Received 8 July 2023, accepted 28 August 2023, date of publication 5 September 2023, date of current version 11 September 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3312133

RESEARCH ARTICLE

Channel Contract Coordination for Supply Chain With Behavior Preferences Under Uncertainties

BAO-LIN ZHU, JIA-YUE ZHANG, SHOU-FENG JI, AND RUO-ZHEN QIU

School of Business Administration, Northeastern University, Shenyang 110189, China

Corresponding author: Bao-Lin Zhu (blzhu@mail.neu.edu.cn)

This work was supported in part by the National Natural Science Foundation of China under Grant 71971049 and Grant 72272030, and in part by the Ministry of Education in China (MOE) Project of Humanities and Social Sciences under Grant 22YJA630064.

ABSTRACT This paper studies the coordination of a dual-channel supply chain with behavior preferences under uncertainties of yield and demand. According to an improved FS model and mean-CVaR (Conditional Value-at-Risk) criterion, we construct optimal decision models in the centralized and decentralized situations, and propose the joint contract of revenue-sharing and risk-sharing to coordinate the dual-channel supply chain. Furthermore, this paper investigates the effects of fairness concerns and risk-averse preferences on supply chain members' profits and decisions, and studies the feasible region for joint contracts to achieve Pareto improvement. This paper finds that: 1 fairness concerns and risk aversion preferences exacerbate the double marginalization effect, 2 fairness concerns and risk aversion have a negative impact on manufacturer's decision in a manufacturer-led dual-channel supply chain, 3 the possibility of joint contract to achieve coordination increases with the increases of degree of fairness concerns and risk aversion.

INDEX TERMS Supply chain, channel coordination, behaviors, uncertainties.

I. INTRODUCTION

Driven by the Internet and information technology, commercial trade activities gradually tend to be electronic, digital and networked, and online marketing model is developing rapidly. According to the National Bureau of Statistics, the market scale of Chinese online retail reached 13.09 trillion Chinese Yuan in 2021 with a year-on-year increase of 14.1%. More and more companies adopt online direct sales as a new marketing channel for products. While the dual-channel model helps companies reduce costs and expand their market share, it also poses an increasing threat to offline retailers, leading traditional retailers to take a resistant attitude toward online direct sales. Ultimately, channel conflict and double marginalization of the supply chain occur. In the face of multi-channel competition of supply chain, supply chain members pay more attention to behavioral factors including risk preference and fairness concerns, which further intensify channel competition in the supply chain. How to identify and coordinate multi-channel supply chains with behavioral considerations has become one of the main issues of current supply chain management.

In contrast to the rational behavior of decision makers in traditional studies, real-life decisions are often influenced by irrational behavioral factors. Relevant scholars have introduced behavioral factors as parameters in the study of supply chain-related decision models and have applied them in economic, financial, market, and organizational behavior, such as Bendoly et al. [1] who introduced behavioral research theories in operational management research, including overconfidence, loss aversion, and fairness concerns. Behavioral science research shows that supply chain system is influenced by human behavior and psychological awareness, which can lead to deviations between experience observations and theoretical predictions, and the introduction of behavioral factors can make more accurate predictions of supply chain behavior. The research on the behavioral factors of supply chain members mainly includes risk aversion, fairness concerns, overconfidence, reference effect, loss aversion, reciprocal preference, etc. Among them, the fairness and risk preferences of decision makers are of major interests due to competition and market demand fluctuations within the

The associate editor coordinating the review of this manuscript and approving it for publication was Nikhil Padhi.

dual-channel supply chain. Fairness concern is an important concept in social psychology. Social psychologists argue that humans focus on their own gains in economic activities, and at the same time, compare them with the gains of others to judge whether the distribution of gains is fair. Cui et al. [2] firstly introduced fairness concerns to two-echelon supply chains and demonstrated that supply chain coordination can be achieved through wholesale price contracts. Risk preferences belong to the scope of cognitive psychology, such as risk aversion and other behaviors. In the field of supply chain operations and management, measurable uncertainty is generally defined as risk. Effective management of uncertainty and risky behavior helps to improve the operational efficiency of supply chains. Generally, most of the studies on multi-channel supply chain coordination considering behavioral factors assume that some supply chain members have irrational behavior characteristics, but rarely consider the joint effect of two irrational behavior characteristics at the same time, or only study the impact of fairness concerns or risk aversion behavior on supply chain related decisions individually.

In actual production activities, market demand is becoming increasingly diversified, and there may be situations where demand and production cannot be accurately predicted due to technological changes, weather, natural disasters or policy restrictions, exacerbating the double marginalization effect and thus affecting the sustainable and stable development of the supply chain system. Supply chain contract is a form of contractual cooperation to align individual motives with system goals, and eventually achieve the purpose of supply chain coordination and avoid the problem of double marginalization. Pasternack [3] firstly proposed the concept of supply chain contract in 1985. Supply chain contracts generally include revenue-sharing contracts, repurchase contracts, risk sharing contracts, etc. In practice, market uncertainty and channel conflicts often make supply chain participants' revenue risky, and contractual mechanisms that ignore behavioral factors such as risk and fairness preferences are difficult to implement effectively in supply chain practice. Generally speaking, the traditional single contract model cannot achieve dual-channel supply chain coordination with risk-averse. The adoption of improved or joint contracts is the main way of dual-channel supply chain coordination at present.

In summary, we study the dual-channel supply chain coordination of retailers with fairness concerns and risk-averse behaviors under manufacturer yield and market demand uncertainty. Based on the above analysis, we raise the following questions: What is the optimal decision in the decentralized and centralized models? What effects do fairness concerns and risk aversion have on the optimal decision in dual-channel supply chain? How to realize Pareto improvement of dual-channel supply chain through the joint contract? What are the effects of fairness concerns and risk aversion on Pareto improvement region under joint contract? In order to address the above problems, this paper constructs optimal decision models for the centralized and decentralized retailer with dual behavioral preferences, and designs a joint contract of revenue-sharing and risk-sharing, which realizes dual-channel Pareto improvement. In numerical examples, we prove the effectiveness of joint contract coordination, and thoroughly analyze effects of fairness concern coefficient, risk-averse coefficient and the joint contract parameters on the optimal decision, the profit and Pareto improvement region of the dual-channel supply chain.

The rest of this paper is organized as follows. In Section II, we elaborate a literature review in three aspects. In Section III, we introduce the description of the problem. In Section IV and Section V, we explore centralized and decentralized optimal decision models respectively. In Section VI, we develop a new joint contract that combines revenue-sharing and cost-sharing contracts to coordinate the dual-channel supply chain. In Section VII, we analyze some numerical results by validating the model and discuss some managerial implications. Finally, in Section VIII, we summarize our research and provide ideas for future research. All proofs of the propositions presented in this paper are provided in Appendix.

II. LITERATURE REVIEW

Relevant to our study of the multi-channel supply chain coordination considering fairness concerns and risk-averse behavior and their impacts on decision makings and performance, there are three streams of literature most closely related to our work, fairness concerns, risk-averse supply chain, and dual-channel supply chain contract coordination.

At present, the research of fairness concerns mainly focuses on supply chain coordination and operation strategy. Some scholars have shown great interest in the research on supply chain coordination with fairness concerns. Cui et al. [2] introduced fairness into simple two-echelon supply chain coordination, and analyzed the impact of fairness concerns of supply chain members on channel coordination in term of wholesale price contracts. Yoshihara and Matsubayashi [4] studied the coordination of a supply chain composed of a manufacturer and two fairness concerns retailers, and examined the impact of retailer's horizontal differences and fairness concerns on the channel coordination. The results showed that only differentiated retailers can realize channel coordination under fairness concerns. In the dual-channel supply chain environment, Li et al. [5] compared the impact of fairness concerns, bargaining power of manufacturers and retailers, and benefit under three contract forms: wholesale price contract, buyback contract and revenue-sharing contract. Wang et al. [6] constructed a Stackelberg game for the supply chain system composed of e-commerce platform and fairness-concerned manufacturers, and used cost-sharing joint commission contract to coordinate the supply chain system. They discussed the impact of fairness concerns on the green level and e-commerce platform service level. Zhao et al. [7] constructed an experimental study of retailer's fairness concerns, and compared the supply chain inventory management mechanisms under the two contract models of revenue-sharing contract and retailer's voluntary compensation mode. The results revealed that the voluntary compensation model is more conducive to suppliers paying attention to retailer's fairness preferences. In the green clothing supply chain, Adhikari and Bisi [8] explored the impact of fairness concerns on greening quality and profitability of the supply chain under the green cost sharing and revenue-sharing contract, and showed that fairness concerns would reduce the green level. Yu et al. [9] investigated ordering strategies in a dual-channel supply chain context with three scenarios: manufacturer with fairness concerns, retailer with fairness concerns, and bidirectional fairness concerns, for a dual-channel supply chain context, and used an inventory parceling strategy to achieve dual-channel supply chain coordination. Zhang and Li [10] discussed the impact of manufacturer fairness concerns and whether retailers consider manufacturer fairness concerns on supply chain greenness in a green closed-loop supply chain, and supply chain coordination was achieved using revenue sharing contracts. In addition, other scholars focused on operational strategies with fairness concerns. In this field of research, Zhong and Sun [11] studied the impact of manufacturer's distributional fairness and retailer's peer-induced distribution fairness on pricing and carbon emission reduction decisions in a supply chain composed of one manufacturer and two retailers. Li et al. [12] designed a controlled experiment for the cooperative advertising strategy, and the experimental results showed that the unfair aversion to advertising cost and income distribution in the actual decision-making would reduce the manufacturer's advertising participation rate and the retailer's advertising expenditure. In the retailer-led closed-loop supply chain, Wang et al. [13] compared the impact of manufacturer's fairness concerns on supply chain decision-making and profits under the conditions of information symmetry and information asymmetry. Du and Zhao [14] considered the impact of retailer's fairness preference and consumer channel preference on the supply chain by constructing a Stackelberg game model in the manufacturer-led dual-channel supply chain. The results showed that manufacturers should consider the fairness preferences of retailer. Zheng et al. [15] discussed the impact of fair concern retailers on supply chain pricing strategy and profit distribution in three-level closed-loop supply chain. The results showed that the profit loss of the channel would increase with the increase of the dispersion degree of the supply chain system.

In recent years, the research on risk-averse supply chain has attracted more and more domestic and international scholars, mainly including single-channel and multi-channel supply chain decision-making. Some scholars have studied the risk aversion problem of single-channel chain. Qi et al. [16] used the CVaR method to study the impact of retailer's risk-averse on supply chain ordering and emission reduction decisions under the limit of cap-and-trade carbon regulation. Song et al. [17] compared the impact of risk-averse retailers and overconfident manufacturers on the optimal decisions and profits of participants under the push strategy, pull strategy and other strategy in the uncertain demand environment. Tarei et al. [18] analyzed the impact of different risk preferences of decision makers on supply chain costs in a stochastic uncertain environment and constructed a mean-variance robust optimization model. Zhao et al. [19] used a joint contract consisting of revenue sharing and repurchase to coordinate supply chains with a risk-averse retailer under demand uncertainty, and showed that a joint contract can achieve higher supply chain revenue compared to a single revenue sharing or repurchase contract. Song et al. [20] adopted CVaR criterion to compare the impact of retailer's risk aversion degree on the optimal decision in the presence or absence of quality information, and the results showed that retailer's risk aversion would reduce the order quantity. Kang et al. [21] investigated the pricing strategy of green supply chains considering risk-averse suppliers and used the mean variance measure of risk preference to show that excessive supply chain risk aversion reduces the green level of the supply chain. As to the study on risk aversion focuses on multi-channel supply chain, Zhu et al. [22] used the CVaR method to establish a dual-channel supply chain decision model considering risk-averse retailer based on the uncertain conditions of production and market demand, and realized supply chain coordination by designing a joint contract of revenue-sharing and buyback. Li et al. [23] analyzed the impact of retailer's risk-averse behavior on the optimal inventory and profit under different logistics integration strategies for the choice of logistics strategies for omnichannel orders. Wang et al. [24] studied the optimal decision-making in dual-channel supply chain considering retailer's risk-averse and consumer's channel preferences based on the consistent pricing strategy, and constructed the Stackelberg game model by mean-variance method. In addition, some literatures also considered the impact of dual behavior factors on supply chain decision-making and coordination. Tao et al. [25] studied a three-tier supply chain sourcing and distribution problem for manufacturers considering risk-averse and fairness concerns, and developed a Monte Carlo multi-objective stochastic model to find the Pareto bound for the optimal decision. Yan et al. [26] considered risk inequity averse of retailer as a new behavioral factor, applied a downside-risk approach to consider supply chain decisions under wholesale price contracts, and proved that risk inequity aversion would reduce the efficiency of supply chain system.

The following is a brief review of the literature on dual-channel supply chain contract coordination. Bonzelet [27] compared the impact of retailer's risk-averse on order quantity under the coordination of buyback contract and real options contract. Sun et al. [28] explored the impact of digital showroom strategies on channel profits in the context of a dual-channel supply chain, and verified that the use of quantity discount and anti-showroom revenue-sharing joint contract can achieve supply chain channel coordination. Li and Liu [29] considered a newsboy model composed of suppliers and retailers, and compared the conditions that wholesale price contracts should meet to realize supply chain coordination in the case of symmetric information and asymmetric information. Liu et al. [30] investigated the effect of retailer risk preference on supply chain decisions based on two supply chain structures, supplier-led and retailer-led, and demonstrated that these two structures can be coordinated under the same conditions. Heydari and Asl-Najafi [31] constructed the optimal decision models under centralized and decentralized conditions for the green supply chain, and adopted the joint contract of cost sharing and revenue sharing to realize supply chain coordination and improve the green quality of products. Gao et al. [32] discussed the impact of government subsidies on supply chain decisions in dual-channel supply chain with green standard restrictions and constructed a Stackelberg game model. Their study showed that two-part tariff contract could achieve channel coordination. Nouri et al. [33] studied the supply chain composed of a manufacturer and two price-competing retailers, established a decentralized model to get optimal price and service decisions, and proposed a two-part tariff contract to eliminate channel conflicts. Zhang et al. [34] used Stackelberg model to explore the impact of reference price and green level on dual-channel supply chain pricing and ordering strategy, and constructed the centralized, decentralized, coordination model under a cost-sharing contract respectively.

We will consider fairness concerns and risk-averse behaviors in a dual-channel supply chain with uncertain manufacturer yield and market demand, and demonstrate that joint contracts for revenue sharing and risk sharing can achieve Pareto improvements. Specifically, we would analyze the impact of fairness concern coefficient, risk aversion coefficient and joint contract parameters on dual-channel supply chain. We believe that this paper would make contributions to the growing researches considering fairness concerns and risk-aversion behavior under uncertain manufacturing yield and market demand.

III. MATH

A. MODEL DESCRIPTION

We analyze a dual-channel supply chain that consists of a manufacturer and a fairness concerned and risk-averse retailer, shown in Figure 1. The manufacturer in this paper owns an online direct channel and distributes the product through a traditional retail channel. The retailer sells products through the traditional offline channel, and faces manufacturer's direct channel competition and market demand uncertainty.

In this model, q_m denotes the manufacturer's planned production. q_r denotes the order quantity from the retailer. It holds that $yq_m > q_r$ because the actual manufacturing yield is greater than the order quantity from the retailer. y is a random variable with a probability density function $g(y)$ and a cumulative distribution function. c_m is the unit cost of manufacturer's production. c_r is the unit cost of goods sold from the retailer. D_r and D_d represent market demand in the retail channel and direct channel, respectively. D_r and D_d are defined as:

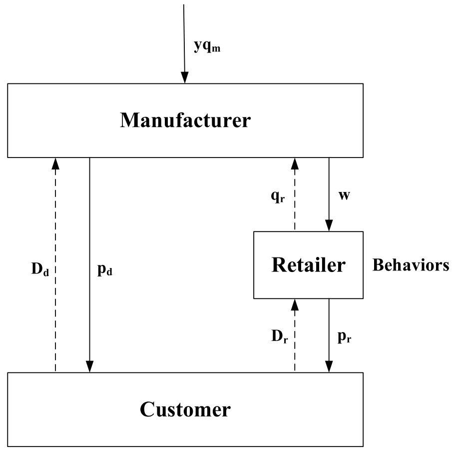


FIGURE 1. The dual channel supply chain model for retailer behaviors.

$$D_r = \theta x - p_r + \beta_r p_d, \tag{1}$$
$$D_d = (1-\theta)x - p_d + \beta_d p_r, \tag{2}$$

where θ is the market share of the retail channel. x is the overall market demand with a probability density function $f(x)$ and a cumulative distribution function $F(x)$. $F(x)$ is differentiable and strictly monotonically increasing. β_r and β_d represent price sensitive coefficients of the retailer and manufacturer in the cross-channel $0 < \beta_r < 1$, satisfying, $0 < \beta_m < 1$. At the end of the sales unit period, the retailer and the manufacturer have salvage values V_r and V_m for the unsold products, and we assumed $V_r < V_m$.

B. SYMBOL AND PARAMETER DESCRIPTION

The list of variables and parameters mentioned in this paper is provided in Table 1.

IV. CENTRALIZED OPTIMAL DECISION MODEL

In this section, the retailer determines the order quantity and retail price as a follower based on the wholesale price given by the manufacturer. The manufacturer as the leader makes decisions based on the retailer's responses. The retailer's profit function is expressed as:

$$\pi_r = p_r \min(q_r, D_r) + V_r[q_r - D_r]^+ - wq_r - c_r q_r \tag{3}$$

Equation (3) represents the retailer's profit function consisting of retailer's sales revenue, retailer's salvage revenue, wholesale cost, and sales cost. The retailer's expected profit function is defined as:

$$E(\pi_r) = p_r S(q) + V_r[q_r - S(q)] - (w + c_r)q_r \tag{4}$$

where,

$$S(q) = E[\min(q_r, D_r)] = \int_0^{x_r} (\theta x - p_r + \beta_r p_d) f(x)dx + \int_{x_r}^{+\infty} q_r f(x)dx$$

TABLE 1. Summary of notation.

Notation	Description
p_r, p_d	The unit price of the retail channel and direct channels
β_r, β_d	Cross-channel price sensitivity factor for retailer and manufacturer
D_r, D_d	Market demand in the retail channel and direct channel
V_r, V_d	Unit salvage value in the retail channel and direct channel
w	Unit wholesale price
w^{d*}	The optimal unit wholesale price in the decentralized dual-channel supply chain
w^{b*}	The optimal unit wholesale price under joint contract
q_r	The order quantity of the retailer
q_r^{d*}	The optimal order quantity of the retailer in the decentralized dual-channel supply chain
q_r^{c*}	The optimal order quantity of the retailer in the centralized dual-channel supply chain
q_r^{b*}	The optimal order quantity of retailer under joint contract
q_m	The planned yield of the manufacturer
q_m^{d*}	The optimal planned yield of the manufacturer in the decentralized dual-channel supply chain
q_m^{c*}	The optimal planned yield of the manufacturer in the centralized dual-channel supply chain
q_m^{b*}	The optimal planned yield of the manufacturer under joint contract
c_r	Cost of sales per unit of the retailer
c_m	Production cost per unit of the manufacturer
θ	Market share of the retail channel
λ	The fairness concern coefficient of the retailer
γ	The profit reference coefficient of the retailer
μ	The pessimistic coefficient of the retailer
η	The risk-averse coefficient of the retailer
φ	The percentage of revenue residual after the manufacturer has shared it with the retailer
p_b	The residual product unit price compensation from manufacturer to retailer
x	The overall market demand, $x\in[c,d]$ and $0<c<d$
y	The stochastic yield factor of manufacturer, $y\in[a,b]$ and $0<a<b\le 1$
$E(\pi_r)$	The expected profit of the retailer
$E(\pi_r^{d*})$	The optimal expected profit of the retailer in the decentralized dual-channel supply chain
$E(\pi_r^{b*})$	The optimal expected profit of the retailer under joint contract
$\Delta E(\pi_r)$	The change in the expected profit of the retailer before and after contract coordination
$E(\pi_m)$	The expected profit of the manufacturer
$E(\pi_m^{d*})$	The optimal expected profit of the manufacturer in the decentralized dual-channel supply chain
$E(\pi_m^{b*})$	The optimal expected profit of the manufacturer under joint contract
$\Delta E(\pi_m)$	The change in the expected profit of the manufacturer before and after contract coordination
$E(\pi_t^{c*})$	The optimal expected profit of the supply chain in the centralized dual-channel supply chain
$CVaR_\eta(\pi(p_r,q_r))$	The CVaR value of the retailer
$G_\eta(\pi(p_r,q_r))$	The mean-CVaR value of the retailer

$$= q_r - \theta\int_0^{x_r} F(x)dx \tag{5}$$

$$x_r = \frac{p_r + q_r - \beta_r p_d}{\theta} \tag{6}$$

The manufacturer's profit function is expressed as:

$$\pi_m = p_d \min(D_d, yq_m - q_r) + V_m[yq_m - q_r - D_d]^+ + wq_r - c_m q_m \tag{7}$$

Equation (7) represents the manufacturer's profit function consisting of direct channel sales revenue, manufacturer's salvage revenue, retail channel sales revenue and production costs. The manufacturer's expected profit function is defined as:

$$E(\pi_m) = p_d F_1 + V_m F_2 + wq_r - c_m q_m \tag{8}$$

where,

$$F_1 = \int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} (yq_m - q_r)g(y)f(x)dydx + \int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} D_d g(y)f(x)dydx \tag{9}$$

$$F_2 = \int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} (yq_m - q_r - D_d)g(y)f(x)dydx \tag{10}$$

The entire supply chain's expected profit function in the centralized model is defined as:

$$E(\pi_t^c) = p_r S(q) + V_r[q_r - S(q)] - c_r q_r + p_d F_1 + V_m F_2 - c_m q_m \tag{11}$$

Proposition 1: In the centralized decision, the expected maximal profit of dual-channel supply chain exists if the following conditions on $(p_r^{c*}, q_r^{c*}, q_m^{c*}, p_d^{c*})$ are satisfied:

$$q_r^{c*} - \theta\int_0^{x_r} F(x)dx - (p_r^{c*} - V_r)F(x_r) + (p_d^{c*} - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r^{c*}}{q_m^{c*}}}^{b} \beta_d g(y)f(x)dydx = 0 \tag{12}$$

$$p_r^{c*} - c_r - (p_r^{c*} - V_r)F(x_r) - (p_d^{c*} - V_m)\int_0^{+\infty}\int_a^{\frac{D_d+q_r^{c*}}{q_m^{c*}}} g(y)f(x)dydx - V_m = 0 \tag{13}$$

$$p_d^{c*}\int_0^{+\infty}\int_a^{\frac{D_d+q_r^{c*}}{q_m^{c*}}} yg(y)f(x)dydx + V_m\int_0^{+\infty}\int_{\frac{D_d+q_r^{c*}}{q_m^{c*}}}^{b} yg(y)f(x)dydx - c_m = 0 \tag{14}$$

$$(p_r^{c*} - V_r)\beta_r F(x_r) + F_1 - (p_d^{c*} - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r^{c*}}{q_m^{c*}}}^{b} g(y)f(x)dydx = 0 \tag{15}$$

For the proof, see Appendix.

V. DECENTRALIZED OPTIMAL DECISION MODEL

A. IMPROVED FS MODEL

FS model is an inequity aversion model constructed by Fehr and Schmidt [35], in which decision makers compared their own profits with those of others to judge whether the distribution of gains is fair. The utility expression is:

$$U_i(x) = x_i - \alpha_i \max\{x_j - x_i, 0\} - \beta_i \max\{x_i - x_j, 0\}, \quad (16)$$

where α_i denotes the decision maker's loss utility from disadvantageous inequity and β_i denotes the decision maker's loss utility from advantageous inequity. Since it is difficult for retailers to directly take manufacturer's income as the profit reference point, Cui et al. [2] introduced the retailer's profit reference coefficient γ based on the FS model and defined the fair utility function as:

$$U_i(x) = x_i - \alpha_i \max\{\gamma x_j - x_i, 0\} - \beta_i \max\{x_i - \gamma x_j, 0\}. \quad (17)$$

For simplicity and without losing generality, the improved fairness concern model is expressed as:

$$U_i = \pi_i - \lambda(\gamma\pi_j - \pi_i), \quad (18)$$

where $\lambda \in [0, +\infty)$ denotes the fairness concern coefficient of the decision maker and $\gamma \in (0, 1]$ denotes the profit reference coefficient of the decision maker. When $\lambda = 0$, the decision maker is fairness-neutral. When $\lambda > 0$, the decision maker is fairness concerns. If $\gamma\pi_j - \pi_i > 0$, then the negative utility from the decision maker's fairness concerns increases as λ increases; If $\gamma\pi_j - \pi_i \leq 0$, then the positive utility from the decision maker's fairness concerns increases as λ increases.

B. MEAN-CONDITIONAL VALUE-AT-RISK CRITERION

Conditional value-at-risk is proposed by Rockafellar and Uryasev [36] as a tool for measuring the degree of risk, and its general definition formula is:

$$CVaR_\eta(\pi(p_r, q_r)) = \max_{v\in R}\{v + \frac{1}{\eta}E[\min(\pi(p_r, q_r) - v, 0)]\}. \quad (19)$$

Equation (19) represents that the average profit is lower than the quantile level set by VaR (Value-at-Risk). CVaR is a coherent risk measure, and has properties of convexity, monotonicity, translation equivariance and positive homogeneity. CVaR measures the average profit falling below η-quantile level and ignores the contributions of profit beyond the specified quantile. In order to overcome the shortcomings of CVaR, this paper uses the mean-CVaR measure of risk-averse decision makers, because it can maximize the expected profit of risk-averse decision makers and minimize the downside risk profit. The mean-CVaR metric formula is expressed as:

$$G_\eta(\pi(p_r, q_r)) = \mu E(\pi(p_r, q_r)) + (1-\mu) CVaR_\eta(\pi(p_r, q_r)), \quad (20)$$

where $\eta \in (0, 1]$ denotes the risk-averse coefficient of the decision maker. The risk aversion of the decision maker increases as η decreases. If $\eta = 1$, the decision maker is risk-neutral. $\mu \in [0, 1]$ denotes the pessimistic coefficient of the decision maker. If $\mu = 0$, it means that the decision maker is risk-averse, and expected profit is the CVaR value; If $\mu = 1$, the decision maker is risk-neutral.

C. OPTIMAL DECISION MODEL OF FAIRNESS CONCERNED AND RISK-AVERSION RETAILER

In the dual-channel supply chain environment, there are risk aversion and fairness concerns caused by uncertainty and channel competition. According to the improved FS model and the mean-CVaR method, the expected profit function of fairness concerned and risk-averse retailer is defined as:

$$\begin{aligned} E(\pi_r^d) &= G_\eta(\pi(p_r, q_r)) - \lambda[\gamma E(\pi_m) - G_\eta(\pi(p_r, q_r))] \\ &= -(1+\lambda)(\mu + \frac{1-\mu}{\eta})(p_r - V_r)\theta \int_0^{x_r} F(x)dx \\ &\quad - \lambda\gamma(p_d F_1 + V_m F_2 + w q_r - c_m q_m) \\ &\quad + (1+\lambda)(p_r - c_r - w)q_r \end{aligned} \quad (21)$$

Proposition 2: In the decentralized decision, the retailer's expected maximal profit exists if the following conditions on (q_r^{d*}, p_r^{d*}) are satisfied:

$$\begin{aligned} &(1+\lambda)[p_r^{d*} - w - c_r - (\mu + \frac{1-\mu}{\eta})(p_r^{d*} - V_r)F(x_r)] \\ &+ \lambda\gamma[(p_d - V_m)\int_0^{+\infty}\int_a^{\frac{D_d+q_r^{d*}}{q_m}} g(y)f(x)dydx - w + V_m] = 0 \end{aligned} \quad (22)$$

$$\begin{aligned} &(1+\lambda)q_r^{d*} - \lambda\gamma\beta_d(p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r^{d*}}{q_m}}^{b} g(y)f(x)dydx \\ &- (1+\lambda)(\mu + \frac{1-\mu}{\eta})[\theta\int_0^{x_r} F(x)dx + (p_r^{d*} - V_r)F(x_r)] = 0 \end{aligned} \quad (23)$$

For the proof, see Appendix.

D. OPTIMAL DECISION MODEL OF MANUFACTURER

The expected profit functions of fairness-neutral and risk-neutral manufacturer is defined as:

$$E(\pi_m) = p_d F_1 + V_m F_2 + w q_r - c_m q_m \quad (24)$$

Proposition 3: In the decentralized decision, the manufacturer's expected maximal profit exists if the following conditions on $(w^{d*}, q_m^{d*}, p_d^{d*})$ are satisfied:

$$\begin{aligned} &(p_d^{d*} - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m^{d*}}}^{b} (A_1 + \beta_d B_1)g(y)f(x)dydx \\ &+ (w^{d*} - p_d^{d*})A_1 + q_r = 0 \end{aligned} \quad (25)$$

$$\begin{aligned} &-(p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} (y - A_2 - \beta_d B_2)g(y)f(x)dydx \\ &+ p_d(\bar{y} - A_2) + wA_2 - c_m = 0 \end{aligned} \quad (26)$$

$$\begin{aligned} &(p_d^{d*} - V_m)(A_3 - 1 + \beta_d B_3)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m^{d*}}}^{b} g(y)f(x)dydx \\ &+ F_1 + (w^{d*} - p_d^{d*})A_3 = 0 \end{aligned} \quad (27)$$

For the proof, see Appendix.

VI. COORDINATION MODEL BASED ON JOINT CONTRACT

In this paper, we introduce a joint revenue-sharing and risk-sharing contract, where revenue-sharing means that the manufacturer shares φ times its own revenue with the retailer in response to the retailer's reduced market share due to channel competition. Risk sharing means that the manufacturer compensates the retailer p_b per unit for unsold products per unit in order to reduce the retailer's risk of stagnant sales due to demand uncertainty. We assume $0 \le \varphi < 1, p_b \le w$. So that it can prevent retailers from over-ordering and guarantee the manufacturer's base revenue.

Specifically, the coordination process before the start of the sales cycle is described as follows. (1) The manufacturer, as the dominant player, determines the contract form and provides the wholesale price, revenue sharing coefficient and unit compensation price. (2) The manufacturer determines the planned yield q_m and direct selling price p_d according to the contract. (3) The retailer determines the order quantity q_r and retail price p_r based on the wholesale price and market demand forecast. (4) The manufacturer and retailer reach an agreement on the joint contract mechanism. This paper uses backward induction method to calculate the retailer decision variables first and the manufacturer decision variables second.

A. RETAILER'S COORDINATION MODEL

The profit function of fairness-neutral and risk-neutral retailer under the joint contract is expressed as:

$$\pi_r = (1-\varphi)\{p_d \min(D_d, yq_m - q_r) + V_m[yq_m - q_r - D_d]^+\} + p_r \min(q_r, D_r) - wq_r - c_r q_r + (V_r + p_b)[q_r - D_r]^+ \quad (28)$$

Equation (28) represents the retailer's profit function consisting of the manufacturer's shared revenue part, retailer's sales revenue, wholesale cost, sales cost and manufacturer's compensation revenue. The profit function of manufacturer under the joint contract is expressed as:

$$\pi_m = \varphi\{p_d \min(D_d, yq_m - q_r) + V_m[yq_m - q_r - D_d]^+\} + wq_r - c_m q_m - p_b[q_r - D_r]^+ \quad (29)$$

Equation (29) represents the manufacturer's profit function consisting of the sales revenue and salvage value revenue, retail channel revenue, production cost and subsidy cost after the manufacturer's sharing. The expected profit function of the fairness-neutral and risk-neutral retailer contract coordination is defined as:

$$E(\pi_r) = (p_r - w - c_r)q_r - (p_r - V_r - p_b)\theta \int_o^{x_r} F(x)dx + (1-\varphi)(p_d F_1 + V_m F_2) \quad (30)$$

According to the FS model and the mean-CVaR method, we define the profit function for the contract coordination of fairness concerned and risk-averse retailer as:

$$\begin{aligned} E(\pi_r^b) &= G_\eta(\pi(p_r, q_r)) - \lambda[\gamma E(\pi_m) - G_\eta(\pi(p_r, q_r))] \\ &= [(1+\lambda)(1-\varphi) - \lambda\gamma\varphi](p_d F_1 + V_m F_2) \\ &\quad - (1+\lambda)(\mu + \frac{1-\mu}{\eta})(p_r - V_r - p_b)\theta \int_0^{x_r} F(x)dx] \\ &\quad - \lambda\gamma(wq_r - c_m q_m - p_b\theta \int_0^{x_r} F(x)dx) \\ &\quad + (1+\lambda)(p_r - w - c_r)q_r \end{aligned} \quad (31)$$

Proposition 4: Under the joint contract, the retailer's expected maximal profit exists if the following conditions on (p_r^{b*}, q_r^{b*}) are satisfied:

$$\begin{aligned} &(1+\lambda)[p_r^{b*} - w - c_r - (\mu + \frac{1-\mu}{\eta})(p_r^{b*} - V_r - p_b)F(x_r)] \\ &- [(1+\lambda)(1-\varphi) - \lambda\gamma\varphi](p_d - V_m) \\ &\times \int_0^{+\infty} \int_a^{\frac{D_d + q_r^{b*}}{q_m}} g(y)f(x)dydx - \lambda\gamma(w - p_b F(x_r)) \\ &- [(1+\lambda)(1-\varphi) - \lambda\gamma\varphi]V_m = 0 \end{aligned} \quad (32)$$

$$\begin{aligned} &[(1+\lambda)(1-\varphi) - \lambda\gamma\varphi](p_d - V_m) \\ &\times \int_0^{+\infty} \int_a^{\frac{D_d + q_r^{b*}}{q_m}} g(y)f(x)dydx \\ &- (1+\lambda)(\mu + \frac{1-\mu}{\eta}) \\ &\times [\theta \int_0^{x_r} F(x)dx + (p_r^{b*} - V_r - p_b)F(x_r)] \\ &+ (1+\lambda)q_r^{b*} + \lambda\gamma p_b F(x_r) = 0 \end{aligned} \quad (33)$$

For the proof, see Appendix.

B. MANUFACTURE'S COORDINATION MODEL

We define the profit function of manufacturer under the joint contract as:

$$E(\pi_m) = \varphi(p_d F_1 + V_m F_2) + wq_r - c_m q_m - p_b\theta \int_o^{x_r} F(x)dx \quad (34)$$

Proposition 5: Under the joint contract, the manufacturer's expected maximal profit exists if the following conditions on $(w^{b*}, q_m^{b*}, p_d^{b*})$ are satisfied:

$$\begin{aligned} &\varphi(p_d^{b*} - V_m) \int_0^{+\infty} \int_{\frac{D_d + q_r}{q_m^{b*}}}^{b} (A_4 + \beta_d B_4)g(y)f(x)dydx \\ &+ q_r + w^{b*}A_4 - p_b(A_4 + B_4)F(x_r) - \varphi p_d^{b*} A_4 = 0 \end{aligned} \quad (35)$$

$$\begin{aligned} &\varphi p_d^{b*} \int_0^{+\infty} \int_a^{\frac{D_d + q_r}{q_m^{b*}}} (y - A_5 - \beta_d B_5)g(y)f(x)dydx \\ &+ \varphi V_m \int_0^{+\infty} \int_{\frac{D_d + q_r}{q_m^{b*}}}^{b} (y - A_5 - \beta_d B_5)g(y)f(x)dydx \\ &+ wA_5 - c_m - p_b(A_5 + B_5)F(x_r) + \varphi p_d^{b*} \beta_d B_5 = 0 \end{aligned} \quad (36)$$

$$\varphi(p_d^{b*} - V_m)(A_6 - 1 + \beta_d B_6)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m^{b*}}}^{b} g(y)f(x)dydx + w^{b*}A_6 - p_b(A_6+B_6-\beta_r)F(x_r)+\varphi(F_1 - p_d A_6)=0 \quad (37)$$

For the proof, see Appendix.

Proposition 6: Under the joint contract, the dual-channel supply chain can achieve coordination if the following conditions on (φ, w, p_b) are satisfied, (38) and (39) as shown at the bottom of the page.

For the proof, see Appendix.

Proposition 6 shows that: (1) The manufacturer's wholesale price and the unit compensation price increase with the increase of the revenue sharing factor. (2) If the revenue sharing factor is constant, the manufacturer's wholesale price and unit compensation price decrease with the increase of the retailer's risk aversion and fairness concern.

VII. NUMBERICAL EXPERIMENTS

This section further discusses some factors affecting the dual-channel supply chain, such as the effects of retailer fairness concerns and risk-averse on the decisions and utilities of each supply chain member. Suppose that the market random demand x follows a uniform distribution of [0,500] and the manufacturer random yield factor y follows a uniform distribution of [0.5,1]. We provide a numerical experiments by setting $c_m = 30, c_r = 12, \theta = 0.6, \beta_r = 0.6, \beta_d = 0.8, V_m = 20, V_r = 15, \gamma = 0.5$, and $\mu = 0.8$.

A. ANALYSIS OF DUAL BEHAVIORAL PREFERENCE UNDER UNCERTAINTIES OF YIELD AND DEMAND

According to the above assumptions, we can get the optimal ordering quantity, the optimal retail price, the optimal manufacturer's yield, and the optimal direct selling price under centralized decision as 143.778, 230.522, 391.999, and 211.064. The expected profit of the supply chain under centralized case is 12803.8. In addition, by adjusting the fairness concern coefficients and risk-averse coefficients, we can get Tables 2. The results show that the decisions and supply chain profits for decentralized decisions are less than the corresponding results under the centralized decision. There

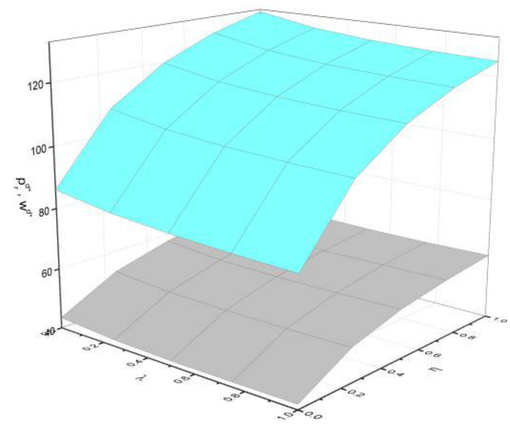


FIGURE 2. Effects of η and λ on the optimal retail's price and manufacturer's optimal wholesale price.

is an obvious ''double marginalization'', which indicates that the simple wholesale price contract cannot achieve supply chain coordination.

The optimal decisions under decentralized scenarios with different degrees of fairness concerns and risk-averse are shown in Table 2. If the retailer's attention to revenue distribution equity increases, then retail prices, manufacturers' wholesale prices, manufacturers' yield, and expected profits of the supply chain decrease and retailers' order quantity increases. In addition, retailer order quantity, retail price, manufacturer wholesale price, manufacturer output, and expected profit in the supply chain all decrease with the increase of retailer risk aversion. The degree of retailer fairness concerns and risk aversion is negatively related to the retailer and manufacturer profits.

Figure 2 illustrates the effects of the retailer's risk-averse coefficient and fairness concern coefficient on the retail's optimal price and manufacturer's optimal wholesale price. As shown in Figure 2, the optimal retail's price and manufacturer's optimal wholesale price decrease with the increase of λ when η is fixed. This implies that the retailer competes with manufacturers' direct channels by decreasing retail prices to expand the consumer market. In addition, this figure shows that the optimal retail's price and manufacturer's optimal

$$p_b = \frac{\left\{\begin{array}{l}(1+\lambda)(\mu+\frac{1-\mu}{\eta})(p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} g(y)f(x)dydx) \\ -[(1+\lambda)(1-\varphi)-\lambda\gamma\varphi](p_d - V_m)\int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} g(y)f(x)dydx \\ +(1+\lambda)(\mu+\frac{1-\mu}{\eta}-1)q_r\end{array}\right\}}{[(1+\lambda)(\mu+\frac{1-\mu}{\eta})+\lambda\gamma]p_b F(x_r)} \quad (38)$$

$$w = \frac{\left\{\begin{array}{l}(1+\lambda)[p_r - q_r - c_r + (\mu+\frac{1-\mu}{\eta})\theta\int_0^{x_r} F(x)dx] \\ -[(1+\lambda)(1-\varphi)-\lambda\gamma\varphi]V_m \\ -2[(1+\lambda)(1-\varphi)-\lambda\gamma\varphi](p_d - V_m)\int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} g(y)f(x)dydx\end{array}\right\}}{1+\lambda+\lambda\gamma} \quad (39)$$

TABLE 2. The decentralized optimal decisions with different degrees of fairness concerns and risk-averse.

η	λ	Decentralized optimal decision						
		p_r^{d*}	q_r^{d*}	w^{d*}	q_m^{d*}	p_d^{d*}	$E(\pi_r^{d*})$	$E(\pi_m^{d*})$
0.2	0.2	86.1	50.0	43.5	181.8	108.7	354.4	1978.7
	0.4	83.2	51.9	42.1	176.7	105.5	278.6	1809.8
	0.6	81.6	53.4	41.6	173.1	103.61	183.0	1709.4
	0.8	80.6	54.5	41.6	170.4	102.4	73.9	1645.2
0.4	0.2	108.1	71.9	52.9	217.9	124.5	678.8	3676.6
	0.4	104.9	74.1	51.3	210.8	121.0	541.0	3439.1
	0.6	103.2	75.9	50.9	205.7	119.1	363.0	3302.2
	0.8	102.3	77.2	50.9	201.9	117.9	157.2	3217.6
0.6	0.2	119.7	83.8	57.7	238.2	132.6	905.0	4758.6
	0.4	116.4	86.2	56.1	230.0	129.0	733.3	4477.4
	0.6	114.7	88.1	55.6	224.0	127.0	508.0	4317.2
	0.8	113.7	89.6	55.7	219.5	125.9	224.9	4219.6
0.8	0.2	126.9	91.3	60.7	251.2	137.6	1065.1	5492.6
	0.4	123.5	93.8	59.0	242.2	133.9	872.5	5181.6
	0.6	121.7	95.7	58.5	235.6	131.8	616.9	5005.5
	0.8	120.7	97.3	58.7	230.7	130.7	316.8	4898.9
1	0.2	131.7	96.4	62.7	260.2	140.9	1183.1	6019.8
	0.4	128.3	98.9	60.9	250.6	137.1	976.4	5687.4
	0.6	126.5	101.0	60.5	243.7	135.1	699.9	5499.8
	0.8	125.5	102.6	60.6	238.5	134.0	374.0	5386.7

TABLE 3. The optimal decision under different degrees of risk-averse.

risk-averse coefficient	Contract parameters			Optimal decision		Profit increase	
	φ	w	p_b	$E(\pi_r^{b*})$	$E(\pi_m^{b*})$	$\Delta E(\pi_r)$	$\Delta E(\pi_m)$
$\eta = 0.75$	0.75	139.5	137.4	6626.6	5644.5	5507.4	-281.5
	0.81	150.2	146.7	5202.5	7131.9	4083.3	1206.0
	0.87	160.8	155.9	3778.4	8619.3	2659.2	2693.4
	0.93	171.4	165.2	2354.3	10106.8	1235.1	4180.8
	0.99	182.0	174.5	930.2	11594.2	-189.0	5668.2
$\eta = 0.8$	0.75	137.8	134.2	6660.6	5727.3	5504.8	-372.1
	0.81	148.5	143.6	5236.5	7199.6	4080.7	1100.3
	0.87	159.1	153.0	3812.4	8672.0	2656.7	2572.6
	0.93	169.7	162.5	2388.3	10144.3	1232.6	4045.0
	0.99	180.3	171.9	964.2	11616.7	-191.5	5517.4
$\eta = 0.85$	0.75	136.3	131.2	6690.6	5809.1	5501.0	-450.0
	0.81	147.0	140.8	5266.5	7267.8	4076.9	1008.7
	0.87	157.4	157.7	3842.4	8726.4	2652.8	2467.3
	0.93	168.2	160.0	2418.3	10185.0	1228.7	3925.9
	0.99	178.8	169.5	994.2	11643.7	-195.4	5384.6
$\eta = 0.9$	0.75	135.0	128.6	6717.2	5889.0	5496.3	-517.6
	0.81	145.6	138.3	5293.2	7335.2	4072.2	928.5
	0.87	156.2	148.0	3869.1	8781.3	2648.1	2374.7
	0.93	166.9	157.7	2445.0	10227.4	1224.0	3820.8
	0.99	177.5	167.4	1020.9	11673.5	-200.1	5266.9
$\eta = 0.95$	0.75	133.8	126.1	6741.1	5966.5	5491.0	-576.9
	0.81	144.4	135.9	5317.0	7401.2	4066.9	857.8
	0.87	155.0	145.8	3892.9	8835.8	2642.8	2292.4
	0.93	165.7	155.6	2468.8	10270.5	1218.7	3727.1
	0.99	176.3	165.4	1044.7	11705.1	-205.4	5161.7

wholesale price increase with the increase of η when λ is fixed. This means that the optimal retail price decreases as the retailer's level of risk aversion increases in order to attract consumers and avoid product surplus. Figure 3 illustrates the effects of the retailer's risk-averse coefficient and fairness concern coefficient on the retail's optimal order quantity and manufacturer's optimal yield. As shown in Figure 3, the retail's optimal order quantity increases and manufacturer's optimal yield decreases with the increase of λ when η is fixed. This implies that the manufacturer's optimal yield decreases with the increase of the level of retail's fairness concern, namely the decrease of manufacturer's direct channel market demand. The retailer's price reduction strategy has a negative impact on the manufacturer. In addition, this figure shows that the retail's optimal order quantity and manufacturer's optimal yield increase with the increase of η when λ is fixed.

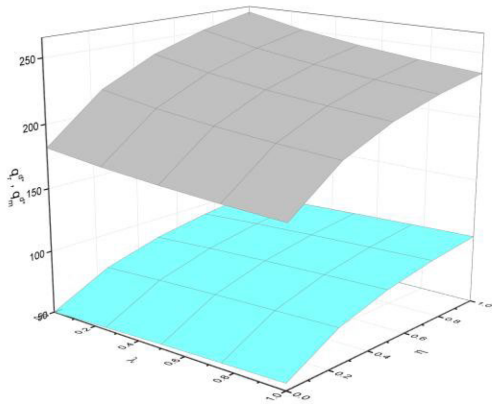


FIGURE 3. Effects of η and λ on the optimal retail's optimal order quantity and manufacturer's optimal yield.

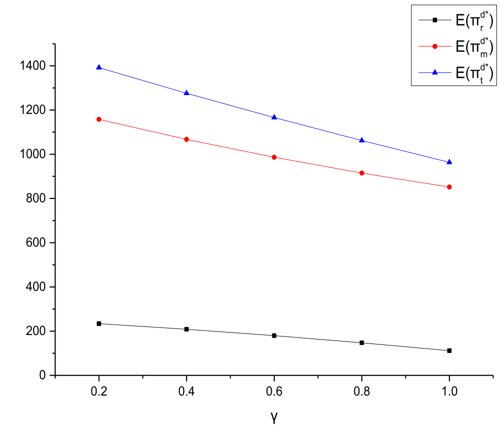


FIGURE 5. Effects of retailer profit reference coefficient on profits.

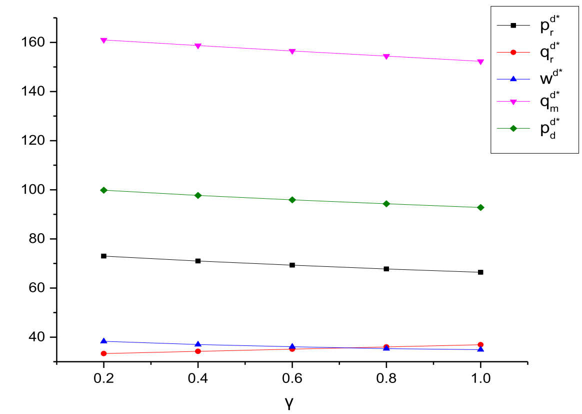


FIGURE 4. Effects of retailer profit reference coefficient on decision variables.

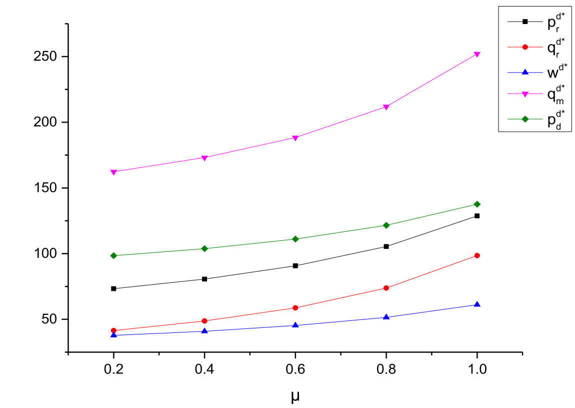


FIGURE 6. Effects of retailer pessimism coefficient on decision variables.

This means that the retail's optimal order quantity decreases with the increase of the level of retail's risk aversion because the retailer reduces risk by avoiding product surplus. In the meanwhile, the manufacturer adjusts the yield according to the degree of risk.

Figure 4 and Figure 5 illustrate the effects of the retailer's profit reference coefficient on the decision variables and profits when $\lambda = 0.2, \mu = 0$, and $\eta = 0.4$, respectively. Figure 4 indicates that if the retailer's profit reference coefficient increases, then the retailer's optimal order quantity decreases, and the optimal retail price, the manufacturer's optimal wholesale price, the manufacturer's optimal yield, and the optimal direct sales price all increase. Figure 5 indicates that if the retailer's profit reference coefficient increases, then the profits of retailer, manufacturer and supply chain system show a declining trend.

Figure 6 and Figure 7 illustrate the effects of the retailer's pessimism coefficient on the decision variables and profits when $\lambda = 0.2, \gamma = 0.8$, and $\eta = 0.4$, respectively. Figure 6 indicates that if the retailer's pessimism coefficient increases, then the retailer's optimal order quantity, the optimal retail price, the manufacturer's optimal wholesale price, the manufacturer's optimal yield, and the optimal direct sales price all increase. Figure 7 indicates that if the retailer's pessimism coefficient increases, then the profits of retailer, manufacturer and supply chain system show an increasing trend.

B. ANALYSIS OF DUAL BEHAVIORAL PREFERENCE UNDER JOINT CONTRACT

In Table 3, the specific coordination results based on the risk-averse coefficient and the joint contract parameters are shown. Where, $\Delta E(\pi_r)$ represents the change of the retailer's expected profit before and after contract coordination, and $\Delta E(\pi_m)$ represents the change of the manufacturer's expected profit before and after contract coordination. It can be seen from Table 3 that the joint contract composed of revenue-sharing and risk-sharing achieves a win-win situation of supply members' income. That means that Pareto improvement of dual-channel supply chain is realized.

Figure 8 illustrates the effects of the risk-averse coefficient η and contract parameter φ on the Pareto improvement region. Figure 9 illustrates the effects of fairness concern coefficient λ, risk-averse coefficient η and contract parameter φ on Pareto improvement regions. To compare the possibility

TABLE 4. Pareto improvement region with different degrees of risk-averse and fairness concerns.

η	λ			
	λ =0.2	λ =0.4	λ =0.6	λ =0.8
	Coordination region			
η =0.8	$0.739<\varphi<0.955$	$0.726<\varphi<0.941$	$0.718<\varphi<0.933$	$0.714<\varphi<0.928$
	$135.5<w<173.726$	$132.954<w<171.003$	$131.37<w<169.419$	$130.54<w<168.412$
	$131.662<p_b<165.769$	$129.126<p_b<163.153$	$127.526<p_b<161.607$	$126.648<p_b<160.609$
η =0.85	$0.742<\varphi<0.956$	$0.731<\varphi<0.942$	$0.721<\varphi<0.934$	$0.716<\varphi<0.928$
	$134.643<w<172.515$	$131.354<w<169.864$	$130.635<w<168.33$	$129.664<w<167.182$
	$129.411<p_b<163.647$	$124.924<p_b<161.114$	$125.46<p_b<159.6$	$124.481<p_b<158.519$
η =0.9	$0.744<\varphi<0.956$	$0.731<\varphi<0.942$	$0.723<\varphi<0.934$	$0.718<\varphi<0.929$
	$133.764<w<170.282$	$131.354<w<168.695$	$129.863<w<167.204$	$129.924<w<166.265$
	$127.253<p_b<161.569$	$124.924<p_b<159.114$	$123.473<p_b<157.688$	$122.549<p_b<156.782$
η =0.95	$0.744<\varphi<0.956$	$0.733<\varphi<0.942$	$0.725<\varphi<0.934$	$0.720<\varphi<0.930$
	$133.191<w<170.178$	$130.662<w<167.649$	$129.21<w<166.198$	$128.3<w<165.464$
	$125.476<p_b<159.668$	$123.077<p_b<157.286$	$121.693<p_b<155.914$	$120.819<p_b<155.213$

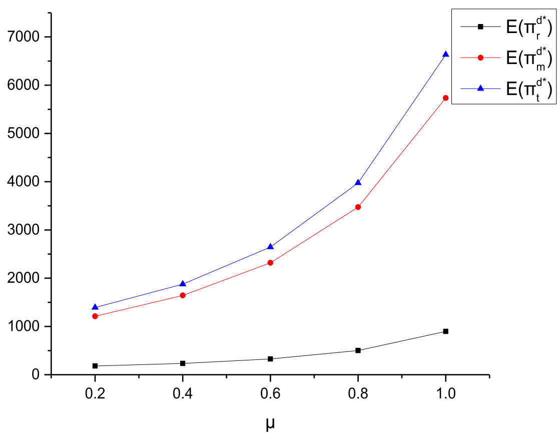


FIGURE 7. Effects of retailer pessimism coefficient on profits.

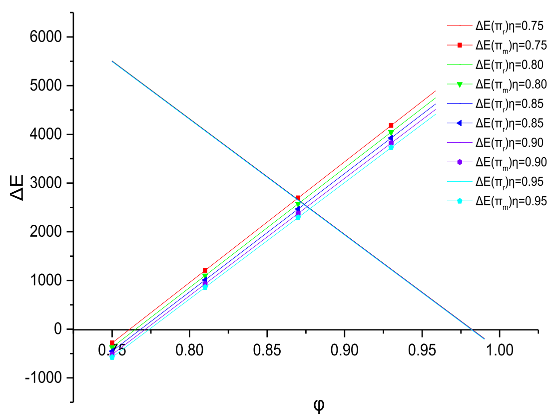


FIGURE 8. Effects of η and φ on Pareto improvement region.

of achieving dual-channel supply chain coordination with joint contracts under different risk aversion levels ($\eta = 0.75, 0.80, 0.85, 0.90, 0.95$), we plot the Pareto improvement region according to Table 3, as shown in Figure 8. To compare the possibility of achieving dual-channel supply chain coordination with joint contracts under different fairness concerned levels ($\lambda = 0.2, 0.4, 0.6, 0.8$), we plot the Pareto improvement region according to Table 4, as shown in Figure 9. These figures indicate that, (1) There is always a triangular area surrounded by the incremental profits of the retailer, the incremental profits of the manufacturer, and the horizontal coordinates based on different risk-averse coefficient. (2) With the increase of the retailer's risk aversion, the profit change of the manufacturer and retailer increases and the Pareto improvement region also increases. (3) With the increase of the retailer's fairness concern, the profit change of the retailer increases, the profit change of the manufacturer decreases, and the Pareto improvement region increases. The above results show that when the retailer devotes more attention to risk aversion and fairness in revenue allocation, the manufacturer would promote the implementation of joint contracts through revenue allocation adjustment and risk sharing in order to reduce the negative utility from the retailer's behavioral preferences.

Table 4 shows Pareto improvement region with different degrees of risk-averse and fairness concerns. The coordination region under joint contract coordination decreases with the increase of risk aversion coefficient, which indicates that retailer's risk aversion will increase the possibility of dual-channel coordination. The coordination region under joint contract coordination increases with the increase of fairness concern coefficient, which indicates that retailer's attention

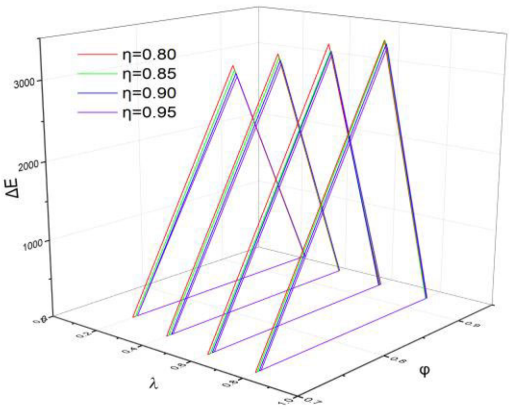


FIGURE 9. Effects of λ, η and φ on Pareto improvement region.

to revenue sharing equity is conducive to the realization of dual-channel coordination under joint contract.

According to this section for numerical analysis we can see that: (1) With the increase of retailer's fairness concern coefficient λ, the retailer's order quantity will increase, and retail prices, manufacturer's wholesale prices, manufacturer's yield and direct sales prices will decrease.

The expected profit of the retailer and the manufacturer shows a decreasing trend. (2) With the increase of retailer's risk-averse coefficient η, the retailer's order quantity, retail prices, manufacturer's wholesale prices, manufacturer's yield and direct sales prices will increase. The expected profit of the retailer and the manufacturer shows an increasing trend. (3) When applying joint contracts for coordination, manufacturer's wholesale prices, manufacturer's unit compensation price, retailer's incremental profit and manufacturer's incremental profit will decrease with the increase of risk-averse coefficient η when revenue-sharing factor φ is fixed. Manufacturer's wholesale prices, manufacturer's unit compensation price, and manufacturer's incremental profit will increase with the increase of revenue-sharing factor φ when risk-averse coefficient η is fixed, and at the same time, retailer's incremental profit will decrease. (4) The joint contract consisting of revenue-sharing and risk-sharing can achieve Pareto improvement in dual-channel supply chain with fairness concerns and risk aversion retailer.

VIII. CONCLUSION

In this paper, we study the optimal decision and coordination of a dual-channel supply chain with fairness concerns and risk aversion under uncertainties. The optimal decision models based on the Stackelberg game are constructed respectively under centralized and decentralized conditions for dual behavior preference. We adopt a joint contract with revenue-sharing and risk sharing to achieve dual-channel supply chain coordination and improve the performance of the supply chain. Numerical experiments demonstrate the effectiveness of the model and the joint contract. Based on the above research, we have the following managerial insights. (1) The benefits of dual-channel supply chains decrease as fairness concerns and risk aversion increase, which indicates that fairness concerns and risk aversion exacerbate the double marginalization effect. (2) In manufacturer-led dual-channel supply chains, manufacturers have a bargaining advantage in the Stackelberg game. The retailer competes with the manufacturer's direct channel by reducing retail price and increasing order quantity, which leads to the decrease of the overall profit of the supply chain. (3) In response to the risk preference in the behavior, the retailer reduces the order quantity according to the degree of risk to avoid the loss of its own profit, and the manufacturer adjusts the yield according to the degree of risk. The overall profit of the supply chain decreases with the increase of risk aversion. (4) In response to the fairness concerns in the behavior, the retailer reduces retail price according to the extent of its own unfair treatment, which has negative effect on the manufacturer. Meanwhile, the manufacturer should increase the retailer's order quantity by reducing the wholesale price. (5) The joint contract combining revenue-sharing and risk sharing can coordinate the dual-channel supply chain and finally achieve the win-win goal of the dual-channel supply chain. In this paper, we focus on retailer fairness preferences and risk preferences to investigate the coordination of dual-channel supply chains. The multi-risk aversion and multi-fairness concerns and the multi-channel supply chain coordination problem need to be further studied.

APPENDIX

A. PROOF OF PROPOSITION 1

From Equation (11), taking the first-order and second-order partial derivatives of $E(\pi_t^c)$ with respect to p_r, q_r, q_m and p_d, we obtain:

$$\frac{\partial E(\pi_t^c)}{\partial p_r} = q_r - \theta \int_0^{x_r} F(x)dx - (p_r - V_r)F(x_r) + (p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} \beta_d g(y)f(x)dydx$$

$$\frac{\partial E(\pi_t^c)}{\partial q_r} = p_r - c_r - (p_r - V_r)F(x_r) - V_m - (p_d - V_m)\int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} g(y)f(x)dydx$$

$$\frac{\partial E(\pi_t^c)}{\partial q_m} = p_d\int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} yg(y)f(x)dydx + V_m\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} yg(y)f(x)dydx - c_m$$

$$\frac{\partial E(\pi_t^c)}{\partial p_d} = (p_r - V_r)\beta_r F(x_r) + F_1 - (p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} g(y)f(x)dydx$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial q_r^2} = -\frac{p_d - V_m}{q_m}\int_0^{+\infty} g(\frac{D_d+q_r}{q_m})f(x)dx - \frac{p_r - V_r}{\theta}f(x_r)$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial p_r^2} = -2F(x_r)\frac{p_r - V_r}{\theta}f(x_r) - \frac{(p_d - V_m)\beta_d^2}{q_m}\int_0^{+\infty} g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial q_m^2} = -\frac{(p_d - V_m)}{q_m^3}\int_0^{+\infty}(D_d + q_r)^2 g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial p_d^2} = -\frac{(p_r - V_r)\beta_r^2}{\theta}f(x_r) - 2\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} g(y)f(x)dydx - \frac{p_d - V_m}{q_m}\int_0^{+\infty} g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial p_r \partial q_r} = 1 - F(x_r) - \frac{p_r - V_r}{\theta}f(x_r) - \frac{(p_d - V_m)\beta_d}{q_m}\int_0^{+\infty} g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial p_r \partial q_m} = \frac{\beta_d(p_d - V_m)}{q_m^2}\int_0^{+\infty}(D_d + q_r)g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial p_r \partial p_d} = -\frac{(p_r - V_r)\beta_r}{\theta}f(x_r) + \int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} \beta_d g(y)f(x)dydx + \beta_r F(x_r) + \frac{(p_d - V_m)\beta_d}{q_m}\int_0^{+\infty} g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial q_r \partial q_m} = \frac{(p_d - V_m)}{q_m^2}\int_0^{+\infty}(D_d + q_r)g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_t^c)}{\partial q_r \partial p_d} = \frac{(p_r - V_r)\beta_r}{\theta}f(x_r) - \int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} g(y)f(x)dydx + \frac{p_d - V_m}{q_m}\int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} g(\frac{D_d + q_r}{q_m})f(x)dydx$$

Thus, we have the Hessian matrix:

$$H(p_r, q_r, q_m, p_d) = \begin{vmatrix} \frac{\partial^2 E(\pi_t^c)}{\partial p_r^2} & \frac{\partial^2 E(\pi_t^c)}{\partial p_r \partial q_r} & \frac{\partial^2 E(\pi_t^c)}{\partial p_r \partial q_m} & \frac{\partial^2 E(\pi_t^c)}{\partial p_r \partial p_d} \\ \frac{\partial^2 E(\pi_t^c)}{\partial q_r \partial p_r} & \frac{\partial^2 E(\pi_t^c)}{\partial q_r^2} & \frac{\partial^2 E(\pi_t^c)}{\partial q_r \partial q_m} & \frac{\partial^2 E(\pi_t^c)}{\partial q_r \partial p_d} \\ \frac{\partial^2 E(\pi_t^c)}{\partial q_m \partial p_r} & \frac{\partial^2 E(\pi_t^c)}{\partial q_m \partial q_r} & \frac{\partial^2 E(\pi_t^c)}{\partial q_m^2} & \frac{\partial^2 E(\pi_t^c)}{\partial q_m \partial p_d} \\ \frac{\partial^2 E(\pi_t^c)}{\partial p_d \partial p_r} & \frac{\partial^2 E(\pi_t^c)}{\partial p_d \partial q_r} & \frac{\partial^2 E(\pi_t^c)}{\partial p_d \partial q_m} & \frac{\partial^2 E(\pi_t^c)}{\partial p_d^2} \end{vmatrix} > 0,$$

and $|H_1(p_r, q_r, q_m, p_d)| < 0$, $|H_2(p_r, q_r, q_m, p_d)| > 0$, $|H_3(p_r, q_r, q_m, p_d)| < 0$, $|H_4(p_r, q_r, q_m, p_d)| > 0$. The even-order sequential major minor has a positive value and the odd-order major minor has a negative value. Hessian matrix is negative definite. Thus $E(\pi_t^c)$ is a concave function of p_r, q_r, q_m and p_d. There exists a unique $(p_r^{c*}, q_r^{c*}, q_m^{c*}, p_d^{c*})$ maximizing $E(\pi_t)$ when $\frac{\partial E(\pi_t^c)}{\partial p_r} == 0$, $\frac{\partial E(\pi_t^c)}{\partial q_r} = 0$, $\frac{\partial E(\pi_t^c)}{\partial q_m} = 0$ and $\frac{\partial E(\pi_t^c)}{\partial p_d} = 0$.

Proposition 1 is proved.

B. PROOF OF PROPOSITION 2

From Equation (21), taking the first-order and second-order partial derivatives of $E(\pi_r^d)$ with respect to q_r and p_r, we obtain:

$$\frac{\partial E(\pi_r^d)}{\partial q_r} = (1+\lambda)[p_r - w - c_r - (\mu + \frac{1-\mu}{\eta})(p_r - V_r)F(x_r)] + \lambda\gamma[(p_d - V_m)\int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} g(y)f(x)dydx - w + V_m]$$

$$\frac{\partial^2 E(\pi_r^d)}{\partial q_r^2} = -(1+\lambda)(\mu + \frac{1-\mu}{\eta})\frac{p_r - V_r}{\theta}f(x_r) + \frac{(p_d - V_m)\lambda\gamma}{q_m}\int_0^{+\infty} g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial E(\pi_r^d)}{\partial p_r} = -(1+\lambda)(\mu + \frac{1-\mu}{\eta})[\theta\int_0^{x_r} F(x)dx + (p_r - V_r)F(x_r)] - \lambda\gamma\beta_d(p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} g(y)f(x)dydx + (1+\lambda)q_r$$

$$\frac{\partial^2 E(\pi_r^d)}{\partial p_r^2} = -(1+\lambda)(\mu + \frac{1-\mu}{\eta})[\frac{p_r - V_r}{\theta}f(x_r) + 2F(x_r)] + \lambda\gamma\frac{(p_d - V_m)\beta_d^2}{q_m}\int_0^{+\infty} g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_r^d)}{\partial q_r p_r} = (1+\lambda)[1 - (\mu + \frac{1-\mu}{\eta})(F(x_r) + \frac{p_r - V_r}{\theta}f(x_r))] + \lambda\gamma\frac{(p_d - V_m)\beta_d}{q_m}\int_0^{+\infty} g(\frac{D_d + q_r}{q_m})f(x)dx$$

Thus, we have the Hessian matrix: $H = \begin{vmatrix} \frac{\partial^2 E(\pi_r^d)}{\partial p_r^2} & \frac{\partial^2 E(\pi_r^d)}{\partial p_r \partial q_r} \\ \frac{\partial^2 E(\pi_r^d)}{\partial q_r \partial p_r} & \frac{\partial^2 E(\pi_r^d)}{\partial q_r^2} \end{vmatrix} > 0$, and $\frac{\partial^2 E(\pi_r^d)}{\partial p_r^2} < 0$. The even-order sequential major minor has a positive value and the odd-order major minor has a negative value. Hessian matrix is negative definite. Thus $E(\pi_r^d)$ is a concave function of q_r and p_r. There exists a unique (q_r^{d*}, p_r^{d*}) maximizing $E(\pi_r)$ when $\frac{\partial E(\pi_r^d)}{\partial q_r} = 0$ and $\frac{\partial E(\pi_r^d)}{\partial p_r} = 0$.

Proposition 2 is proved.

C. PROOF OF PROPOSITION 3

We document $\frac{dq_r^{d*}}{dw} = A_1$, $\frac{dp_r^{d*}}{dw} = B_1$, $\frac{dq_r^{d*}}{dq_m} = A_2$, $\frac{dp_r^{d*}}{dq_m} = B_2$, $\frac{dq_r^{d*}}{dp_d} = A_3$, $\frac{dp_r^{d*}}{dp_d} = B_3$. From Equation (22) and Equation (23), the optimal decision q_r^{d*}, p_r^{d*} is obtained by taking the derivative of w, q_m, p_d respectively, we obtain:

$$(1+\lambda)[B_1 - 1 - (\mu + \frac{1-\mu}{\eta})F(x_r) - (\mu + \frac{1-\mu}{\eta_r})(p_r - V_r)\frac{A_1+B_1}{\theta}f(x_r)] + \lambda\gamma[(p_d - V_m)\frac{\beta_d B_1 + A_1}{q_m}\int_0^{+\infty} g(\frac{D_d+q_r}{q_m})f(x)dx - 1] = 0$$

$$-(1+\lambda)(\mu + \frac{1-\mu}{\eta})(p_r - V_r)\frac{A_1+B_1}{\theta}f(x_r) + (1+\lambda)[A_1 - (\mu + \frac{1-\mu}{\eta})(A_1+2B_1)F(x_r)] + \lambda\gamma\beta_d(p_d - V_m)\frac{\beta_d B_1 + A_1}{q_m} \times \int_0^{+\infty} g(\frac{D_d+q_r}{q_m})f(x)dx = 0$$

$$(1+\lambda)[B_2 - (\mu + \frac{1-\mu}{\eta})(F(x_r)B_2 + (p_r - V_r)\frac{A_2+B_2}{\theta}f(x_r))] + \lambda\gamma(p_d - V_m)\int_0^{+\infty} \frac{(\beta_d B_2 + A_2)q_m - (D_d+q_r)}{q_m^2} \times g(\frac{D_d+q_r}{q_m})f(x)dx = 0$$

$$-(1+\lambda)(\mu + \frac{1-\mu}{\eta})[F(x_r)(A_2+2B_2)(p_r - V_r)\frac{A_2+B_2}{\theta}f(x_r)] + \lambda\gamma\beta_d(p_d - V_m)\int_0^{+\infty} \frac{(\beta_d B_2 + A_2)q_m - (D_d+q_r)}{q_m^2} \times g(\frac{D_d+q_r}{q_m})f(x)dx + (1+\lambda)A_2 = 0$$

$$-(1+\lambda)(\mu + \frac{1-\mu}{\eta})[F(x_r)B_3 + (p_r - V_r)\frac{A_3+B_3-\beta_r}{\theta}f(x_r)] + \lambda\gamma(p_d - V_m)\frac{\beta_d B_3 + A_3 - 1}{q_m}\int_0^{+\infty} g(\frac{D_d+q_r}{q_m})f(x)dx + \lambda\gamma\int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m^{d*}}} g(y)f(x)dydx + (1+\lambda)B_3 = 0$$

$$-(1+\lambda)(\mu + \frac{1-\mu}{\eta})F(x_r)(A_3 + 2B_3 - \beta_r) - (1+\lambda)(\mu + \frac{1-\mu}{\eta})(p_r - V_r)\frac{A_3+B_3-\beta_r}{\theta}f(x_r) + \lambda\gamma\beta_d(p_d - V_m)\frac{\beta_d B_3 + A_3 - 1}{q_m}\int_0^{+\infty} g(\frac{D_d+q_r}{q_m})f(x)dx - \lambda\gamma\beta_d\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m^{d*}}}^{b} g(y)f(x)dydx + (1+\lambda)A_3 = 0$$

From Equation (24), taking the first-order and second-order partial derivatives of $E(\pi_m)$ with respect to w, q_m and p_d, we obtain:

$$\frac{\partial E(\pi_m)}{\partial w} = (p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} (A_1 + \beta_d B_1)g(y)f(x)dydx + (w - p_d)A_1 + q_r$$

$$\frac{\partial^2 E(\pi_m)}{\partial w^2} = -\frac{(p_d - V_m)}{q_m}\int_0^{+\infty} (A_1 + \beta_d B_1)^2 g(\frac{D_d+q_r}{q_m})f(x)dx + 2A_1$$

$$\frac{\partial E(\pi_m)}{\partial q_m} = p_d(\bar{y} - A_2) + wA_2 - c_m - (p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} (y - A_2 - \beta_d B_2)g(y)f(x)dydx$$

$$\frac{\partial^2 E(\pi_m)}{\partial q_m^2} = \frac{p_d - V_m}{q_m}\int_0^{+\infty} (\frac{D_d+q_r}{q_m} - A_2 - \beta_d B_2)^2 g(\frac{D_d+q_r}{q_m})f(x)dx$$

$$\frac{\partial E(\pi_m)}{\partial p_d} = \int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} (yq_m - q_r)g(y)f(x)dydx + \int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} D_d g(y)f(x)dydx + (w - p_d)A_3 + (p_d - V_m)(A_3 - 1 + \beta_d B_3)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} g(y)f(x)dydx$$

$$\frac{\partial^2 E(\pi_m)}{\partial p_d^2} = 2\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} (A_3 - 1 + \beta_d B_3)g(y)f(x)dydx - 3A_3 + (p_d - V_m)\int_0^{+\infty} (A_3 - 1 + \beta_d B_3)^2 g(\frac{D_d+q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_m)}{\partial q_m p_d} = \int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} (y - A_2 - \beta_d B_2)g(y)f(x)dydx + \beta_d B_2 - \frac{(p_d - V_m)(1 - A_3 - \beta_d B_3)}{q_m} \times \int_0^{+\infty} (\frac{D_d+q_r}{q_m} - A_2 - \beta_d B_2)g(\frac{D_d+q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_m)}{\partial w q_m} = +A_2 + \frac{(p_d - V_m)(A_1 + \beta_d B_1)}{q_m} \times \int_0^{+\infty} (\frac{D_d+q_r}{q_m} - A_2 - \beta_d B_2)g(\frac{D_d+q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_m)}{\partial w p_d}$$

$$= \beta_d B_1 - \int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} (A_1 + \beta_d B_1)g(y)f(x)dydx + A_3 + \frac{(p_d - V_m)}{q_m}\int_0^{+\infty} (A_1 + \beta_d B_1)(1 - A_3 - \beta_d B_3) \times g(\frac{D_d + q_r}{q_m})f(x)dx$$

Thus, we have the Hessian matrix:
$H(w, q_m, p_d) = \begin{vmatrix} \frac{\partial^2 E(\pi_m)}{\partial w^2} & \frac{\partial^2 E(\pi_m)}{\partial w \partial q_m} & \frac{\partial^2 E(\pi_m)}{\partial w \partial p_d} \\ \frac{\partial^2 E(\pi_m)}{\partial q_m \partial w} & \frac{\partial^2 E(\pi_m)}{\partial q_m^2} & \frac{\partial^2 E(\pi_m)}{\partial q_m \partial p_d} \\ \frac{\partial^2 E(\pi_m)}{\partial p_d \partial w} & \frac{\partial^2 E(\pi_m)}{\partial p_d \partial q_m} & \frac{\partial^2 E(\pi_m)}{\partial p_d^2} \end{vmatrix} < 0$, and $|H_1(w, q_m, p_d)| < 0$, $|H_2(w, q_m, p_d)| > 0$, $|H_3(w, q_m, p_d)| < 0$. The even-order sequential major minor has a positive value and the odd-order major minor has a negative value. Hessian matrix is negative definite. Thus $E(\pi_m)$ is a concave function of q_r hand p_r. There exists a unique $(w^{d*}, q_m^{d*}, p_d^{d*})$ maximizing $E(\pi_m)$ when $\frac{\partial E(\pi_m)}{\partial w} = 0$, $\frac{\partial E(\pi_m)}{\partial p_d} = 0$ and $\frac{\partial E(\pi_m)}{\partial p_d} = 0$.

Proposition 3 is proved.

D. PROOF OF PROPOSITION 4

From Equation (31), taking the first-order and second-order partial derivatives of $E(\pi_r^b)$ with respect to q_r and p_r,, same as proposition 2.

Thus, we have the Hessian matrix:
$H = \begin{vmatrix} \frac{\partial^2 E(\pi_r^d)}{\partial p_r^2} & \frac{\partial^2 E(\pi_r^d)}{\partial p_r \partial q_r} \\ \frac{\partial^2 E(\pi_r^d)}{\partial q_r \partial p_r} & \frac{\partial^2 E(\pi_r^d)}{\partial q_r^2} \end{vmatrix} > 0$, and $\frac{\partial^2 E(\pi_r^d)}{\partial p_r^2} < 0$. The even-order sequential major minor has a positive value and the odd-order major minor has a negative value. Hessian matrix is negative definite. Thus $E(\pi_r^b)$ is a concave function of q_r land p_r. There exists a unique (p_r^{b*}, q_r^{b*}) maximizing $E(\pi_r^b)$ when $\frac{\partial E(\pi_r^b)}{\partial q_r} = 0$ and $\frac{\partial E(\pi_r^b)}{\partial p_r} = 0$. Proposition 4 is proved.

E. PROOF OF PROPOSITION 5

We document $\frac{dq_r^{b*}}{dw} = A_4$, $\frac{dp_r^{b*}}{dw} = B_4$, $\frac{dq_r^{b*}}{dq_m} = A_5$, $\frac{dp_r^{b*}}{dq_m} = B_5$, $\frac{dq_r^{b*}}{dp_d} = A_6$, $\frac{dp_r^{b*}}{dp_d} = B_6$. From Equation (32) and Equation (33), the optimal decision q_r^{b*}, p_r^{b*} is obtained by taking the derivative of w, q_m, p_d respectively, same as proposition 3. From Equation (34), taking the first-order and second-order partial derivatives of $E(\pi_m)$ with respect to w, q_m and p_d, we obtain:

$$\frac{\partial E(\pi_m)}{\partial w} = \varphi(p_d - V_m)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} (A_4 + \beta_d B_4)g(y)f(x)dydx + q_r + wA_4 - p_b(A_4 + B_4)F(x_r) - \varphi p_d A_4$$

$$\frac{\partial^2 E(\pi_m)}{\partial w^2} = -\frac{\varphi(p_d - V_m)}{q_m}\int_0^{+\infty} (A_4 + \beta_d B_4)^2 g(\frac{D_d + q_r}{q_m})f(x)dx + 2A_4 - \frac{p_b(A_4 + B_4)^2}{\theta}f(x_r)$$

$$\frac{\partial E(\pi_m)}{\partial q_m} = \varphi p_d[\beta_d B_5 + \int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} (y - A_5 - \beta_d B_5)g(y)f(x)dydx] + \varphi V_m \int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} (y - A_5 - \beta_d B_5)g(y)f(x)dydx + wA_5 - c_m - p_b(A_5 + B_5)F(x_r)$$

$$\frac{\partial^2 E(\pi_m)}{\partial q_m^2} = -\frac{p_b(A_4 + B_4)^2}{\theta}f(x_r) - \frac{p_d - V_m}{q_m}\int_0^{+\infty} (\frac{D_d + q_r}{q_m} - A_4 - \beta_d B_4)^2 \times g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial E(\pi_m)}{\partial p_d} = \varphi(p_d - V_m)(A_6 - 1 + \beta_d B_6)\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} g(y)f(x)dydx + wA_6 - p_b(A_6 + B_6 - \beta_r)F(x_r) - \varphi(F_1 + p_d A_6)$$

$$\frac{\partial^2 E(\pi_m)}{\partial p_d^2} = -2\varphi[\int_0^{+\infty}\int_{\frac{D_d+q_r}{q_m}}^{b} (1 - A_6 - \beta_d B_6)g(y)f(x)dydx + A_6] + \varphi(p_d - V_m)\int_0^{+\infty} (A_6 - 1 + \beta_d B_6)^2 g(\frac{D_d + q_r}{q_m})f(x)dx - A_6 - \frac{p_b(A_6 + B_6)^2}{\theta}f(x_r)$$

$$\frac{\partial^2 E(\pi_m)}{\partial q_m p_d} = \varphi[\int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} (y - A_5 - \beta_d B_5)g(y)f(x)dydx + \beta_d B_5] - \frac{\varphi(p_d - V_m)(1 - A_6 - \beta_d B_6)}{q_m} \times \int_0^{+\infty} (\frac{D_d + q_r}{q_m} - A_5 - \beta_d B_5)g(\frac{D_d + q_r}{q_m})f(x)dx - \frac{p_b(A_5 + B_5)(A_6 + B_6)}{\theta}f(x_r)$$

$$\frac{\partial^2 E(\pi_m)}{\partial w q_m} = -\frac{p_b(A_4 + B_4)(A_5 + B_5)}{\theta}f(x_r) + A_5 + \frac{\varphi(p_d - V_m)(A_4 + \beta_d B_4)}{q_m} \times \int_0^{+\infty} (\frac{D_d + q_r}{q_m} - A_5 - \beta_d B_5)g(\frac{D_d + q_r}{q_m})f(x)dx$$

$$\frac{\partial^2 E(\pi_m)}{\partial w p_d}$$
$$= \varphi[\beta_d B_4 - \int_0^{+\infty}\int_a^{\frac{D_d+q_r}{q_m}} (A_4+\beta_d B_4)g(y)f(x)dydx]$$
$$- \frac{p_b(A_4+B_4)(A_6+B_6)}{\theta} f(x_r) + A_6$$
$$+ \frac{\varphi(p_d-V_m)}{q_m}\int_0^{+\infty} g(\frac{D_d+q_r}{q_m})f(x)dx$$
$$\times (A_4+\beta_d B_4)(1-A_6-\beta_d B_6)$$

Thus, we have the Hessian matrix:

$$H(w,q_m,p_d) = \begin{vmatrix} \frac{\partial^2 E(\pi_m)}{\partial w^2} & \frac{\partial^2 E(\pi_m)}{\partial w \partial q_m} & \frac{\partial^2 E(\pi_m)}{\partial w \partial p_d} \\ \frac{\partial^2 E(\pi_m)}{\partial q_m \partial w} & \frac{\partial^2 E(\pi_m)}{\partial q_m^2} & \frac{\partial^2 E(\pi_m)}{\partial q_m \partial p_d} \\ \frac{\partial^2 E(\pi_m)}{\partial p_d \partial w} & \frac{\partial^2 E(\pi_m)}{\partial p_d \partial q_m} & \frac{\partial^2 E(\pi_m)}{\partial p_d^2} \end{vmatrix} < 0,$$

and $|H_1(w,q_m,p_d)| < 0$, $|H_2(w,q_m,p_d)| > 0$, $|H_3(w,q_m,p_d)| < 0$. The even-order sequential major minor has a positive value and the odd-order major minor has a negative value. Hessian matrix is negative definite. Thus $E(\pi_m)$ is a concave function of w, q_m and p_d. There exists a unique $(w^{b*}, q_m^{b*}, p_d^{b*})$ maximizing $E(\pi_m)$ when $\frac{\partial E(\pi_m)}{\partial w} = 0$, $\frac{\partial E(\pi_m)}{\partial p_d} = 0$ and $\frac{\partial E(\pi_m)}{\partial p_d} = 0$.

Proposition 5 is proved.

F. PROOF OF PROPOSITION 6

Under joint contract coordination, to realize dual-channel supply chain coordination, it should satisfy $p_r^{b*} = p_r^{c*}$, $q_r^{b*} = q_r^{c*}$, $q_m^{b*} = q_m^{c*}$ and $p_d^{b*} = p_d^{c*}$, From Equation (13), Equation (32) and Equation (33), we have:

$$\begin{cases} p_r^{c*} - c_r - (p_r^{c*} - V_r)F(x_r) \\ -(p_d^{c*} - V_m)\int_0^{+\infty}\int_a^{\frac{D_d+q_r^{c*}}{q_m^{c*}}} g(y)f(x)dydx - V_m = 0 \\ -[(1+\lambda)(1-\varphi) - \lambda\gamma\varphi][(p_d - V_m) \\ \quad \times \int_0^{+\infty}\int_a^{\frac{D_d+q_r^{b*}}{q_m}} g(y)f(x)dydx + V_m] \\ +(1+\lambda)[p_r^{b*} - w - c_r - (\mu + \frac{1-\mu}{\eta})(p_r^{b*} - V_r - p_b)F(x_r)] \\ -\lambda\gamma(w - p_bF(x_r)) = 0 \\ -(1+\lambda)(\mu + \frac{1-\mu}{\eta})[\theta\int_0^{x_r} F(x)dx + (p_r^{b*} - V_r - p_b)F(x_r)] \\ +[(1+\lambda)(1-\varphi) - \lambda\gamma\varphi](p_d^{b*} - V_m) \\ \quad \times \int_0^{+\infty}\int_a^{\frac{D_d+q_r^{b*}}{q_m}} g(y)f(x)dydx \\ +(1+\lambda)q_r^{b*} + \lambda\gamma p_bF(x_r) = 0 \end{cases}$$

we get Equation (38) and Equation (39). Proposition 6 is proved.

REFERENCES

[1] B. Fahimnia, M. Pournader, E. Siemsen, E. Bendoly, and C. Wang, "Behavioral operations and supply chain management—A review and literature mapping," *Decis. Sci.*, vol. 50, no. 6, pp. 1127–1183, Dec. 2019.

[2] T. H. Cui, J. S. Raju, and Z. J. Zhang, "Fairness and channel coordination," *Manage. Sci.*, vol. 53, no. 8, pp. 1303–1314, Aug. 2007.

[3] B. A. Pasternack, "Optimal pricing and return policies for perishable commodities," *Marketing Sci.*, vol. 4, no. 2, pp. 166–176, May 1985.

[4] R. Yoshihara and N. Matsubayashi, "Channel coordination between manufacturers and competing retailers with fairness concerns," *Eur. J. Oper. Res.*, vol. 290, no. 2, pp. 546–555, Apr. 2021.

[5] Z.-P. Li, J.-J. Wang, S. Perera, and J. Shi, "Coordination of a supply chain with Nash bargaining fairness concerns," *Transp. Res. E, Logistics Transp. Rev.*, vol. 159, Mar. 2022, Art. no. 102627.

[6] Y. Wang, R. Fan, L. Shen, and M. Jin, "Decisions and coordination of green e-commerce supply chain considering green manufacturer's fairness concerns," *Int. J. Prod. Res.*, vol. 58, no. 24, pp. 7471–7489, Dec. 2020.

[7] X. Zhao, D. Si, W. Zhu, J. Xie, and Z. Shen, "Behaviors and performance improvement in a vendor-managed inventory program: An experimental study," *Prod. Oper. Manage.*, vol. 10, pp. 1818–1836, Mar. 2019.

[8] A. Adhikari and A. Bisi, "Collaboration, bargaining, and fairness concern for a green apparel supply chain: An emerging economy perspective," *Transp. Res. E, Logistics Transp. Rev.*, vol. 135, Mar. 2020, Art. no. 101863.

[9] X. Yu, S. Wang, and X. Zhang, "Ordering decision and coordination of a dual-channel supply chain with fairness concerns under an online-to-offline model," *Asia–Pacific J. Oper. Res.*, vol. 36, no. 2, Apr. 2019, Art. no. 1940004.

[10] N. Zhang and B. Li, "Pricing and coordination of green closed-loop supply chain with fairness concerns," *IEEE Access*, vol. 8, pp. 224178–224189, 2020.

[11] Y. Zhong and H. Sun, "Game theoretic analysis of prices and low-carbon strategy considering dual-fairness concerns and different competitive behaviours," *Comput. Ind. Eng.*, vol. 169, Jul. 2022, Art. no. 108195.

[12] Y. Li, X. Zhao, J. Xie, and W. Zhu, "Inequality aversion in cooperative advertising in supply chain: An experimental study," *Int. J. Prod. Res.*, vol. 60, no. 23, pp. 7113–7135, Dec. 2022.

[13] Q. Wang, K. Chen, S. Wang, and X. Cao, "Optimal decisions in a closed-loop supply chain: Fairness concerns, corporate social responsibility and information value," *Ann. Oper. Res.*, vol. 309, no. 1, pp. 277–304, Feb. 2022.

[14] X. Du and W. Zhao, "Managing a dual-channel supply chain with fairness and channel preference," *Math. Problems Eng.*, vol. 2021, pp. 1–10, Jan. 2021.

[15] X.-X. Zheng, Z. Liu, K. W. Li, J. Huang, and J. Chen, "Cooperative game approaches to coordinating a three-echelon closed-loop supply chain with fairness concerns," *Int. J. Prod. Econ.*, vol. 212, pp. 92–110, Jun. 2019.

[16] Q. Qi, R.-Q. Zhang, and Q. Bai, "Joint decisions on emission reduction and order quantity by a risk-averse firm under cap-and-trade regulation," *Comput. Ind. Eng.*, vol. 162, Dec. 2021, Art. no. 107783.

[17] Z. Song, W. Tang, R. Zhao, and G. Zhang, "Inventory strategy of the risk averse supplier and overconfident manufacturer with uncertain demand," *Int. J. Prod. Econ.*, vol. 234, Apr. 2021, Art. no. 108066.

[18] P. Kumar Tarei, G. Kumar, and M. Ramkumar, "A mean-variance robust model to minimize operational risk and supply chain cost under aleatory uncertainty: A real-life case application in petroleum supply chain," *Comput. Ind. Eng.*, vol. 166, Apr. 2022, Art. no. 107949.

[19] H. Zhao, S. Song, Y. Zhang, J. N. D. Gupta, A. G. Devlin, and R. Chiong, "Supply chain coordination with a risk-averse retailer and a combined buy-back and revenue sharing contract," *Asia–Pacific J. Oper. Res.*, vol. 36, no. 5, Oct. 2019, Art. no. 1950028.

[20] Y. Song, T. Fan, Y. Tang, and F. Zou, "Quality information acquisition and ordering decisions with risk aversion," *Int. J. Prod. Res.*, vol. 59, no. 22, pp. 6864–6880, Nov. 2021.

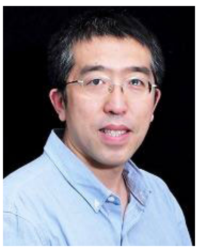
[21] K. Kang, S. Gao, T. Gao, and J. Zhang, "Pricing and financing strategies for a green supply chain with a risk-averse supplier," *IEEE Access*, vol. 9, pp. 9250–9261, 2021.

[22] B. Zhu, B. Wen, S. Ji, and R. Qiu, "Coordinating a dual-channel supply chain with conditional value-at-risk under uncertainties of yield and demand," *Comput. Ind. Eng.*, vol. 139, Jan. 2020, Art. no. 106181.

[23] Z. Li, J. Wang, and J. Liu, "Integrative strategies for omnichannel order fulfillment with risk aversion," *IEEE Trans. Eng. Manag.*, early access, Aug. 16, 2022, doi: 10.1109/TEM.2022.3189690.

[24] R. Wang, X. Zhou, and B. Li, "Pricing strategy of dual-channel supply chain with a risk-averse retailer considering consumers' channel preferences," *Ann. Oper. Res.*, vol. 309, no. 1, pp. 305–324, Feb. 2022.

[25] J. Tao, L. Shao, Z. Guan, W. Ho, and S. Talluri, "Incorporating risk aversion and fairness considerations into procurement and distribution decisions in a supply chain," *Int. J. Prod. Res.*, vol. 58, no. 7, pp. 1950–1967, Apr. 2020.
[26] X. Yan, S. Du, and L. Hu, "Supply chain performance for a risk inequity averse newsvendor," *Ann. Oper. Res.*, vol. 290, nos. 1–2, pp. 897–921, Jul. 2020.
[27] S. Bonzelet, "How increasing relative risk aversion affects retailer orders under coordinating contracts," *Int. J. Prod. Econ.*, vol. 251, Sep. 2022, Art. no. 108500.
[28] Y. Sun, Z. Wang, S. Yan, and X. Han, "Digital showroom strategies for dual-channel supply chains in the presence of consumer webrooming behavior," *Ann. Oper. Res.*, vol. 2022, pp. 1–40, Jan. 2022.
[29] L. Li and K. Liu, "Coordination contract design for the newsvendor model," *Eur. J. Oper. Res.*, vol. 283, no. 1, pp. 380–389, May 2020.
[30] Z. Liu, S. Hua, and X. Zhai, "Supply chain coordination with risk-averse retailer and option contract: Supplier-led vs. retailer-led," *Int. J. Prod. Econ.*, vol. 223, May 2020, Art. no. 107518.
[31] J. Heydari and J. Asl-Najafi, "A revised sales rebate contract with effort-dependent demand: A channel coordination approach," *Int. Trans. Oper. Res.*, vol. 28, no. 1, pp. 438–469, Jan. 2021.
[32] J. Gao, Z. Xiao, and H. Wei, "Competition and coordination in a dual-channel green supply chain with an eco-label policy," *Comput. Ind. Eng.*, vol. 153, Mar. 2021, Art. no. 107057.
[33] M. Nouri-Harzvili, S.-M. Hosseini-Motlagh, and P. Pazari, "Optimizing the competitive service and pricing decisions of dual retailing channels: A combined coordination model," *Comput. Ind. Eng.*, vol. 163, Jan. 2022, Art. no. 107789.
[34] C. Zhang, Y. Liu, and G. Han, "Two-stage pricing strategies of a dual-channel supply chain considering public green preference," *Comput. Ind. Eng.*, vol. 151, Jan. 2021, Art. no. 106988.
[35] E. Fehr and K. M. Schmidt, "A theory of fairness, competition, and cooperation," *Quart. J. Econ.*, vol. 114, no. 3, pp. 817–868, Aug. 1999.
[36] R. T. Rockafellar and S. Uryasev, "Optimization of conditional value-at-risk," *J. Risk*, vol. 2, no. 3, pp. 21–41, 2000.



BAO-LIN ZHU is currently an Associate Professor with the School of Business Administration, Northeastern University, China. His research interests include supply chain management and business intelligence.

JIA-YUE ZHANG received the master's degree from the School of Business Administration, Northeastern University, China. Her research interests include supply chain coordination and risk management.

SHOU-FENG JI is currently a Professor with the School of Business Administration, Northeastern University, China. His research interests include logistics system modeling and supply chain system optimization.

RUO-ZHEN QIU is currently a Professor with the School of Business Administration, Northeastern University, China. His research interests include supply chain management and robust optimization.