + \xi - q$, where q is the total number of the product deployed for sale, including the retailer's ordering quantity q_r and the supplier's direct stock q_s, p is the market clearing price.

According to Jammernegg and Kischka [20], we use a Mean-CVaR method to characterize the different risk preferences of the supplier and the retailer. As $p = 1 + \xi - q$, then the expected profits of the supplier and the retailer are:

$$E(\pi_s) = E[(p - c)q_s + wq_r] = (1 - q_r - q_s - c)q_s + wq_r \tag{3.1}$$

$$E(\pi_r) = E[(p - w)q_r] = (1 - q_r - q_s - w)q_r. \tag{3.2}$$

Then, we need deduce the η_i-CVaR value of the supplier and the retailer, where $i = s, r$. The CVaR criterion measures the average profit falling below the η_i-quantile level v, where $\eta_i(\eta_i \in (0, 1])$ is a confidence indicator specified by the decision maker to attain a certain level of profit v. $v^\eta(\pi_i)$ is the player's VaR, which is defined as follows [2]:

$$v^\eta(\pi_i) = \inf\{Pr(\pi_i \leq v) \geq \eta_i\}. \tag{3.3}$$

Thus, the players' $\eta_i - \text{CVaR}$ value is defined as follows [27]:

$$\text{CVaR}^{\eta}(\pi_i) = E\left[\pi_i | \pi_i \le v^{\eta}(\pi_i)\right]. \tag{3.4}$$

Furthermore, to simplify the computation, we use the following equivalent definition [27]:

$$\text{CVaR}^{\eta}(\pi_i) = \max_{v \in R}\left\{v + \frac{1}{\eta_i} E\left[\min\left(\pi_i - v, 0\right)\right]\right\}. \tag{3.5}$$

Then

$$\begin{aligned}\text{CVaR}^{\eta}(\pi_s) &= \max_{v \in R}\left\{v + \frac{1}{\eta_s} E\left[\min\left(\pi_s - v, 0\right)\right]\right\} \\ &= \max_{v \in R}\left\{v + \frac{1}{\eta_s}\int_{-U}^{c+\frac{v-wq_r}{q_s}+q_r+q_s-1}\left(q_s\left(-c+\xi-q_r-q_s+1\right)+wq_r-v\right)\mathrm{d}G(\xi)\right\}.\end{aligned}$$

Let $H(v) = \left\{v + \frac{1}{\eta_s}\int_{-U}^{c+\frac{v-wq_r}{q_s}+q_r+q_s-1}\left(q_s\left(-c+\xi-q_r-q_s+1\right)+wq_r-v\right)\mathrm{d}G(\xi)\right\}$, and $\frac{\mathrm{d}H^2(v)}{\mathrm{d}v^2} < 0$, which means $H(v)$ is a concave function with v. Let $\frac{\mathrm{d}H(v)}{\mathrm{d}v} = 0$, thus $v^* = (G^{-1}(\eta_s) + 1 - q_r - q_s - c)q_s + wq_r$.

Therefore,

$$\text{CVaR}^{\eta}(\pi_s) = (1 - q_r - q_s - c + M_s)q_s + wq_r \tag{3.6}$$

where $M_s = G^{-1}(\eta_s) - \frac{1}{\eta_s}\int_{-U}^{G^{-1}(\eta_s)} G(\xi)\mathrm{d}\xi$. Similarly, we can obtain the retailer's $\eta - \text{CVaR}$ value:

$$\text{CVaR}^{\eta}(\pi_r) = q_r M_r + (1 - q_r - q_s - w)q_r \tag{3.7}$$

where $M_r = G^{-1}(\eta_r) - \frac{1}{\eta_r}\int_{-U}^{G^{-1}(\eta_r)} G(\xi)\mathrm{d}\xi$. Let $\Gamma(\pi_i)$ represents the Mean-CVaR utility function for player i, then

$$\begin{aligned}\Gamma(\pi_i) &= (1-\lambda_i)\, E\left(\pi_i | \pi_i \ge v^{\eta_i}(\pi_i)\right) + \lambda_i E\left(\pi_i | \pi_i \le v^{\eta_i}(\pi_i)\right) \\ &= \frac{\text{CVaR}(\pi_i)\left(\lambda_i - \eta_i\right)}{1-\eta_i} + \frac{E\left(\pi_i\right)\left(1-\lambda_i\right)}{1-\eta_i}\end{aligned} \tag{3.8}$$

where $\lambda_i (0 \le \lambda_i \le 1)$ is a weighting factor, and represents the coefficient of pessimism. The higher λ_i the more weight the manager puts to low profit. Thus, based on equations (3.7) and (3.8), we have

$$\begin{aligned}\Gamma(\pi_s) &= \frac{\text{CVaR}(\pi_s)\left(\lambda_s - \eta_s\right)}{1-\eta_s} + \frac{E\left(\pi_s\right)\left(1-\lambda_s\right)}{1-\eta_s} \\ &= q_s\left(1 - c - q_r - q_s\right) + \frac{M_s q_s\left(\lambda_s - \eta_s\right)}{1-\eta_s} + wq_r\end{aligned} \tag{3.9}$$

$$\begin{aligned}\Gamma(\pi_r) &= \frac{\text{CVaR}(\pi_r)\left(\lambda_r - \eta_r\right)}{1-\eta_r} + \frac{E\left(\pi_r\right)\left(1-\lambda_r\right)}{1-\eta_r} \\ &= (1 - q_r - q_s - w)q_r + \frac{q_r M_r(\lambda_r - \eta_r)}{1-\eta_r}\cdot\end{aligned} \tag{3.10}$$

3.1. Players only care about themselves

The time line in the model is as follows. Firstly, the supplier establishes its wholesale price w. Secondly, the retailer chooses its utility-maximizing ordering quantity q_r. Finally, the supplier determines the initial stock q_s in the direct channel.

Proposition 3.1. *The optimal decisions under the different risk preferences are:*

$$w^* = \frac{(3-c+N_s+2N_r)}{6}, q_r^* = \frac{2(c+N_r-N_s)}{3}, q_s^* = \frac{(3-5c-2N_r+5N_s)}{6},$$

where $N_r = \frac{M_r(\lambda_r-\eta_r)}{1-\eta_r}$ *and* $N_s = \frac{M_s(\lambda_s-\eta_s)}{1-\eta_s}$.

As we can see from Proposition 3.1, if the supplier's unit selling cost is higher than $N_s - N_r$, then the retailer is willing to order products, otherwise, she will quit ordering. Thus, in order to guarantee the model practical meaning, we set $c \geq N_s - N_r$. In the same way, some additional conditions should be satisfied to make our model reasonable, such as $p \geq w \geq c$ and $q_s \geq 0$.

First, from $p \geq w$, and $p^* = 1 - q_r^* - q_s^*$, bring the optimal results in Proposition 3.1 into p^*, Then $p^* = 1 - q_r^* - q_s^* = 1/2 + c/6 - N_r/3 - N_s/6$. Further, from $p \geq w$, we can see that $c \geq 2N_r + N_s$. That is, $c \geq \max(N_s - N_r, 2N_r + N_s)$.

Next, the conditions that $w \geq c$, and $q_s \geq 0$ is considered. From $w \geq c$ and $w^* = (3-c+N_s+2N_r)/6$, there is $c \leq (3+N_s+2N_r)/7$. While from $q_s \geq 0$, there is $c \geq (3-2N_r+5N_s)/5$.

Combining the above two formulas, we can obtain that $c \leq \min((3+N_s+2N_r)/7, (3-2N_r+5N_s)/5)$. Above all, set $C_1 = [\max(N_s - N_r, 2N_r + N_s), \min((3+N_s+2N_r)/7, (3-2N_r+5N_s)/5)]$.

so $c \in C_1$. Too big or too small cost will lead to this supply chain collapse, and c will also affect the players' choices of the partner with risk preference. Therefore, we have the utilities of the supplier and the retailer as follows:

$$\Gamma(\pi_r) = 2(c+N_r-N_s)^2/9$$
$$\Gamma(\pi_s) = (3-2N_r+5N_s-5c)(3+2N_r+N_s-c)/36 + 4(c+N_r-N_s)^2/9.$$

Then the utility of the entire supply chain is $\Gamma(\pi_c) = \Gamma(\pi_s) + \Gamma(\pi_r) = (9 - 18c + 29c^2 + 40cN_r + 20(N_r)^2 - 58cN_s + 18N_s - 40N_rN_s + 29{N_s}^2)/36$.

The proof is in Appendix A. Here, we assume that ξ follows a uniform distribution, that is $\xi \in [-U, U]$, then $g(\xi) = 1/2U, G(\xi) = (\xi+U)/2U$. From the definition $M_r = G^{-1}(\eta_r) - \frac{1}{\eta_r}\int_{-U}^{G^{-1}(\eta_r)} G(\xi)\mathrm{d}\xi$. so $G^{-1}(\eta_r) = 2U\eta_r - U$, and $\frac{1}{\eta_r}\int_{-U}^{G^{-1}(\eta_r)} G(\xi)\mathrm{d}\xi = U\eta_r^2$.

From the above formulas, we can compute $M_r = -U(\eta_r+1)^2 < 0$.

Similarly, $M_s = -U(\eta_s+1)^2 < 0$, then $N_i = U(\eta_i - \lambda_i)$.

Therefore, the players' risk preferences could be characterized as follows:

(a) Risk-neutral if $\lambda_i = \eta_i$, then $N_i = 0$;
(b) Risk-averse if $\lambda_i > \eta_i$, then $N_i < 0$;
(c) Risk-taking if$\lambda_i < \eta_i$, then $N_i > 0$; where $i = r$ or s.

Obviously, $\frac{\partial N_i}{\partial \eta} > 0$, $\frac{\partial N_i}{\partial \lambda} < 0$, so the players tend to be more risk taking as N_i increases, *i.e.*, the players have higher risk tolerance as N_i increases. The optimal decisions and utilities are the functions of the players' risk preferences, and then we can get the following propositions.

Proposition 3.2. *The optimal wholesale price increases as the players become more risk taking. However, the optimal order quantities increase as the player becomes more risk taking and decrease as the opponent player's risk tolerance increases.*

As $\frac{\partial w}{\partial N_r} = 1/3 > 0$, $\frac{\partial w}{\partial N_s} = 1/6 > 0$, it is easy to understand that the retailer will accept a higher wholesale price if her risk tolerance is high, and the supplier will also enhance the wholesale price when he becomes more risk-taking. But, the wholesale price is more sensitive to the retailer's risk preference, which indicates that her risk preference impacts the wholesale price to a larger extent than the supplier's does. As to the order quantities, we have $\frac{\partial q_r}{\partial N_r} = 2/3 > 0$, $\frac{\partial q_s}{\partial N_s} = 5/6 > 0, \frac{\partial q_r}{\partial N_s} = -2/3 < 0$, $\frac{\partial q_s}{\partial N_r} = -1/3 < 0$, obviously, if they become more risk-taking, their optimistic attitudes toward the market leading them to order more, but their opponents' optimistic forecast leading them to order less. Moreover, the risk preferences of the two players has the same but opposite impact on the retailer's order quantity, however, the supplier's order quantity is more influenced by his own risk preference. This may because the supplier can observe the retailer's order decision before he decides his order quantity on direct channel. Another thing we can find is that the order quantities are more sensitive to the players' risk preferences than the wholesale price, which may because the players' expects toward the market impact their order decisions directly, then these impacts conduct to the wholesale price decision.

Proposition 3.3. *For the retailer, no matter what her risk preference is, she always benefits when choosing a risk-averse supplier, while the supplier always benefits when choosing a risk-taking retailer. In addition, the retailer's utility increases as she becomes more risk-taking, while the supplier's utility may increase or decrease as his risk preference changes.*

On the one hand, as $(\partial\Gamma(\pi_r))/(\partial N_s) = -4(c+N_r-N_s)/9 \le 0$ and $(\partial\Gamma(\pi_s))/(\partial N_r) = 2(c+N_r-N_s)/3 \ge 0$, it is interesting to find that the retailer and the supplier have different preferences when choosing a partner to trade. For the retailer, if she trades with a risk-averse supplier, the wholesale price will be lower, the supplier will order less, which leads to the selling price increase or the retailer order more. All these cases are beneficial to the retailer, and no wonder she prefers a risk-averse supplier. However, as to the supplier, if he chooses a risk-taking retailer, the retailer will order more, also she can accept a higher wholesale price, which leads to a much more retail profit. In this case, even if the supplier has to order less or the selling price is lower, this loss can be offset by the increased retail profit.

On the other hand, since $(\partial\Gamma(\pi_s))/(\partial N_s) = (3-7c-4N_r+7N_s)/6$, it is surprising that even though a risk-averse supplier is the retailer's favorite, it doesn't mean it always bring harm to him. Specifically, in set C_1, when $c \le (3-4N_r+7N_s)/7$, the supplier's utility increases as he becomes more risk-taking, on the contrary, it decreases with his risk tolerance increases. Actually, a risk-averse supplier has lower wholesale price, lower online sales order, but more retail orders and higher selling price, which may bring him more money compared to a risk-taking supplier. This implies that the retail profit is still the most important part to the supplier. As to the retailer, we have $(\partial\Gamma(\pi_r))/(\partial N_r) = 4(c+N_r-N_s)/9 \ge 0$, so her utility increases as she becomes more risk-taking.

Proposition 3.4. *For the whole supply chain, when $c \in C_1$ and $c \le (9-20N_r-29N_s)/29$, the combination of a risk-taking retailer and a risk-taking supplier could achieve the most supply chain utility. When $c \in C_1$ and $c \ge (9-20N_r-29N_s)/29$, the combination of a risk-taking retailer and a risk-averse supplier could achieve the most supply chain utility.*

As $(\partial\Gamma(\pi_c))/(\partial N_r) = 10(c+N_r-N_s)/9 \ge 0$, $(\partial\Gamma(\pi_c))/(\partial N_s) = (9-29c-20N_r-29N_s)/18$, we can see from Proposition 3.3, a risk-taking retailer can benefit the supplier without doing any harm to herself, certainly it can benefit the whole supply chain too. A risk-averse supplier also do good to the retailer, however, it may cause loss to him and to the total supply chain.

3.2. Players care about themselves and their opponents

On the other hand, players may show different attitudes towards their opponents' gains. For example, two clothing companies may consider opening new stores in the same area, then the profit will come from the market of potential customers in this area. The objective of each company may differ a lot: One may consider maximizing its own profit while the other one may consider suppressing the opponent's profit or a combination of both. It depends on the developing stage and corporate mind setting of a particular company. A new comer or a conservative company tends to survive by maximizing its own profit, and an aggressive company cares more about the gap between the two investors' profits, while a well-established dominating company may care about minimizing the opponent's profit, and a friendly company incorporated with cooperation awareness may pursue the win-win outcome [33].

Then, similarly to Wang *et al.* [33], when players not only care about their own utilities, but also care about their opponents' utilities, we allow that the objective function of each player to be a linear combination of the utility of both players. That is,

$$\Phi(\pi_i) = \beta_{ii}\Gamma(\pi_i) - \beta_{ij}\Gamma(\pi_j),$$

where $i, j = 1, 2$ and $i \neq j, \beta_{ii} \geq 0, \beta_{ii} > |\beta_{ij}|$. The nonnegativity of β_{ii} indicates that both players value their own profits positively. When $\beta_{ij} = 0$, player i minds only his own utility. When $\beta_{ij} > 0$, player i is concerned about the weighted gap between his and opponent's obtainable utility. When $\beta_{ij} < 0$, player i is interested in the weighted total obtainable utility for both players. In the latter case, we assume that $\beta_{ii} > |\beta_{ij}|$, which indicates that player i minds his utility more than the opponent's.

Then we have

$$\Phi(\pi_r) = \beta_{11}\Gamma(\pi_r) - \beta_{12}\Gamma(\pi_s) \tag{3.11}$$
$$\Phi(\pi_s) = \beta_{22}\Gamma(\pi_s) - \beta_{21}\Gamma(\pi_r). \tag{3.12}$$

To simplify the calculation, specify $\beta_{11} = \beta_{22} = 1$. Then we have the following proposition.

Proposition 3.5. *If the players care not only about their own utilities, but also each other's utility, then the optimal decisions are:*

$$w^* = \frac{1}{6}\left[3\left(1 + N_r + \frac{c + N_r - N_s}{1 + \beta_{12}}\right) - \frac{4(c + N_r - N_s)}{1 + \beta_{21}} + \frac{(c + N_r - N_s)\beta_{12}}{3 + \beta_{12}(1 - 2\beta_{21})}\right],$$
$$q_r^* = \frac{2(c + N_r - N_s)(1 - \beta_{12}\beta_{21})}{(1 + \beta_{21})^2(3 + \beta_{12}(1 - 2\beta_{21}))}, q_s^* = \frac{F_0 + \beta_{12}F_1}{2(1 + \beta_{21})^2(3 + \beta_{12}(1 - 2\beta_{21}))},$$

where $F_0 = 2\beta_{21}(3 - 2c + N_r + 2N_s) + 3\beta_{21}^2(1 - c + N_s) - 5c - 2N_r + 5N_s + 3, F_1 = -\beta_{21}^2(3 - c + 2N_r + N_s) + 2\beta_{21}(c + N_r - N_s) - 2\beta_{21}^3(1 - c + 2N_s) - c + N_s + 1.$

Similarly, according to $p \geq w \geq c$, $q_s \geq 0$ and $q_r \geq 0$, we have $c \in C_2$,

$$C_2 = \left[\max\left(0, N_s - N_r, \frac{\beta_{12}^2F_{10} + \beta_{12}F_9 + F_8}{\beta_{12}^2F_{12} + \beta_{12}F_{11} - 1}\right), \min\left(1, \frac{\beta_{12}^2F_4 + \beta_{12}F_3 + F_2}{\beta_{12}^2F_7 + \beta_{12}F_6 + F_5}, \frac{\beta_{12}F_{14} + F_{13}}{\beta_{12}F_{16} + F_{15}}\right)\right]$$

where $F_2 \sim F_{16}$ and the proof is shown in Appendix B.

As the expression of solutions under this situation is quite complicated, so we conduct some numerical experiments to gain more managerial insights. As $N_i = U(\eta_i - \lambda_i)$, we set $N_i \in [-U, U]$. Set $U = 0.1$ and $c = 0.35$. We are interested in exploring how optimal decisions and players' utilities are impacted by their attitude towards risk and the other ones' utility. Specifically, we compare the following five cases through numerical analysis in the following figures.

Case 0: $\beta_{12} = \beta_{21} = 0$ (green with no grid in the figures), players don't care about each other's utility, *i.e.* both players are selfish.

Case 1: $\beta_{12} = \beta_{21} = 0.1$, players care about the bad side of each other's utility, *i.e.* both players are aggressive.

Case 2: $\beta_{12} = \beta_{21} = -0.1$, players care about the bright side of each other's utility, *i.e.* both players are altruistic.

Case 3: $\beta_{12} = -0.1, \beta_{21} = 0.1$ (purple with grid lines in the figures), the retailer cares about the bright side of the supplier's utility, while the supplier cares about the bad side of the retailer's utility, *i.e.* the retailer is altruistic, while the supplier is aggressive.

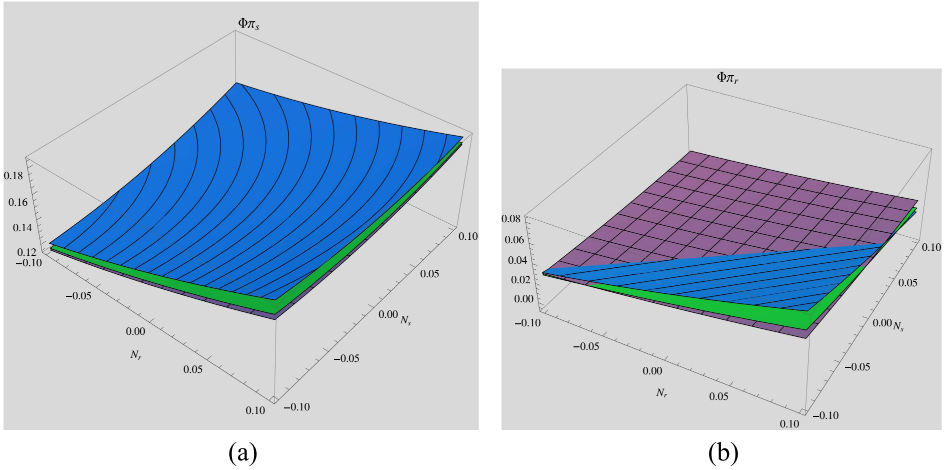


FIGURE 1. The supplier's and the retailer's utilities under uniform perceived quality.

Case 4: $\beta_{12} = 0.1, \beta_{21} = -0.1$ (blue with slashes in the figures), the retailer cares about the bad side of the supplier's utility, while the supplier cares about the bright side of the retailer's utility, *i.e.* the retailer is aggressive, while the supplier is altruistic.

Case 1 and case 2 are not shown in figures, because case 1 always shows the lowest utilities for the players and the whole supply chain, while case 2 shows the highest utilities. It is easy to understand, when the players show aggressive behaviors, it does harm to their earnings, while altruistic behaviors bring benefits to both players and the entire chain. Therefore, we focus on the other three cases in which they cannot always be dominant among cases.

From Figure 1a, we can see that no matter what the supplier's risk preference is, he always trends to trade with a risk-taking retailer. This is because the more optimistic the retailer forecast the market, she will order more, and can accept a higher wholesale price, so the supplier can benefit with a risk-taking retailer. On the other hand, the supplier's utility changes little with his risk preference changes, which indicates that most of his utility comes from the traditional channel and the retailer's risk preference has significant impact on his gains. Comparing different cases, we find that the supplier's utilities under different cases are very close to each other. Relatively speaking, case 4 achieves the most utility, while case 3 achieves the least, which indicates that even though the supplier shows altruistic behavior, it brings him more benefit in return. However, it is surprising that if the retailer shows altruistic behavior, the result is not as good as expected, since the supplier can achieve less utility compared with the case when both players do not care about each other's utility.

As to the retailer (see Fig. 1b), risk-taking attitude is still beneficial for her because she has advantage in selling products. However, the supplier opens up an online channel and competes with her, so she doesn't like him to be more risk-taking, because this means the supplier can seize a larger market share. Besides, different cases have different influences on the retailer's utilities, and it is more complex. Specifically, under most conditions, the retailer can gain more utility if she is altruism, while she gains less under other conditions. In fact, similar to the supplier, the retailer's utility under case 3 is lower than case 0 under some conditions, which means the altruistic behavior is not always beneficial to the players. We also can find that there exists a small region where the retailer's altruistic behavior brings her more benefit than the case when no one cares about each other's utility, and less than the case when the supplier is altruism.

To the whole supply chain, just as discussed above, a risk-taking retailer is preferred by the supplier and also benefits herself. Therefore, the retailer's risk-taking behavior is beneficial to the entire supply chain. However, even though the supplier's risk preference barely has any impact on his utility, his risk-taking behavior will

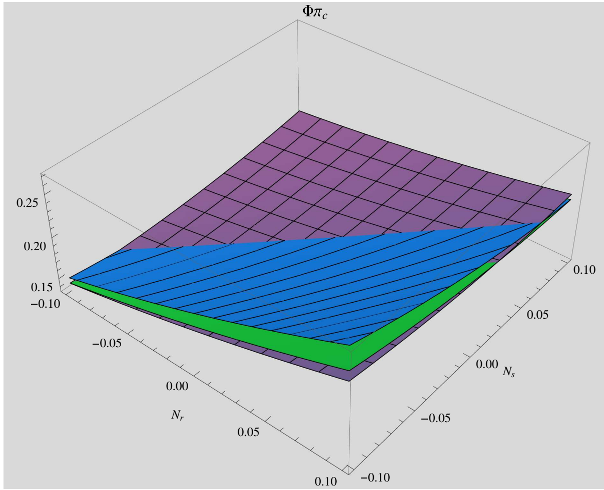


FIGURE 2. The whole supply chain utility under uniform perceived quality.

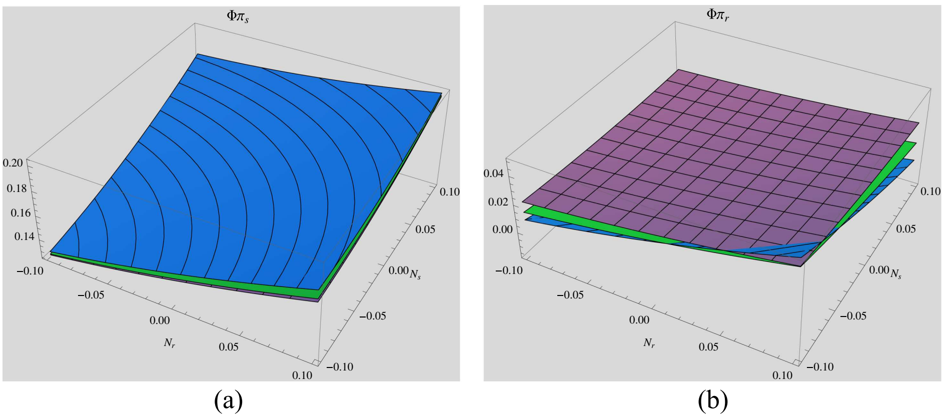


FIGURE 3. The supplier's and the retailer's utilities under uniform perceived quality.

reduce the retailer's utility considerably. In order to achieve the optimal supply chain utility, a combination of a risk-taking retailer and a risk-averse supplier would be the best choice. Among different cases, it is interesting to find that there is a half probability that supplier altruism or retailer altruism can achieve the most total utility or the worst utility. This is not a good signal because altruistic behavior is not always benefit the whole supply chain. In fact, in most conditions, when the supplier's risk tolerance is lower than the retailer's, the supplier altruism is beneficial to the supply chain, and *vice versa*.

Through the numerical experiments, we find that the supplier's online operational cost has significant impact on the players' choices of risk combination and utilities under different cases. To be specific, we assume that the supplier has a smaller cost, *i.e.* $c = 0.25$, in which case the retailer's advantage in selling product is weakened.

From Figure 3a, we can see that if the supplier's cost reduces, it doesn't change his preference for the retailer, but will impact his utility under different risk tolerances. Actually, when the supplier's selling disadvantage is alleviated, being optimistic (risk-taking) is beneficial to him. However, the selling cost does not change the supplier's relative utility position under different cases. But, we can find a bigger region where the supplier's utilities under three cases are overlapped.

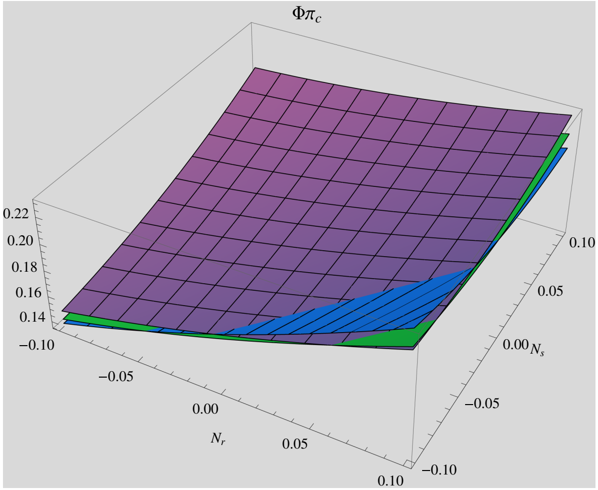


FIGURE 4. The whole supply chain utility under uniform perceived quality.

For the retailer, when her selling advantage is weakened, it doesn't change her risk preference towards the supplier and her own risk tolerance. But her utility under this situation is lower than Figure 1b. Another interesting finding is that to a large extent the retailer's altruistic behavior is always benefit to her, while the supplier's altruistic behavior is not preferred by the retailer except the situation when the supplier is extremely risk averse and the retailer is extremely risk-taking. It is hard to understand that the retailer's utility is much smaller than the supplier's. Why does her altruistic behavior bring her more benefit, while supplier altruism does notThis is because even though the retailer has to accept a higher wholesale price and make less orders, she earns less money than that in other cases; however, as she is altruism, her utility has much to do with the supplier's utility, which is much more than hers, so the increase of the supplier's utility improves her utility indirectly.

As to the whole supply chain, it shows different shapes compared to those in Figure 2. Similarly, a risk-taking retailer is still beneficial to the whole supply chain. However, when the supplier's selling cost is sufficiently low, the players' altruistic behaviors have impact on optimal risk combinations. When the supplier is altruism, a combination of a risk-taking retailer and a risk averse supplier can achieve the most total utility; when the retailer shows altruistic behavior, a combination of a risk-taking retailer and a risk-taking supplier is most beneficial to the whole supply chain. Comparing different cases, it is surprising to find that retailer altruism is more beneficial to the whole supply chain in most region except when the retailer is extremely risk-taking and the supplier is extremely risk-averse. This is because when the supplier is extremely risk-averse, his utility drops very quickly and the retailer's altruistic behavior cannot compensate his loss in this case. But if the supplier shows altruistic behavior, the retailer can achieve her highest utility in this region, and then the supplier's expected utility is higher. Further, in this small region, we find a good signal that no matter retailer altruism or supplier altruism are beneficial to the entire supply chain, and can achieve higher utility than that when both of them are selfish. Another interesting finding is that when the supplier is altruism, supplier being conservative is better than being risk-taking. However, when neither of the retailer nor the supplier shows altruistic behavior, it is no big difference when the supplier's risk tolerance changes. But if both of them are risk-averse, then the utility of the total supply chain is severely damaged (Fig. 4).

4. ENCROACHMENT WITH DIFFERENTIATED PERCEIVED QUALITY

In the above section, we have explored the optimal decisions when consumers perceive no quality difference between retail channel and online channel, however, in practice, consumers typically perceive lower product quality when they shopping online.

In this case, we suppose the consumer's valuation through the retailer channel is δ and a valuation of $\theta\delta$ through the direct channel [8,9,15], where $\theta \in (0,1]$, representing the consumers' acceptance of network, θ also can be interpreted as the intensity of competition between the two channels, and the bigger θ means the two channels are highly replaceable. When the price for the online channel is low enough relative to that for the retail channel, that is, $\theta p_r \geq p_s$, both channels have positive demand. Consumers with $\delta \in [\frac{p_r-p_s}{1-\theta}, 1]$ buy product through the retail channel, and consumers with $\delta \in [\frac{p_s}{\theta}, \frac{p_r-p_s}{1-\theta}]$ buy product through online channel, while consumers with $\delta \in [0, \frac{p_s}{\theta}]$ buy nothing. Then the market is thus segmented, we can obtain $q_r = 1 - \frac{p_r-p_s}{1-\theta}$, $q_s = \frac{p_r-p_s}{1-\theta} - \frac{p_s}{\theta}$, hence $q = q_r + q_s = 1 - \frac{p_s}{\theta}$. Similarly, in order to characterize market uncertainty, we assume $q = 1+\xi-\frac{p_s}{\theta}$, then the respective inverse demand functions are $p_r = 1+\theta\xi-q_r-\theta q_s$, and $p_s = \theta(1+\xi-q_r-q_s)$, where p_r and p_s correspond to the market-clearing prices of the direct channel and the retail channel products respectively.

Then we have

$$E(\pi_s) = E[(p_s - c)q_s + wq_r] = (\theta(1 - q_r - q_s) - c)q_s + wq_r. \tag{4.1}$$

$$E(\pi_r) = E[(p_r - w)q_r] = (1 - q_r - \theta q_s - w)q_r. \tag{4.2}$$

$$\begin{aligned}\mathrm{CVaR}^{\eta}(\pi_s) &= \max_{v\in R}\left\{v + \frac{1}{\eta_s}E\left[\min(\pi_s - v, 0)\right]\right\}\\ &= \max_{v\in R}\left\{v + \frac{1}{\eta_s}E[\min((\theta(1+\xi-q_r-q_s)-c)q_s + wq_r - v, 0)]\right\}\\ &= \max_{v\in R}\left\{v + \frac{1}{\eta_s}\int_{-U}^{\frac{1}{\theta}(\frac{v-wq_r}{q_s}+c)+q_r+q_s-1}((\theta(1+\xi-q_r-q_s)-c)q_s + wq_r - v)\,\mathrm{d}G(\xi)\right\}.\end{aligned}$$

Let $H(v) = v + \frac{1}{\eta_s}\int_{-U}^{\frac{1}{\theta}(\frac{v-wq_r}{q_s}+c)+q_r+q_s-1}((\theta(1+\xi-q_r-q_s)-c)q_s + wq_r - v)\mathrm{d}G(\xi)$, then

$$\begin{aligned}\frac{\mathrm{d}H(v)}{\mathrm{d}v} &= 1 + \frac{1}{\eta_s}\int_{-U}^{\frac{1}{\theta}(\frac{v-wq_r}{q_s}+c)+q_r+q_s-1}(-1)\mathrm{d}G(\xi) + 0 - 0\\ &= 1 - \frac{1}{\eta_s}G\left(\frac{1}{\theta}\left(\frac{v-wq_r}{q_s}+c\right)+q_r+q_s-1\right).\end{aligned}$$

$\frac{\mathrm{d}H^2(v)}{\mathrm{d}v^2} = -\frac{1}{\eta_s}\frac{1}{\theta q_s}g(\frac{1}{\theta}(\frac{v-wq_r}{q_s}+c)+q_r+q_s-1) < 0$, so $H(v)$ is a concave function with v. Let $\frac{\mathrm{d}H(v)}{\mathrm{d}v} = 0$, thus $v^* = (\theta(G^{-1}(\eta_s)+1-q_r-q_s)-c)q_s + wq_r$.

Therefore,

$$\begin{aligned}\mathrm{CVaR}^{\eta}(\pi_s) &= (\theta(G^{-1}(\eta_s)+1-q_r-q_s)-c)q_s + wq_r - \frac{\theta q_s}{\eta_s}\int_{-U}^{G^{-1}(\eta_s)}G(\xi)\mathrm{d}\xi\\ &= (\theta(1-q_r-q_s)-c)q_s + wq_r + \theta q_s M_s.\end{aligned}$$

Then

$$\begin{aligned}\Gamma(\pi_s) &= \frac{1-\lambda_s}{1-\eta_s}E(\pi_s) + \frac{\lambda_s-\eta_s}{1-\eta_s}\mathrm{CVaR}^{\eta}(\pi_s)\\ &= \frac{1-\lambda_s}{1-\eta_s}[(\theta(1-q_r-q_s)-c)q_s + wq_r]\\ &\quad + \frac{\lambda_s-\eta_s}{1-\eta_s}[(\theta(1-q_r-q_s)-c)q_s + wq_r + \theta q_s M_s]\\ &= (\theta(1-q_r-q_s)-c)q_s + wq_r + \theta q_s N_s.\end{aligned}$$

Similarly, we can obtain the retailer's utility

$$\begin{aligned}\Gamma(\pi_r) &= \frac{1-\lambda_r}{1-\eta_r}E(\pi_r) + \frac{\lambda_r-\eta_r}{1-\eta_r}\mathrm{CVaR}^{\eta}(\pi_r)\\ &= \frac{1-\lambda_r}{1-\eta_r}[(1-q_r-\theta q_s-w)q_r] + \frac{\lambda_r-\eta_r}{1-\eta_r}[(1-q_r-\theta q_s-w)q_r+\theta q_r M_r]\\ &= (1-q_r-\theta q_s-w)q_r+\theta q_r N_r,\end{aligned}$$

where N_r and N_s are defined as before.

4.1. Players only care about themselves

The time line has been descriped above, so we can gain the following proposition.

Proposition 4.1. *When supplier encroachment with differentiated perceived quality, the optimal decisions with different risk preferences players are:*

$$\begin{aligned}w^* &= \frac{8-\theta(6+c-8N_r)+\theta^2(1-6N_r+N_s)}{2(8-5\theta)},\\ q_r^* &= \frac{2(1+c-\theta(1-N_r+N_s))}{8-5\theta},\\ q_s^* &= \frac{-8c+\theta(6+3c+8N_s)-\theta^2(3+2N_r+3N_s)}{2\theta(8-5\theta)}.\end{aligned}$$

In addition, we explore the effects of players' risk preferences on their utilities and the whole supply chain utility. Therefore, we have the following proposition.

Proposition 4.2. *When players only care about their own utilities, supplier encroachment with differentiated perceived quality does not change the players' risk preferences towards their partners.*

The proof of Propositions 4.1 and 4.2 is in Appendix C.

4.2. Players care about themselves and their opponents

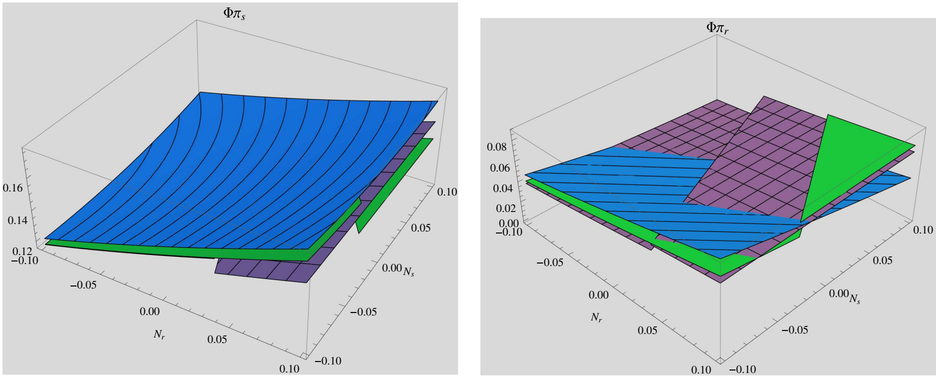
According to Section 3, we have

$$\Phi(\pi_r) = \Gamma(\pi_r) - \beta_{12}\Gamma(\pi_s) \tag{4.3}$$

$$\Phi(\pi_s) = \Gamma(\pi_s) - \beta_{21}\Gamma(\pi_r) \tag{4.4}$$

where β_{12} and β_{21} are defined as before. The expression of solutions under this situation is quite complex, so we carry out numerical experiments to gain managerial insights. Similarly, set $c = 0.35, U = 0.1, \theta = 0.85$, We also focus on Case 0, Case 3 and Case 4 for the same reason as in Section 3.

Comparing Figure 5a with Figure 1a, we can see that there are some differences between them. When consumers perceive lower quality of the product on the direct channel, which is common in reality, the direct price is consequently lower than the retail price. When the retailer or both of them are over-optimistic about the market, they will order too much, which results in the direct price falling to the wholesale price. However, the direct price cannot be lower than the wholesale price, otherwise the retailer should order the product directly through online channel. In this situation, the direct price is equal to the wholesale price, but the supplier should not prepare any product online, because he is better off when he sales product through the retailer. Figure 5a also shows that the above situation would not appear when supplier shows altruistic behavior, this may be because the supplier would not occupy too much market share when he is altruism. But we can see that the generous behavior of supplier also bring himself the most utility. Similar to Figure 1a, the supplier also prefers a risk-taking retailer, but his utility is not so sensitive to his own risk attitude.



(a) (b)

FIGURE 5. The supplier's and the retailer's utilities under differentiated perceived quality.

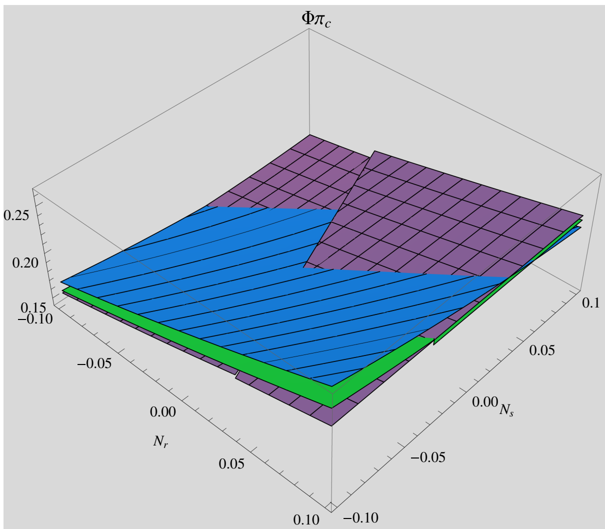


FIGURE 6. The whole supply chain utility under differentiated perceived quality.

As to the retailer (see Fig. 5b), when supplier shows altruistic behavior, it is more beneficial to trade with a risk averse supplier, which is similar to Figure 1b. Surprisingly, when retailer shows altruistic behavior or the players are indifferent towards each other's utility, and then the retailer is beneficial to trade with a risk-taking supplier. This is because in this situation, the online sales are zero, which is the most favored by the retailer. The supplier is more risk taking, the wholesale price is lower, and consequently the retailer is happy to see it. But there exists a region when both the supplier and the retailer are risk-taking that neither supplier altruism nor retailer altruism brings more benefit to the retailer than nobody cares about each others utility.

Comparing those in Figures 1 and 5, we can also find out that the supplier's utility is slightly decreasing while the retailer's utility is slightly increasing. This indicates that when consumers perceive lower quality through online shopping, even though the direct price is consequently reduced, it is still harm to the supplier. When the situation becomes serious, the supplier cannot achieve any needs on the direct channel.

As to the whole supply chain, a risk-taking retailer is always beneficial to the whole supply chain, because the retail channel is still an important sales channel, and her optimistic attitude toward the market is quite important. However, when supplier shows altruistic behavior, a risk averse supplier is more beneficial to the whole system, this may be because the retailer can play all the power to sell products at this time, which benefits the supplier's traditional channel in turn. But, when retailer shows altruistic behavior or the players are indifferent towards each other's utility, the supplier's risk attitude is not quite sensitive to the whole supply chain's utility. This may be because the supplier put zero stock online, which hurts the supplier's utility but brings benefit to the retailer, so in this case the whole supply chain's utility is not commonly changed (Fig. 6).

5. Conclusions

In this paper, a dual-channel supply chain consisting of a supplier and a retailer who show different risk preferences are considered. The supplier is leader and sells products through both retail channel and online channel. We adopt Mean-CVaR criterion to measure players' risk attitude. Using Stackelberg game model, we explore two scenarios based on the consumers' perceived quality through this two channels: uniform perceived quality or differentiated perceived quality. We find out that the retailer always prefers a risk-averse supplier, while the supplier always prefers a risk-taking retailer. However, a risk-averse supplier and a risk-taking retailer is not always the best combination for the whole supply chain. Then, we extend our model to capture that players show different attitudes towards their opponents' gains. We find that players' choices of choosing a partner is impacted by their selfish, aggressive and altruistic behaviors. Furthermore, we perform experiments to explore the impact of supplier's selling cost and the players' selfish, aggressive and altruistic behaviors on optimal utilities and risk combinations.

However, this paper also shows some limitations. For example, we assume that the price is a clearing price. In practice, the prices on retail channel and online channel can be determined and are dynamic with time. Moreover, we show that the players' risk preferences, their selfish, aggressive and altruistic behaviors and the supplier's selling cost all influence players' choices. In fact, many other factors also influence their choices of choosing a partner to trade with, such as power, loss-averse, forward looking or myopic. It would be interesting to cover these factors in further research.

Compliance with ethical standards

No conflict of interest exits in the submission of this manuscript, and the manuscript is approved by all authors for publication.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

Appendix A

$$\frac{\partial\Gamma(\pi_s)}{\partial q_s} = \frac{\lambda_s - \eta_s}{1-\eta_s} M_s + 1 - q_r - 2q_s - c = 0,$$

then

$$q_s = \frac{1-q_r-c}{2} + \frac{1}{2}\frac{\lambda_s - \eta_s}{1-\eta_s} M_s.$$

As to the retailer,

$$\frac{\partial\Gamma(\pi_r)}{\partial q_r} = \frac{\lambda_r - \eta_r}{1-\eta_r} M_r + 1 - 2q_r - q_s - w + \frac{q_r}{2} = 0,$$

thus

$$q_r = \frac{1+c-2w}{2} + \frac{\lambda_r-\eta_r}{1-\eta_r}M_r - \frac{1}{2}\frac{\lambda_s-\eta_s}{1-\eta_s}M_s.$$

Finally,

$$\frac{\partial\Gamma(\pi_s)}{\partial w} = \frac{1-q_r-2q_s-c}{2} + \frac{1}{2}\frac{\lambda_s-\eta_s}{1-\eta_s}M_s + q_s - w + q_r = 0,$$

so

$$\begin{aligned}
w^* &= \frac{3-c}{6} + \frac{1}{6}\left(\frac{\lambda_s-\eta_s}{1-\eta_s}M_s + 2\frac{\lambda_r-\eta_r}{1-\eta_r}M_r\right),\\
q_r^* &= \frac{2c}{3} + \frac{2}{3}\left(\frac{\lambda_r-\eta_r}{1-\eta_r}M_r - \frac{\lambda_s-\eta_s}{1-\eta_s}M_s\right),\\
q_s^* &= \frac{3-4c}{6} - \frac{1}{3}\frac{\lambda_r-\eta_r}{1-\eta_r}M_r + \frac{5}{6}\frac{\lambda_s-\eta_s}{1-\eta_s}M_s.\\
\Gamma(\pi_r) &= \frac{2}{9}\left(c + \frac{\lambda_r-\eta_r}{1-\eta_r}M_r - \frac{\lambda_s-\eta_s}{1-\eta_s}M_s\right)^2.
\end{aligned}$$

$$\begin{aligned}
\Gamma(\pi_s) &= \frac{1}{36}\left(3 - 2\frac{\lambda_r-\eta_r}{1-\eta_r}M_r + 5\frac{\lambda_s-\eta_s}{1-\eta_s}M_s - 5c\right)\left(3 + 2\frac{\lambda_r-\eta_r}{1-\eta_r}M_r + \frac{\lambda_s-\eta_s}{1-\eta_s}M_s - c\right)\\
&\quad + \frac{4}{9}\left(c + \frac{\lambda_r-\eta_r}{1-\eta_r}M_r - \frac{\lambda_s-\eta_s}{1-\eta_s}M_s\right)^2\\
&= \frac{3-6c+7c^2}{12} + \frac{1}{2} - \frac{7c}{6}\frac{\lambda_s-\eta_s}{1-\eta_s}M_s + \frac{2c}{3}\frac{\lambda_r-\eta_r}{1-\eta_r}M_r + \frac{1}{3}\left(\frac{\lambda_r-\eta_r}{1-\eta_r}M_r\right)^2\\
&\quad - \frac{2}{3}\frac{\lambda_r-\eta_r}{1-\eta_r}M_r\frac{\lambda_s-\eta_s}{1-\eta_s}M_s + \frac{7}{12}\left(\frac{\lambda_s-\eta_s}{1-\eta_s}M_s\right)^2.
\end{aligned}$$

Let $N_r = \frac{\lambda_r-\eta_r}{1-\eta_r}M_r$, and $N_s = \frac{\lambda_s-\eta_s}{1-\eta_s}M_s$, then

$$\begin{aligned}
\Gamma(\pi_r) &= \frac{2}{9}(c+N_r-N_s)^2,\\
\Gamma(\pi_s) &= \frac{1}{36}(3-2N_r+5N_s-5c)(3+2N_r+N_s-c) + \frac{4}{9}(c+N_r-N_s)^2\\
&= \frac{3-6c+7c^2}{12} + \frac{1}{2}N_s - \frac{7c}{6}N_s + \frac{2c}{3}N_r + \frac{1}{3}N_r^2 - \frac{2}{3}N_rN_s + \frac{7}{12}N_s^2.
\end{aligned}$$

Appendix B

$\Phi(\pi_r) = \Gamma(\pi_r) - \beta_{12}\Gamma(\pi_s)$, $\Phi(\pi_s) = \Gamma(\pi_s) - \beta_{21}\Gamma(\pi_r)$, then $\frac{\partial\Phi(\pi_s)}{\partial q_s} = 1 - c + N_s - q_r - 2q_s + q_r\beta_{21}$, then $q_s = \frac{1}{2}(1-c+N_s-q_r+q_r\beta_{21})$. As to the retailer, $\frac{\partial\Phi(\pi_r)}{\partial q_r} = \frac{1}{2}(1+c+2N_r-N_s-2q_r-2w-2q_r\beta_{21}+\beta_{12}(1-c+N_s-q_r-2w+q_r\beta_{21}^2)) = 0$, thus $q_r = \frac{-1-c-2N_r+N_s+2w-\beta_{12}+c\beta_{12}-N_s\beta_{12}+2w\beta_{12}}{(1-\beta_{21})(-2-\beta_{12}+\beta_{12}\beta_{21})}$. Finally, substituting q_r and

q_s to $\Phi(\pi_s)$, let $\frac{\partial \Phi(\pi_s)}{\partial w}=0$, we can get the optimal decisions:

$$\begin{aligned}
w^* &= \frac{1}{6}\left[3(1+N_r+\frac{c+N_r-N_s}{1+\beta_{12}})-\frac{4(c+N_r-N_s)}{1+\beta_{12}}+\frac{(c+N_r-N_s)\beta_{12}}{3+\beta_{12}(1-2\beta_{21})}\right],\\
q_r^* &= \frac{2(c+N_r-N_s)(1-\beta_{12}\beta_{21})}{(1+\beta_{12})^2(3+\beta_{12}(1-2\beta_{21}))},\\
q_s^* &= \frac{F_0+\beta_{12}F_1}{2(1+\beta_{21})^2(3+\beta_{12}(1-2\beta_{21}))}.
\end{aligned}$$

According to $p \geq w \geq c$, $q_s \geq 0$ and $q_r \geq 0$, we have

$$c \in \left[\max\left(0, N_s-N_r, \frac{F_8+\beta_{12}F_9+\beta_{12}^2F_{10}}{-1+\beta_{12}F_{11}+\beta_{12}^2F_{12}}\right), \min\left(1, \frac{F_2+\beta_{12}F_3+\beta_{12}^2F_4}{F_5+\beta_{12}F_6+\beta_{12}^2F_7}, \frac{F_{13}+\beta_{12}F_{14}}{F_{15}+\beta_{12}F_{16}}\right)\right].$$

where

$$\begin{aligned}
F_2 &= -3-2N_r-N_s-3(1+2N_r-N_s)\beta_{21},\\
F_3 &= -4(1+N_s)-2(1+2N_r-N_s)\beta_{21}+2(1+2N_r-N_s)\beta_{21}^2,\\
F_4 &= -1-N_s+(1-2N_r+3N_s)\beta_{21}+2(1+N_r)\beta_{21}^2,\\
F_5 &= -7-3\beta_{21},\\
F_6 &= 2(-6-\beta_{21}+\beta_{21}^2),\\
F_7 &= -3+5\beta_{21}+4\beta_{21}^2,\\
F_8 &= -2N_r-N_s-3N_r\beta_{21},\\
F_9 &= -N_r-3N_s-(N_r+N_s)\beta_{21}+2N_r\beta_{21}^2,\\
F_{10} &= -N_s-N_s\beta_{21}+(N_r+N_s)\beta_{21}^2,\\
F_{11} &= -(3+\beta_{21}),\\
F_{12} &= -1+\beta_{21}+\beta_{21}^2,\\
F_{13} &= -3+2N_r-5N_s-2(3+N_r+2N_s)\beta_{21}-3(1+N_s)\beta_{21}^2,\\
F_{14} &= -1-N_s-2(N_r-N_s)\beta_{21}+(3+2N_r+N_s)\beta_{21}^2+2(1+N_s)\beta_{21}^3,\\
F_{15} &= -5-4\beta_{21}-3\beta_{21}^2,\\
F_{16} &= -1+2\beta_{21}+\beta_{21}^2+2\beta_{21}^3.
\end{aligned}$$

Appendix C

$\frac{\partial \Gamma(\pi_s)}{\partial q_s}=\theta N_s+\theta(1-q_r-q_s)-\theta q_s-c=0$, then $q_s=\frac{\theta-\theta q_r+\theta N_s-c}{2\theta}$. As to the retailer, $\frac{\partial \Gamma(\pi_r)}{\partial q_r}=1-q_r-w+q_r(\frac{\theta}{2}-1)+\theta N_r+\frac{1}{2}(c-\theta-\theta N_s+\theta q_r)=0$, thus $q_r=\frac{2+c-2w-\theta+2\theta N_r-\theta N_s}{2(2-\theta)}$. Finally, let $\frac{\partial \Gamma(\pi_s)}{\partial w}=\frac{(8-\theta(6+c-8N_r)+\theta^2(1-6N_r+N_s)-2w(8-5\theta)}{4(2-\theta)^2}=0$, so

$$\begin{aligned}
w^* &= \frac{8-\theta(6+c-8N_r)+\theta^2(1-6N_r+N_s)}{2(8-5\theta)},\\
q_r^* &= \frac{2(1+c-\theta(1-N_r+N_s))}{8-5\theta},\\
q_r^* &= \frac{-8c+\theta(6+3c+8N_s)-\theta^2(3+2N_r+3N_s)}{2\theta(8-5\theta)}.
\end{aligned}$$

Thus,

$$\Gamma(\pi_r) = \frac{2(2-\theta)(1+c-\theta(1-N_r+N_s))^2}{(8-5\theta)^2},$$
$$\Gamma(\pi_r) = \frac{c^2(8-\theta) - 2\theta c(4+N_s(8-\theta)-\theta-4\theta N_r)}{4\theta(8-5\theta)} + \frac{\theta(4+\theta N_s^2(8-\theta)+2\theta N_s(4-\theta)-\theta^2+4\theta^2 N_r^2+8\theta N_r(1-\theta-\theta N_s))}{4\theta(8-5\theta)}.$$

So we have

$$\frac{\partial\Gamma(\pi_r)}{\partial N_s} = -\frac{4\theta(2-\theta)(1+c-\theta(1-N_r+N_s))}{(8-5\theta)^2} \leq 0,$$
$$\frac{\partial\Gamma(\pi_s)}{\partial N_r} = \frac{2\theta(1+c-\theta(1-N_r+N_s))}{8-5\theta} \geq 0,$$
$$\frac{\partial\Gamma(\pi_r)}{\partial N_r} = \frac{4\theta(2-\theta)(1+c-\theta(1-N_r+N_s))}{(8-5\theta)^2} \geq 0,$$
$$\frac{\partial\Gamma(\pi_s)}{\partial N_s} = \frac{-c(8-\theta)+\theta(4-\theta-4\theta N_r+N_s(8-\theta))}{2(8-5\theta)}.$$

Therefore, when c is in the feasible region, the results of players choosing partners and risk sensitivity analysis are similar to Proposition 3.3.

For the whole supply chain, as

$$\frac{\partial\Gamma(\pi_c)}{\partial N_r} = \frac{2\theta(12-7\theta)(1+c-\theta(1-N_r+N_s))}{(8-5\theta)^2} \geq 0,$$
$$\frac{\partial\Gamma(\pi_c)}{\partial N_s} = \frac{cL_1 - \theta(16-\theta(4+48N_r)-(3-28N_r)\theta^2+N_s L_1)}{2(8-5\theta)^2},$$

where $L_1 = 64 - 32\theta - 3\theta^2$. So when c is in the feasible region, the results of optimal risk combinations are similar to Proposition 3.4.

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