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Ordering policies and coordination in a two-echelon supply chain with Nash bargaining fairness concerns

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This paper investigates the ordering policies of two competitive retailers, and the coordination status of a two-echelon supply chain by considering the fairness concerns of channel members. We consider that two retailers compete with each other over price, where overstock and shortage are allowed. We assume that the demand is stochastic and considered with additive form. First, based on the Nash bargaining fairness reference point, we obtain the optimal decisions of the fairness-concerned channel members in both the centralized and the decentralized cases using a two-stage game theory. Secondly, we analyze the coordination status of the supply chain with Nash bargaining fairness concerns using ideas of optimization. Finally, numerical experiments are used to illustrate the influence of some parameters, the fairness-concerned behavioral preference of the channel members on the optimal decisions and the coordination status of supply chain. Some managerial insights are obtained.

Keywords: supply chain; Nash bargaining; fairness concern; sale price; coordination

1. Introduction

At present, with the rapid progress of scientific technology, the fast development of the global economy and transition of the production mode, the competition among channel members has emerged to replace the one among enterprises. The manufacturer often sells the product to multiple competitive retailers. In particular, business competition among the individual retailers in a two-echelon supply chain is more and more fierce. At the same time, many researchers have paid close attention to fairness in the past few decades. When the individuals are concerned with fairness, they care about their own profits as well as the gap between their own profits and the profits of the fairness reference. For example, Kahneman, Knetsch, and Thaler (1986) pointed that ‘individuals pursue fairness and would like use their own profits to exchange fairness in the channel relationships, and customers and staff were both fairness-concerned for price and salary respectively in the market transaction process’. Kumar, Scheer, and Steenkamp (1995) pointed that fairness had strong effects on the quality of supply chain relationships. Scheer, Kumar, and Steenkamp

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(2003) showed that manufacturer and retailers sacrificed their own profits for the benefit of counterparts because of fairness concerns. Corsten and Kumar (2005) found that fairness had played a positive impact on developing and maintaining channel coordination relationships in marketing and economics. Therefore, the issue of the channel members’ concern with fairness has been an interesting and positive research topic in recent years.

Nowadays, many scholars have focused on the influence of fairness concerns on channel management. For example, Cui, Raju, and Zhang (2007) studied the effects of fairness-concerned behavioral preference on the coordination of the supply chain with a manufacturer and a retailer. Qin and Li (2014) studied a channel coordination model by considering the fairness concerns of both retailer and supplier, at the same time. They supposed that a Nash bargaining game solution was a fairness-concerned reference point in the supply chain with a manufacturer and a retailer. Fei, Feng, Fry, and Raturi (2016) performed human–computer (H-C) and human–human (H-H) experiments, and found that the bounded rationality reduced the profit of the whole supply chain without changing its distribution between the supplier and the retailer, while fairness concerns led to the greater profit of the supply chain and a more balanced supply-chain profit distribution. In addition, some researchers have paid close attention to competition among the retailers. When two retailers competed for price, and the production cost was disrupted, Xiao and Qi (2008) studied the coordination of supply chain with a single manufacturer and two competitive retailers. On account of deterministic market demand and the duopolistic retailers with different competitive behaviors, Yang and Zhou (2006) studied the influence of different competitive behaviors on the optimal pricing and the optimal quantity decisions of a two-echelon supply chain with a manufacturer who supplied a single production to two competitive retailers. This paper considers the optimal decisions of the channel members and coordination analysis in a two-echelon supply chain with Nash bargaining fairness concerns.

This work introduces fairness concerns into a two-echelon supply chain consisting of a single manufacturer and two competitive retailers. Based on the above discussion, we try to solve the following questions. (1) How do two retailers make the ordering decisions as channel members are all concerned with fairness in a two-echelon supply chain consisting of a manufacturer and two competitive retailers? (2) How do we select a more reasonably fairness-concerned reference point? (3) How do we weigh the coordination degree of the supply chain? (4) How do the fairness-concerned behavioral preferences of the channel members, the salvage value, the shortage cost and the substitutability coefficient influence the optimal decisions and the coordination status of the supply chain? To answer these questions, this paper studies the pricing and ordering policies of channel members, the coordination status of the supply chain, respectively, by a two-stage game model and ideas of optimization. We assume that two retailers face different stochastic market demands and compete with each other over price. According to the derivative principle of the inverse function, we analyze the influence of the fairness-concerned behavioral preference and some parameters on the optimal decisions and the coordination status of the supply chain, and obtain some managerial insights.

The rest of the paper is organized as follows. In Section 2, the literature review is described. In Section 3, the model assumptions and notations are presented. In
Section 4, to discuss the fairness-concerned model, we first introduce the basic model, which is given as a benchmark for the latter. In Section 5, we discuss how to obtain a Nash bargaining reference point in a two-echelon supply chain consisting of a single manufacturer and two competitive retailers. In Section 6, we develop the policies model of channel members with a Nash bargaining fairness-concerned reference, and we get the optimal decisions in both the centralized and the decentralized cases. In addition, the coordination status of supply chain is discussed in some detail. In Section 7, numerical examples show the influence of some parameters such as the shortage cost, the salvage value, the substitutability coefficient, the fairness-concerned behavioral preference of the channel members on the optimal decisions and the coordination status of the supply chain. The results and conclusion are given in the final section.

2. Literature review

Many research literatures have considered the coordination model of a supply chain with a single manufacturer and two competitive retailers under fairness-neutrality, while the two retailers compete with each other over price. Mahmoodi and Eshghi (2014) considered an industry consisting of two distinct supply chains which competed with each other over price, and assumed that the demand was stochastic. There are three industry structures: (1) two supply chains are integrated; (2) one of the supply chain is integrated and the other one is decentralized; (3) two supply chains are decentralized. They discussed the effects of competition and demand’s uncertainty on the Nash equilibrium of the structures and channel profit in these three scenarios, respectively. Fang and Shou (2015) considered supply uncertainty with two supply chains’ Cournot competition, where each supply chain consisted of one retailer and one supplier which had random yield. They obtained the equilibrium decisions for ordering decisions and contract terms in centralized, hybrid and competition games, respectively. Giri and Sarker (2016) studied the coordination of a two-echelon supply chain with a single manufacturer who might face a production disruption, and two retailers compete with each other over price and service level. Zhang, Fu, Li, and Xu (2012) analyzed the influence of demand disruptions on the supply chain with a single manufacturer and two competitive retailers, and studied channel coordination with demand disruptions by revenue sharing contracts. Yao and Liu (2005) studied the pricing equilibria of the supply chain consisting of a manufacturer with an e-tail channel and a retail channel under two types of competitive pricing schemes. Adida and Demiguel (2011) studied competition in a supply chain with multiple manufacturers and retailers, where manufacturers competed in quantities to supply a set of products, and retailers competed in quantities to satisfy the uncertain consumer demand. Shang, Ha, and Tong (2016) examined the issue of information sharing in a supply chain consisting of two competitive manufacturers and one retailer, they showed that the retailer’s incentive to share information depended on production cost and competition intensity. However, all of the above researches have their limitations in reality as follows: they neither considered the shortage nor the overstock, and they did not study the optimal order policies of retailers in detail when the market demand was stochastic disruption.
Suppose that decision makers were fully rational in the traditional decision-making model, namely decision makers would always take profit-maximization as the basic decision principle (Su, 2008). However, current behavior research has found that people have a fairness-concerned behavioral preference in the real world (Elena and Diana, 2009). Loch and Wu (2008) found that fairness concerns were incompatible with conventional theory, which violated the assumption that the humans were fully rational, for many experiments and empirical science have demonstrated the existence of fairness-concerned behaviors. Because of information asymmetry with regard to fairness-concerned behavioral preference, Pavlov and Katok (2011) failed to coordinate a supply chain with a manufacturer and a retailer. Qin and Li (2014) studied the channel coordination model as the channel members were concerned with fairness, and they found that supply chain still could not achieve coordination based on a Nash bargaining game solution in the supply with a retailer and a manufacturer. Choi and Messinger (2016) considered a supply chain with two competitive manufacturers and one retailer. They performed an experimental study, and found that fairness played a significant role in competitive supply chain relationships. However, all of these researches did not consider the optimal decisions of a supply chain with a single manufacturer and multiple competitive retailers, where all channel members were concerned with fairness. They mostly studied the decisions problem of a supply chain consisting of a retailer and a manufacturer, and research was focused on the decision problem of constant demand.

Our study has several different aspects compared with previous research. First, when the channel members are all concerned with fairness – namely, they care about their own profits as well as the gap between their own profits and the profits of the fairness reference – we obtain the optimal decisions using two-stage game theory, and discuss the channel coordination status based on ideas of optimization under retailers facing stochastic market demand. Secondly, a Nash bargaining game solution is introduced as a fairness-concerned reference framework in the one-manufacturer-two-retailers supply chain. Thirdly, we consider the shortage, the overstock and the random fluctuations of demand. Finally, we obtain some propositions on supply chain and managerial insights.

3. Model assumptions and notations

This paper considers a two-echelon supply chain consisting of a single monopolistic manufacturer and two competitive retailers. The manufacturer produces only one type of product, and retailers compete with each other over the price of that product. The basic model which we consider is developed under the solidarity-based economy, in which the channel members pursue not only the maximization of profit, but they are also concerned with equity and social fairness.

The following notation is used throughout the paper:

- \( p_i \): the unit sale price of the \( i \)th retailer \((i = 1, 2)\);
- \( \omega \): the unit wholesale price;
- \( c \): the unit production cost;
- \( v \): the unit salvage value (i.e. it is the value of unit remaining product at the end of selling season);
\( s \): the unit shortage cost (i.e. it is the shortage unit product penalty cost for retailers, as retailers cannot meet the market demand in the sales cycle);
\( D_i \): the demand function of the \( i \)th retailer;
\( \varepsilon_i \): the random variable of the market demand of the \( i \)th retailer;
\( a_i \): the potential demand of the \( i \)th retailer (i.e. the maximum possible market demand);
\( \theta \): the substitutability coefficient (i.e. the competing parameter between two retailers, which indicates a measure of the sensitivity of the \( i \)th retailer’s sales to changes in the \( j \)th retailer’s price) \((j = 3 - i)\);
\( b'_i \): the coefficient for the effects of the \( i \)th retailer’s sale price;
\( \pi_{ri} \): the profit of the \( i \)th retailer;
\( \pi_m \): the profit of the manufacturer;
\( \pi \): the profit of the whole supply chain;
\( \mu_{ri} \): the utility of the \( i \)th retailer;
\( \mu_m \): the utility of the manufacturer;
\( \mu \): the utility of the whole supply chain;
\( q_{ri} \): the order quantity of the \( i \)th retailer;
\( \lambda_{ri}, \lambda_{mi} \): the fairness-concerned parameter of the \( i \)th retailer, the manufacturer \((\lambda_{ri} \geq 0, \lambda_{mi} \geq 0)\);
\( \rho_k \): the ratio of the \( k \)th channel members’ profit to the overall channel’s profit \((k = r1, r2, m)\);
\( \bar{\rho}_k \): the corresponding Nash bargaining fairness reference proportion.

Now, we adopt some assumptions in establishing our model.

**Assumption 1.** It is assumed that overstock and shortage are allowed in the two-echelon supply chain, without loss of generality, \( p_i \geq \omega \geq c \geq v \geq 0 \) is indefeasible.

**Assumption 2.** In the decentralized case, assume that the relation in the two-echelon supply chain focuses on the manufacturer-Stackelberg gaming structure: a monopolistic manufacturer acts as a leader and charges a wholesale price to both duopolistic retailers. Then two retailers as the followers determine their sale price and the corresponding order quantity, independently. The Cournot game (Rasmusen, 2006) is assumed between two competitive retailers, who decide the sale price and order quantity simultaneously.

**Assumption 3.** We assume that the demand faced by the \( i \)th retailer is a linear function of his sale price and his rival’s sale price, and subjected to random perturbation of the market simultaneously. According to Xiao and Qi (2008), the demand functions are defined as follows

\[
D_i = a_i - b'_i p_i + \theta (p_j - p_i) + \varepsilon_i \\
= a_i - b'_i p_i + \theta p_j + \varepsilon_i
\]  

(1)

In particular, the demand faced by the \( i \)th retailer increases as the \( i \)th retailer’s sale price is lower than that of his rival, and \( b_i = b'_i + \theta \); \( \varepsilon_i \) denotes an independent
random variable in the range of $[-A, A]$, whose the lower bound and the upper bound are $-A$ and $A$ respectively, $-A$ and $A$ are both constant, and the corresponding probability density function and cumulative distribution function are $f(x)$ and $F(x)$, respectively.

Before discussing the model, we need to illustrate fairness and utility. When the channel members are all concerned with fairness, they care about their own profits as well as the gap between their own profits and the profits of the fairness reference. Thus, they will pursue the maximization of utility $\mu_k$

$$\mu_k = \pi_k + \lambda_k (\pi_k - \overline{\pi_k}) = [\rho_k + \lambda_k (\rho_k - \overline{\rho_k})] \pi$$

(2)

where $\mu_k$ accounts for the channel member profit as well as his or her concern about fairness. Parameter $\lambda_k$ weighs up the fairness-concerned degree of channel members. When $\lambda_k$ is high, the channel members are more concerned with fairness. Note that if $\lambda_{ri}$ and $\lambda_m$ are equal to zero, the utility of channel members is equal to the profits of channel members.

4. The basic model

In this section, we consider the two-echelon supply chain system consisting of a monopolistic manufacturer and two competitive retailers. If the channel members are all fairness-neutral, the profit function of the $i$th retailer, the manufacturer and the whole supply chain are given, respectively, as follows:

$$\pi_{ri} = \begin{cases} p_i D_i - \omega q_i + v(q_i - D_i); & D_i \leq q_i \\ p_i q_i - \omega q_i - s(D_i - q_i); & D_i > q_i \end{cases}$$

(3)

$$\pi_m = (\omega - c)(q_1 + q_2)$$

(4)

$$\pi = \begin{cases} (p_1 - v)D_1 + (p_2 - v)D_2 + (v - c)(q_1 + q_2); & D_1 \leq q_1, \quad D_2 \leq q_2 \\ (p_1 - v)D_1 - sD_2 + vq_1 + sq_2 - c(q_1 + q_2); & D_1 \leq q_1, \quad D_2 > q_2 \\ -sD_2 + (p_2 - v)D_2 + vq_2 + sq_1 - c(q_1 + q_2); & D_1 > q_1, \quad D_2 \leq q_2 \\ -s(D_1 + D_2) + (s - c)(q_1 + q_2) + p_1 q_1 + p_2 q_2; & D_1 > q_1, \quad D_2 > q_2 \end{cases}$$

(5)

To simplify, we set

$$y_i = q_i - (a_i - b_i p_i + \theta p_j)$$

From equation (1), we have

$$D_i = q_i - y_i + \varepsilon_i$$

namely,

$$D_i \leq q_i \iff y_i \geq \varepsilon_i, \quad D_i > q_i \iff y_i < \varepsilon_i.$$
Then, the expected profit of the $i$th retailer is given by:

$$E[\pi_{ri}] = \int_{-A}^{y_i} [p_i(q_i - y_i + x) - \omega q_i + v(y_i - x)]f(x) \, dx$$

$$+ \int_{y_i}^{A} [p_i q_i - \omega q_i - s(-y_i + x)]f(x) \, dx$$

$$= \int_{-A}^{y_i} [p_i q_i - \omega q_i - (p_i - \omega)(y_i - x) + (v - \omega)(y_i - x)]f(x) \, dx$$

$$+ \int_{y_i}^{A} [p_i q_i - \omega q_i + (p_i - \omega)s(-y_i + x) + (\omega - p_i - s)(-y_i + x)]f(x) \, dx$$

$$= p_i q_i - \omega q_i - \int_{-A}^{A} (p_i - \omega)(y_i - x)f(x) \, dx + (v - \omega)$$

$$\times \int_{y_i}^{y_i} (y_i - x)f(x) \, dx + (\omega - p_i - s) \int_{y_i}^{A} (-y_i + x)f(x) \, dx$$

$$= \Psi_{ri}(p_i) - \Gamma_{ri}(p_i, y_i),$$

where

$$\Psi_{ri}(p_i) = (p_i - \omega)(a_i - b_i p_i + \theta p_j) > 0$$

$$\Gamma_{ri}(p_i, y_i) = [(\omega - v)\Theta_1(y_i) + (p_i - \omega - s)\Theta_2(y_i)] > 0$$

We acquire the expected profit of the manufacturer:

$$E[\pi_m] = (\omega - c) \sum_{i=1}^{2} ((a_i - b_i p_i + \theta p_{3-i}) - [\Theta_2(y_i) - \Theta_1(y_i)])$$

(7)

Thus, we get the expected profit of the whole supply chain as follows:

$$E[\pi] = E[\pi_m] + E[\pi_{r_1}] + E[\pi_{r_2}]$$

$$= \sum_{i=1}^{2} \{(p_i - c)(a_i - b_i p_i + \theta p_{3-i}) - [(c - v)\Theta_1(y_i) + (p_i - c - s)\Theta_2(y_i)]\}$$

$$= \sum_{i=1}^{2} [\Psi(p_i) - \Gamma(p_i, y_i)]$$

(8)

where

$$\Psi(p_i) = (p_i - c)(a_i - b_i p_i + \theta p_j) > 0$$

$$\Gamma(p_i, y_i) = [(c - v)\Theta_1(y_i) + (p_i - c - s)\Theta_2(y_i)] > 0$$

$$\Theta_1(y_i) = \int_{-A}^{y_i} (y_i - x)f(x) \, dx > 0$$

$$\Theta_2(y_i) = \int_{y_i}^{A} (-y_i + x)f(x) \, dx < 0$$
Taking the first-order derivation of $Q_1(y_i)$, $Q_2(y_i)$ with respect to $y_i$, we obtain

$$\frac{\partial Q_1(y_i)}{\partial y_i} = \int_{-A}^{y_i} f(x) \, dx = F(y_i)$$

$$\frac{\partial Q_2(y_i)}{\partial y_i} = -\int_{y_i}^{A} f(x) \, dx = F(y_i) - 1$$

There is no doubt that the expected profit of the $i$th retailer is equal to the difference between two profit terms, i.e. $\Psi_{ri}(p_i)$ and $\Gamma_{ri}(p_i, y_i)$. First, the expected profit $\Psi_{ri}(p_i)$ is derived from the expected demand of the $i$th retailer, which is independent of random fluctuations of the market demand. Secondly, the expected value $\Gamma_{ri}(p_i, y_i)$ represents the losses attributed to the expected leftovers and shortages, arising from under- and over-estimating demand (Arcelus, Kumar, and Srinivasan 2012). Similarly, so it is the case with the expected profit of the manufacturer or the whole supply chain.

5. Fairness-concerned model with Nash bargaining reference

In this section, when two competitive retailers and the manufacturer are all concerned with fairness, namely, the channel members care about their own profits as well as the gap between their own profits and the profits of the fairness reference. We consider a fairness-concerned reference point based on a Nash bargaining game solution. Then, we need to compute the Nash bargaining solution. For simplicity, we suppose that a linear form is used to formulate the utility of channel members in a two-echelon supply chain. By taking the expectation of equation (2) with respect to $\varepsilon_i$, we get the expected utility of channel members:

$$E[\mu_k] = E[\pi_k] + \lambda_k(E[\bar{\pi}_k] - E[\pi_k]) = [\rho_k + \lambda_k(\bar{\rho}_k - \rho_k)]E[\pi]$$  \hspace{1cm} (9)

Lemma 1. The fairness-concerned behavioral preference proportions for the manufacturer and two competitive retailers satisfy the following equations:

$$\bar{\rho}_k = \frac{1 + \lambda_k}{3 + \lambda_1 + \lambda_2 + \lambda_m}$$  \hspace{1cm} (10)

Proof. According to the definition of axiomatic Nash bargaining, the solution of Nash bargaining subjected to maximization of the Nash product $E[\mu_1]E[\mu_m]$ and $E[\mu_2]E[\mu_m]$ is as follows:

$$\max_{\rho_1, \rho_2, \rho_m} \{E[\mu_1]E[\mu_m], E[\mu_2]E[\mu_m]\}$$

s.t. \hspace{0.5cm} \begin{align*}
\rho_1 + \rho_2 + \rho_m &= 1 \\
\rho_1, \rho_2, \rho_m &\in [0, 1]
\end{align*}

Since the expected utility of the manufacturer is given,

$$E[\mu_m(\rho_1, \rho_2)] = [1 - (\rho_1 + \rho_2) + \lambda_m(\bar{\rho}_1 + \bar{\rho}_2 - \rho_1 - \rho_2)]E[\pi]$$  \hspace{1cm} (11)
then
\[
E[\mu_r]E[\mu_m(\rho_1, \rho_2)] = [\rho_1 + \lambda r_1(\rho_1 - \rho_1)][1 - (\rho_1 + \rho_2)] + \lambda m(\rho_1 + \rho_1 - \rho_1 - \rho_2)](E[\pi])^2 \tag{12}
\]
\[
E[\mu_r]E[\mu_m(\rho_1, \rho_2)] = [\rho_2 + \lambda r_2(\rho_2 - \rho_2)][1 - (\rho_1 + \rho_2)] + \lambda m(\rho_1 + \rho_1 - \rho_1 - \rho_2)](E[\pi])^2 \tag{13}
\]
We get the matrix of second derivatives of equations (12) and (13), also called the Hessian matrix, i.e.
\[
\begin{pmatrix}
\frac{\partial^2 E[\mu_r]}{\partial \rho_1^2} & \frac{\partial^2 E[\mu_r]}{\partial \rho_1 \partial \rho_2} \\
\frac{\partial^2 E[\mu_r]}{\partial \rho_1 \partial \rho_2} & \frac{\partial^2 E[\mu_r]}{\partial \rho_2^2}
\end{pmatrix}
= \begin{pmatrix}
-(1 + \lambda r_1)(1 + \lambda m) & -(1 + \lambda r_1) \\
-(1 + \lambda r_1) & -(1 + \lambda r_2)(1 + \lambda m)
\end{pmatrix} \tag{14}
\]
It is obvious that the Hessian matrix is strictly negative definite in equation (14). There exists a uniquely optimal \(\rho_1\) and \(\rho_2\) subjected to \(\frac{\partial E[\mu_r]}{\partial \rho_1} = 0\) and \(\frac{\partial E[\mu_r]}{\partial \rho_2} = 0\), namely,
\[
\begin{cases}
(1 + \frac{1 + \lambda m}{1 + \lambda r_1}) \rho_1 + \rho_2 = 1 \\
\rho_1 + \rho_2 = 1
\end{cases}
\]
Through some mathematics, we get a Nash bargaining solution as shown in equation (10).

6. The policies model of channel members with Nash bargaining fairness concerns
In this section, we derive the optimal decisions of two retailers based on Nash bargaining fairness concerns in the centralized and decentralized cases, respectively. Then, we compare the optimal decisions between the centralized channel and the decentralized channel to analyze how to obtain the channel approach coordination. At the same time, we perform an analysis and discuss the influence of parameters, decision variables and the fairness-concerned behavioral preference of the channel members on the optimal decisions, and obtain some managerial insights. In addition, we discuss the coordination status of the supply chain.

6.1. Centralized decision-making model
In the centralized decision-making model, the channel members are centrally controlled and the supply chain performs the best decisions. Maximizing the expected utility of the whole supply chain is the decision objective. Based on the Nash
bargaining reference point, the expected utility of the whole supply chain is given as follows:

\[
E[\mu] = \left(\lambda_m + \frac{3 - \lambda_1^2 - \lambda_2^2 - \lambda_m^2}{3 + \lambda_1 + \lambda_2 + \lambda_m}\right)E[\pi] + (\lambda_{r1} - \lambda_m)E[\pi_{r1}]
\]

\[
+ (\lambda_{r2} - \lambda_m)E[\pi_{r2}]
\]

(15)

Proposition 1. For a given \( y_i \), when channel members are all concerned with fairness, the expected utility of the whole supply chain \( E[\mu] \) is a jointly concave function with respect to \( p_i \), and there exists only one equilibrium point

\[
p_{st}^* = \frac{2b_j(\lambda + \lambda_j)((\lambda + \lambda_j)(\alpha_j - \Theta_2(y_i)) + \omega[b_j(\lambda_{r1} - \lambda_m) - \theta(\alpha_{r1} - \lambda_m)] - c(\lambda + \lambda_m)(\theta - b_j))}{4b_1b_2(\lambda + \lambda_1)(\lambda + \lambda_2) - [\theta(2\lambda + \lambda_1 + \lambda_2)]^2}
\]

\[
- \theta(2\lambda + \lambda_1 + \lambda_2)((\lambda + \lambda_j)(\alpha_j - \Theta_2(y_i)) + \omega[b_j(\lambda_{r1} - \lambda_m) - \theta(\alpha_{r1} - \lambda_m)] - c(\lambda + \lambda_m)(\theta - b_j))
\]

\[
4b_1b_2(\lambda + \lambda_1)(\lambda + \lambda_2) - [\theta(2\lambda + \lambda_1 + \lambda_2)]^2
\]

(16)

such that the expected utility of the whole supply chain is a maximum, where

\[
\lambda = 1 - (\lambda_{r1}\rho_{r1} + \lambda_{r2}\rho_{r2} + \lambda_m\rho_m)
\]

Proof. Taking the second-order partial derivative of \( E[\mu] \), the Hessian matrix of equation (15) is given as follows:

\[
\left(\begin{array}{cc}
\frac{\partial^2 E[\mu]}{\partial p_1^2} & \frac{\partial^2 E[\mu]}{\partial p_1 \partial p_2} \\
\frac{\partial^2 E[\mu]}{\partial p_1 \partial p_2} & \frac{\partial^2 E[\mu]}{\partial p_2^2}
\end{array}\right) = \left(\begin{array}{cc}
-2b_1(\lambda + \lambda_1) & \theta(2\lambda + \lambda_1 + \lambda_2) \\
\theta(2\lambda + \lambda_1 + \lambda_2) & -2b_2(\lambda + \lambda_2)
\end{array}\right)
\]

(17)

It is obvious that equation (17) is a negative definite matrix for \( b_i > 0 \). So \( E[\mu] \) is a jointly concave function with respect to \( p_1 \) and \( p_2 \). The first-order derivatives of \( E[\mu] \) regarding \( p_1 \) and \( p_2 \) are equal to zero, so that one unique optimal sale price \( p_{st}^* \) exists and satisfies equation (16).

Remark 1. For a given \( y_i \), when channel members are all fairness-neutral, i.e. \( \lambda_{ri} \) and \( \lambda_m \) are equal to zero, the optimal sale price of two retailers is equal to

\[
p_{st}^* = \frac{a_ib_j + \theta\alpha_j - b_j\Theta_2(y_i) - \theta\Theta_2(y_i) + c}{2b_1b_2 - 2\theta^2} + \frac{c}{2}
\]

(18)

Proposition 2. For a given \( p_i \), when channel members are all concerned with fairness, the expected utility of the whole supply chain \( E[\mu] \) is a jointly concave function with respect to \( q_i \), and the optimal order quantity \( q_{st}^* \) satisfies

\[
q_{st}^* = (a_i - b_ip_i + \theta p_j) + F^{-1}\left[\frac{(p_i - \omega + s) + \frac{\lambda + \lambda_m(\omega - c)}{\lambda + \lambda_{ri}}}{(p_i - v + s)}\right]
\]

(19)
Proof. See Appendix A.

Remark 2. For a given \( p_i \), when channel members are all fairness-neutral, i.e. \( \lambda_{ri} \) and \( \lambda_m \) are equal to zero, the optimal order quantity \( q_{ri}^* \) satisfies

\[
q_{ri}^* = (a_i - b_i p_i + \theta p_j) + F^{-1} \left[ \frac{(p_i - c + s)}{(p_i - v + s)} \right]
\]

(20)

Proposition 3. For a given \( p_i \), in the centralized case,

(a) the optimal order quantity \( q_{fr}^* \) increases when any one of the following holds:

(1) the unit production cost \( c \) decreases;
(2) the unit shortage cost \( s \) decreases;
(3) the unit salvage value \( v \) increases;
(4) the potential demand \( a_i \) increases;
(5) the coefficient for the effect of prices \( b_i' \) decreases;
(6) the unit wholesale price \( \omega(\lambda_m = \lambda_{ri}) \) increases;
(7) the unit wholesale price \( \omega(\lambda_m < \lambda_{ri}) \) decreases;
(8) the substitutability coefficient between two retailers \( \theta(p_j < p_i) \) decreases;
(9) the substitutability coefficient between two retailers \( \theta(p_j > p_i) \) increases;
(10) the fairness-concerned behavioral preference of the \( i \)th retailer \( \lambda_{ri} \) decreases;
(11) the fairness-concerned behavioral preference of the manufacturer \( \lambda_m \) increases;
(12) the fairness-concerned behavioral preference of the \( j \)th retailer \( \lambda_{rf}(\lambda_m > \lambda_{ri}) \) increases;
(13) the fairness-concerned behavioral preference of the \( j \)th retailer \( \lambda_{rf}(\lambda_m < \lambda_{ri}) \) decreases.

(b) the optimal order quantity \( q_{fr}^* \) is independent of the following parameters:

(1) the unit wholesale price \( \omega(\lambda_m = \lambda_{ri}) \);
(2) the fairness-concerned behavioral preference of the \( j \)th retailer \( \lambda_{rf}(\lambda_m = \lambda_{ri}) \);
(3) the substitutability coefficient between two retailers \( \theta(p_j = p_i) \).

Proof. See Appendix B.
Secondly, when the $i$th retailer cares less about fairness, it is more advantageous to raise the order quantity; it is optimal for the $i$th retailer to order more quantity as the manufacturer is far more concerned with fairness. When the manufacturer is far more concerned with fairness than the $i$th retailer, raising the order quantity is more advantageous for the $i$th retailer’s as his rival is more concerned with fairness; contrarily, when the manufacturer is less concerned with fairness than the $i$th retailer, his rival is less concerned with fairness, so it is optimal for the $i$th retailer to order more quantity. In particular, when the manufacturer is just as concerned with fairness as the $i$th retailer, the fairness-concerned behavioral preference of his rival does not influence the $i$th retailer. From the analytical results of Proposition 3, we discover some specifically managerial implications. When the channel members are all concerned with fairness, the optimal order quantity of the $i$th retailer should increase or decrease under the centralized case. We also find that some parameters do not impact on the optimal order quantity in some cases. Managers can plan and adjust their optimal order quantity as some parameters, decisions variables and the fairness-concerned behavioral preference of the channel members are changeable in the market.

### 6.2. Decentralized decision-making model

In the decentralized decision-making model, all of the channel members are rational and selfish. The channel members share their demand forecasts, and each channel member makes his or her own decisions to maximize his or her expected utility independently. We use a two-stage game to process this model. First, the monopolistic manufacturer acts as a Stackelberg leader and declares the wholesale price. Then, the two duopolistic retailers, as the followers, independently make decisions on the sale price and the corresponding order quantity under the Cournot game.

Based on the Nash bargaining reference point, the expected utility of the $i$th retailer is given as follows:

$$E[\mu_{ri}] = (1 + \lambda_{ri}) \left\{ E[\pi_{ri}] - \frac{\lambda_{ri}}{3 + \lambda_{r1} + \lambda_{r2} + \lambda_m} E[\pi] \right\}$$  \hspace{1cm} (21)

**Proposition 4.** For given $y_i$, $\omega$, when channel members are all concerned with fairness, the expected utility of the $i$th retailer $E[\mu_{ri}]$ is a jointly concave function with respect to $p_i$, and there exists only one equilibrium point

$$p^0_{ri} = \frac{\Theta(1 - 2\bar{\rho}_{ri})(1 - \bar{\rho}_{ij})(a_j - \Theta_2(y_j)) + c\bar{\rho}_{ij}(\theta - b_j) + \omega b_j}{4b_j b_i(1 - \bar{\rho}_{ri})(1 - \bar{\rho}_{ij}) - \theta^2(1 - 2\bar{\rho}_{ri})(1 - 2\bar{\rho}_{ij})}$$  \hspace{1cm} (22)

such that the expected utility of the two retailers is maximum.

**Proof.** See Appendix C.
Remark 3. For given $y_i$, $\omega$, when channel members are all fairness-neutral, i.e. $\lambda_{ri}$ and $\lambda_m$ are equal to zero, the optimal sale price of two retailers is equal to

$$p_{ri}^0 = \frac{\theta[a_j + \omega b_j - \Theta_2(y_j)] + 2b_j[a_i + \omega b_i - \Theta_2(y_i)]}{4b_jb_j - \theta^2}$$  \hspace{1cm} (23)

Proposition 5. For given $p_i$, $\omega$, when channel members are all concerned with fairness, the expected utility of the $i$th retailer $E[\mu_{ri}]$ is a jointly concave function with respect to $q_i$, and the optimal order quantity $q_{fri}^0$ satisfies

$$q_{fri}^0 = (a_i - b_ip_i + \theta p_j) + F^{-1}\left[ \frac{(p_i - \omega + s) - \frac{\lambda_{ri}}{3 + \lambda_m + \lambda_{ij}}(\omega - c)}{(p_i - v + s)} \right]$$  \hspace{1cm} (24)

Proof. See Appendix D.

Remark 4. For given $p_i$, $\omega$, when channel members are all fairness-neutral, i.e. $\lambda_{ri}$ and $\lambda_m$ are equal to zero, the optimal order quantity $q_{ri}^0$ satisfies

$$q_{ri}^0 = (a_i - b_ip_i + \theta p_j) + F^{-1}\left[ \frac{(p_i - \omega + s)}{(p_i - v + s)} \right]$$  \hspace{1cm} (25)

For a given $p_i$, substituting $q_{fri}^0$ into equation (21), we derive an expression for $E[\pi_m]$ in terms of $\omega$:

$$E[\pi_m] = (1 + \lambda_m)(\omega - c) \sum_{i=1}^{2} \{ (a_i - b_ip_i + \theta p_{3-i}) + y_{i}^0 \}
- \frac{\lambda_m(1 + \lambda_m)}{3 + \lambda_m + \lambda_{r1} + \lambda_{r2}} \sum_{i=1}^{2} \{ (p_i - c)(a_i - b_ip_i + \theta p_{3-i})
+ [(v - c)\Theta_1(y_{i}^0) + (c - p_i - s)]\Theta_2(y_{i}^0) \}$$  \hspace{1cm} (26)

where

$$y_{j}^0 = F^{-1}\left[ \frac{(p_i - \omega + s) - \frac{\lambda_{ji}}{3 + \lambda_m + \lambda_{r(3-i)}}(\omega - c)}{(p_i - v + s)} \right]$$

Proposition 6. For a given $p_i$, when channel members are all concerned with fairness, the expected utility of the manufacturer $E[\mu_m]$ is a concave function with
respect to $\omega$, and the optimal wholesale price $\omega^0$ satisfies

$$
\omega^0 = \frac{2A + \sum_{i=1}^{2} (B - A) \left[ p_i + \frac{2c\lambda_{ri}}{3 + \lambda_m + \lambda_{ij}} + \frac{a_i - b_ip_i + \theta p_{3-i}}{B - A} \right] - \frac{\lambda_{ij}}{3 + \lambda_m + \lambda_{ij}} \cdot \frac{2p_i + (1 - \frac{\lambda_{ij}}{3 + \lambda_m + \lambda_{ij}})c + 2s}{p_i - v + s}}{\sum_{i=1}^{2} (B - A)(2 - \frac{\lambda_m}{3 + \lambda_m + \lambda_{ij}})(\frac{1 + \frac{\lambda_{ri}}{3 + \lambda_m + \lambda_{ij}}}{p_i - v + s})}
$$

(27)

**Proof.** We take second-order partial derivative of $E[\mu_m]$ from equation (26) with respect to $\omega$, and we get

$$
\frac{\partial^2 E[\mu_m]}{\partial \omega^2} = \left( -2 + \frac{\lambda_m}{3 + \lambda_m + \lambda_{ij}} \right) \sum_{i=1}^{2} (B - A) \left( 1 + \frac{\lambda_{ri}}{3 + \lambda_m + \lambda_{ij}} \right) \frac{1 + \frac{\lambda_{ij}}{3 + \lambda_m + \lambda_{ij}}}{p_i - v + s} < 0
$$

Let

$$
\frac{\partial E[\mu_m]}{\partial \omega} = 0
$$

then equation (27) is given as above.

**Proposition 7.** For a given $p_i$, in the decentralized decision-making case,

(a) the optimal order quantity $q_{0 fri}$ increases when any one of the following holds:
   (1) the unit production cost $c$ increases;
   (2) the unit shortage cost $s$ decreases;
   (3) the unit salvage value $v$ increases;
   (4) the potential demand $a_i$ increases;
   (5) the coefficient for the effect of prices $b_i'$ decreases;
   (6) the unit wholesale price $\omega$ decreases;
   (7) the substitutability coefficient between two retailers $\theta(p_j < p_i)$ decreases;
   (8) the substitutability coefficient between two retailers $\theta(p_j > p_i)$ increases;
   (9) the fairness-concerned behavioral preference of the $i$th retailer $\lambda_{ri}$ decreases;
   (10) the fairness-concerned behavioral preference of the manufacturer $\lambda_m$ increases;
   (11) the fairness-concerned behavioral preference of the $j$th retailer $\lambda_{rj}$ increases;

(b) the optimal order quantity $q_{0 fri}$ is independent of the substitutability coefficient between two retailers $\theta(p_j = p_i)$.

**Proof.** See Appendix E.

Note that the results of Propoition 7 (in the decentralized decision-making case) are very similar to Proposition 3 (in the centralized decision-making case). The differences
are the influence of the cost, the wholesale price, and the fairness-concerned behavioral preference of channel members on the optimal order quantity. The optimal order quantity decreases with the cost in the centralized decision-making case, whereas it increases with the cost in the decentralized decision-making case. This indicates that it is optimal for the \( i \)th retailer to order more quantity with lower cost in order to maximize expected profit. The order quantity of the \( i \)th retailer is the greater as the wholesale price decreases. The manufacturer and his or her rival are far more concerned with fairness, which is optimal for the \( i \)th retailer to order more quantity.

**Proposition 8.** For a given \( p_i \), when channel members are all concerned with fairness, the size relationship of the optimal order quantity between the decentralized channel and the centralized channel is given, as follows:

1. for \( \lambda_m > \lambda_{ri} \), \( q_{fr}^0 < q_{fr}^* < q_{fr}^* < q_{fri}^* \);
2. for \( \lambda_m = \lambda_{ri} \), \( q_{fr}^0 < q_{fr}^* = q_{fr}^* < q_{fri}^* \);
3. for \( \lambda_m < \lambda_{ri} \), \( q_{fr}^0 < q_{fr}^* < q_{fr}^* < q_{fri}^* \).

**Proof.** See Appendix F.

Proposition 8 suggests several important results under fairness concerns. First, when the manufacturer is more concerned with fairness than the \( i \)th retailer, the gap of the optimal order quantity of the \( i \)th retailer between the centralized channel and the decentralized channel is higher, which means that achieving the coordination of the supply chain is more difficult in this situation. Secondly, when the manufacturer is just as concerned with fairness as the \( i \)th retailer, fairness concerns do not have effects on the optimal order quantity in the centralized decision-making case; the order quantity is lower as the \( i \)th retailer is the more concerned with fairness in the decentralized decision-making case. Finally, when the manufacturer cares less about fairness than the \( i \)th retailer, the optimal order quantity of the channel members under fairness-neutrality is less than the order quantity under fairness concerns. If the manufacturer is not concerned with fairness, it will have the more overstock. For managerial implications, Proposition 8 shows the amount of remaining product connected with the fairness-concerned behavioral preference of the channel members.

**6.3. Coordination analysis of supply chain**

This subsection discusses the channel coordination when channel members are all concerned with fairness. Comparing the optimal order quantity of two retailers between the centralized channel and the decentralized channel, we find from Proposition 8 that the coordination of the supply chain cannot be achieved. However, it is necessary for us to make the channel approach coordination, such that the gap of the optimal order quantity between the centralized channel and the decentralized channel is minimized, i.e.

\[
\min\{q_{fri}^* - q_{fr}^0\}
\]

From Proposition 2 and Proposition 5, we get the equivalent objective function as
follows:

\[
\min \left\{ F^{-1} \left[ \frac{(p_i - \omega^0 + s) + \lambda + \lambda_m (\omega^0 - c)}{(p_i - v + s)} \right] \right. - \left. F^{-1} \left[ \frac{(p_i - \omega^0 + s) - \frac{\lambda_{ij}}{3 + \lambda_m + \lambda_{ij}} (\omega^0 - c)}{(p_i - v + s)} \right] \right\}
\]

where \( F^{-1}(x) \) is a increasing function with respect to \( x \) in \([0, 1]\), where \( \omega^0 \) satisfies equation (27).

Then, sensitivity analysis with respect to the influence of the fairness-concerned behavioral preference, parameters and decision variables on the coordination status of supply chain is performed. Some managerial implications regarding how to raise the coordination degree are presented.

7. Numerical analysis

In this section, numerical examples are given to illustrate the effects of the fairness-concerned behavioral preference of the channel members and some parameters on the optimal decisions and the coordination status of the two-echelon supply chain. Without loss of generality, we assume that the market demand follows a uniform distribution in \([-20, 20]\), and the related parameters are assumed to be as follows: \( a_i = 100, \ b'_i = \theta = 0.25, \ c = 50, i = 1, 2 \).

7.1. Effects of the fairness-concerned behavioral preference on the optimal order quantity

This subsection illustrates how the fairness-concerned behavioral preference of the channel members influences the optimal order quantity in both the centralized and the decentralized cases. Here, we set \( v = 30, \ s = 20, \ \lambda_m = 0.5 \), the values of \( \lambda_{ij}, \lambda_{ij} \) fall in the range of \([0, 1]\). Figures 1(a) and 2(a) show the optimal order quantity of the \( i \)th retailer with respect to \( \lambda_{ij}, \lambda_{ij} \) in the centralized and the decentralized cases, respectively. We see that the optimal order quantity of the \( i \)th retailer in both the

![Figure 1. Effects of \( \lambda_{ij}, \lambda_{ij}, \lambda_m \) on the optimal order quantity under the centralized channel.](image)
centralized and the decentralized cases increases as $\lambda_{ri}$ decreases and $\lambda_{rj}$ increases. When we set $\lambda_{ri} = \lambda_{rj} = 0.5$, the value of $\lambda_m$ falls in the range of $[0, 1]$. Figures 1(b) and 2(b) show the optimal order quantity of the $i$th retailer with respect to $\lambda_m$ in the centralized and the decentralized cases, respectively. Obviously, we find that as $\lambda_m$ increases, the optimal order quantity of the $i$th retailer increases in both the centralized case and the decentralized case. These findings imply that a less fairness-concerned behavioral preference of the $i$th retailer and a more fairness-concerned behavioral preference of the others’ members result in the lower order quantity for the $i$th retailer. Note that the optimal order quantity in the centralized case is always higher than that in the decentralized case. Moreover, we find that as $\lambda_{ri}$ decreases, $\lambda_{rj}$ and $\lambda_m$ increase, and the optimal order quantity in the centralized case increases more quickly than that in the decentralized case, which means that the coordination of the supply chain is more difficult to achieve.

### 7.2. Effects of the shortage cost and the salvage value on the optimal order quantity

Furthermore, we explore how the shortage cost and the salvage value influence the optimal order quantity of the $i$th retailer. We set $\lambda_{r1} = \lambda_{r2} = \lambda_m = 0.5$, and the value of $v$ varies from 20 to 30 and $s$ varies from 10 to 20. Figures 3(a) and 3(b) show the effects of $v, s$ on the optimal order quantity in the centralized case and the decentralized case, respectively. The optimal order quantity increases as $v$ increases and $s$ decreases in both the centralized and the decentralized case. Apparently, we find that the change of the optimal order quantity with respect to $v$ is more obviously than that with respect to $s$, which means that the effects of $v$ on the optimal order quantity are larger.

### 7.3. Effects of the fairness-concerned behavioral preference on the wholesale price and the gap of the optimal order quantity

The most interesting problem is whether the fairness-concerned behavioral preference of the channel members is profitable for the coordination of the supply chain. Then, we find how the fairness-concerned behavioral preference of the channel members
influences the wholesale price. Set $v = 30$, $s = 20$, $\lambda_m = 0.5$, and the values of $\lambda_{ri}$, $\lambda_{rj}$ fall in the range of $[0, 1]$. Figure 4(a) shows the effects of $\lambda_{ri}$, $\lambda_{rj}$ on the optimal wholesale price. We see that the change of the optimal wholesale price with respect to $\lambda_{ri}$, $\lambda_{rj}$ is not obvious. However, Figure 4(b) shows the optimal wholesale price decreases as $\lambda_m$ increases, which is obvious because the manufacturer is concerned with fairness, resulting in the lower wholesale price under the manufacturer-Stackelberg gaming structure. Therefore, the manufacturer is willing to invest more money as he or she is more concerned with fairness. Similarly, Figure 5 shows that the gap of the optimal order quantity of the $i$th retailer between the centralized channel and the decentralized channel increases as $\lambda_{ri}$ decreases, and $\lambda_{rj}$ and $\lambda_m$ increase, which means that achieving the coordination of the supply chain is easier when the $i$th retailer is more concerned with fairness. However, the supply chain is more difficult to be coordinated as the channel’s other members are more concerned with fairness. This is reasonable because the $i$th retailer feels that he should get less profit compared with them, leading to a larger gap of the optimal order quantity of the $i$th retailer.

Figure 3. Effects of $v,s$ on the optimal order quantity.

Figure 4. Effects of $\lambda_{ri}$, $\lambda_{rj}$, $\lambda_m$ on the wholesale price.
between the centralized channel and the decentralized channel, as the channel’s other members are more concerned with fairness.

7.4. Effects of the shortage cost and the salvage value on the wholesale price and the gap of the optimal order quantity

We then discuss how the shortage cost and the salvage value influence the wholesale price and the gap of the optimal order quantity of the $i$th retailer between the centralized channel and the decentralized channel. Similarly, we set $\lambda_{r1} = \lambda_{r2} = \lambda_m = 0.5$, the value of $v$ varies from 20 to 30 and $s$ varies from 10 to 20. Figure 6(a) and Figure 6(b) show the effects of $v, s$ on the wholesale price and the gap of the optimal order quantity. We see that the optimal wholesale price increases as $s$ increases, which is straightforward because the order quantity of the $i$th retailer increases as $s$ increases, leading to the higher wholesale price. When $v$ increases, the manufacturer will be willing to decrease the wholesale price in order to stimulate the order quantity of the $i$th retailer. Figure 6(b) shows that the gap of the optimal order quantity

Figure 6. Effects of $v, s$ on $\omega^0$ and $q_{fri}^* - q_{fri}^0$. 
increases as \( s \) and \( v \) increases, which means the increase of \( s \) and \( v \) is not beneficial to the coordination of the supply chain. It is advantageous for a win-win of the supply chain that the shortage cost and the salvage value decrease.

### 7.5. Effects of the substitutability coefficient on the optimal order quantity and the gap of the optimal order quantity

In addition, we explore how the substitutability coefficient impacts on the optimal order quantity of the \( i \)th retailer and the gap of the optimal order quantity of the \( i \)th retailer between the centralized channel and the decentralized channel. Set \( \lambda_1 = \lambda_2 = \lambda_m = 0.5, \ v = 30, \ s = 20, \ p_1 = 200, \ p_2 = 220, \) the value of \( \theta \) falls in the range of \([0, 0.5]\). Figures 7(a) and Figure 7(b) show the effects of \( \theta \) on the optimal quantity and the gap of the optimal order quantity, respectively. In the centralized case, the optimal order quantity increases as \( \theta \) increases; the optimal order quantity decreases as \( \theta \) increases in the decentralized case. This indicates that more competition between two retailers is more beneficial to the whole supply chain, but more disadvantageous for the channel members. We see that the gap of the optimal order quantity increases as \( \theta \) increases, which means that the competition between two retailers is also disadvantageous for the coordination of the supply chain.

### 8. Concluding remarks

The paper introduces fairness concerns into the two-echelon supply chain consisting of a monopolistic manufacturer and two competitive retailers, and discusses the ordering policies of the two retailers in both the centralized and the decentralized cases using the two-stage game theory. Furthermore, we set the fairness-concerned reference point based on the Nash bargaining game ideas and consider the shortage and overstock. By comparing the optimal order quantity between the centralized and the decentralized channels, we find that the coordination of the supply chain cannot be achieved under fairness concerns. In addition, we analyze the effects of the fairness-concerned behavioral preference of the channel members, some parameters on the
optimal order quantity of the two retailers, the gap of the optimal order quantity between the centralized channel and the decentralized channel and the optimal whole-
sale price. Through the above discussion, we find some interesting results. First, it is more advantageous for the coordination of the supply chain that the shortage cost and the salvage value decrease. Secondly, when the retailers are more concerned with fairness and the channel's other members care less about fairness, the coordination of the supply chain will be easier to achieve. Finally, the competition between two retailers is advantageous for the whole supply chain, but disadvantageous for the channel members and the coordination of the supply chain. However, there are still some limitations as follows: it does not consider imperfect information sharing within the supply chain, we can further study how imperfect information sharing impacts on ordering policies and the coordination of the supply chain with Nash bargaining fairness concerns.

Disclosure statement
No potential conflict of interest was reported by the authors.

References
Appendix A. Proof of Proposition 2

We take first-order partial derivative of $E[\mu]$ from equation (15) with respect to $q_i$, and we get

$$\frac{\partial E[\mu]}{\partial q_i} = (\lambda_m + \lambda)(v - c)F(y_i) + (c - p_i - s)(F(y_i) - 1)]$$

$$+ (\lambda_m - \lambda)((v - \omega)F(y_i) + (\omega - p_i - s)(F(y_i) - 1)]$$

We take second-order partial derivative of $E[\mu]$ from equation (15) with respect to $q_i$, and we get

$$\frac{\partial^2 E[\mu]}{\partial q_i^2} = (\lambda_m + \lambda)(v - p_i - s)f(y_i) < 0, \quad \frac{\partial^2 E[\mu]}{\partial q_1 \partial q_2} = 0.$$

So that the expected utility of the whole supply chain $E[\mu]$ is a jointly concave function with respect to $q_i$. From the first-order conditions, we have

$$\frac{\partial E[\mu]}{\partial q_i} = -(\lambda_m + \lambda)(\omega - p_i - s) + (\lambda_m + \lambda)(v - p_i - s)F(y_i) + (\lambda_m + \lambda)(\omega - c) = 0$$

we obtain the optimal order quantity $q^*_i$ subject to

$$F(q^*_i - a_i + b_ip_i - \theta p_i) = \frac{(\lambda + \lambda_m)(p_i - \omega + s) + (\lambda + \lambda_m)(\omega - c)}{(\lambda + \lambda_m)(p_i - v + s)}$$

where $y_i = q_i - (a_i - b_ip_i + \theta p_i)$.
Appendix B. Proof of Proposition 3

When \(\lambda_{ri}, \lambda_{m}\) are equal to 0. For a given \(p_{i}\), the optimal order quantity \(q_{ri}^{*}\) is subject to

\[
q_{ri}^{*} = (a_{i} - b_{i}p_{i} + \theta p_{j}) + F^{-1}\left(\frac{(p_{i} - c + s)}{(p_{i} - v + s)}\right), \quad i = 1, 2 \text{ and } j = 3 - i
\]

Since \(F(x)\) is an increasing function with respect to \(x\) in \([A, B]\), then \(F^{-1}(x)\) is a increasing function. Thus

\[
\frac{\partial q_{ri}^{*}}{\partial c} = \left(-\frac{1}{(p_{i} - v + s)}\right)(F^{-1})'\left(\frac{(p_{i} - c + s)}{(p_{i} - v + s)}\right) < 0
\]

\[
\frac{\partial q_{ri}^{*}}{\partial s} = \left(c - v\right)\left(p_{i} - v + s\right)(F^{-1})'\left(\frac{(p_{i} - c + s)}{(p_{i} - v + s)}\right) < 0
\]

\[
\frac{\partial q_{ri}^{*}}{\partial v} = \frac{1}{(p_{i} - v + s)^{2}}(F^{-1})'\left(\frac{(p_{i} - c + s)}{(p_{i} - v + s)}\right) < 0,
\]

\[
\frac{\partial q_{ri}^{*}}{\partial a_{i}} = 1 < 0, \quad \frac{\partial q_{ri}^{*}}{\partial b_{j}'} = p_{j} - p_{i}
\]

When \(p_{j} > p_{i}\), we have \(\frac{\partial q_{ri}^{*}}{\partial b_{j}'} > 0\); when \(p_{j} = p_{i}\), we have \(\frac{\partial q_{ri}^{*}}{\partial b_{j}'} = 0\); when \(p_{j} < p_{i}\), we have \(\frac{\partial q_{ri}^{*}}{\partial b_{j}'} < 0\).

Since

\[
q_{ri}^{*} = (a_{i} - b_{i}p_{i} + \theta p_{j}) + F^{-1}\left(\frac{(p_{i} - \omega + s) + \frac{\lambda + \lambda_{m}(\omega - c)}{\lambda + \lambda_{ri}}}{(p_{i} - v + s)}\right), \quad i = 1, 2 \text{ and } j = 3 - i
\]

\[
\frac{\lambda + \lambda_{m}}{\lambda + \lambda_{ri}} = \frac{3(1 + \lambda_{m}) + \lambda_{r1}(\lambda_{m} - \lambda_{r1}) + \lambda_{r2}(\lambda_{m} - \lambda_{r2})}{3(1 + \lambda_{ri}) + \lambda_{rj}(\lambda_{r1} - \lambda_{rj}) + \lambda_{m}(\lambda_{ri} - \lambda_{m})}
\]

When \(\lambda_{m} \nearrow\), we find \(\frac{\lambda + \lambda_{m}}{\lambda + \lambda_{ri}} \nearrow\).

For \((\lambda_{m} > \lambda_{ri})\) \iff \(\frac{\lambda + \lambda_{m}}{\lambda + \lambda_{ri}} > 1\), then \(\lambda_{rj} \nearrow\), \(\frac{\lambda + \lambda_{m}}{\lambda + \lambda_{ri}} \nearrow\)

For \((\lambda_{m} = \lambda_{ri})\) \iff \(\frac{\lambda + \lambda_{m}}{\lambda + \lambda_{ri}} = 1\), then \(\lambda_{rj} \nearrow\), \(\frac{\lambda + \lambda_{m}}{\lambda + \lambda_{ri}} \nearrow\)

For \((\lambda_{m} < \lambda_{ri})\) \iff \(\frac{\lambda + \lambda_{m}}{\lambda + \lambda_{ri}} < 1\), then \(\lambda_{rj} \nearrow\), \(\frac{\lambda + \lambda_{m}}{\lambda + \lambda_{ri}} \nearrow\)
Appendix C. Proof of Proposition 4

We take second-order partial derivative of $E[\mu_{ri}]$ from equation (21) with respect to $p_i$, and we can obtain

$$
\begin{pmatrix}
\frac{\partial^2 E[\mu_{r1}]}{\partial p_i^2} & \frac{\partial^2 E[\mu_{r1}]}{\partial p_1 \partial p_2} \\
\frac{\partial^2 E[\mu_{r2}]}{\partial p_1 \partial p_2} & \frac{\partial^2 E[\mu_{r2}]}{\partial p_2^2}
\end{pmatrix} = 
\begin{pmatrix}
-2b_j(1 - \bar{\rho}_{ri}) & \theta(1 - 2\bar{\rho}_{ri}) \\
\theta(1 - 2\bar{\rho}_{ri}) & -2b_j(1 - \bar{\rho}_{rj})
\end{pmatrix}
$$

It is strictly negative definite, equation (22) can be acquired from the first-order conditions obviously.

Appendix D. Proof of Proposition 5

We take first-order partial derivative of $E[\mu_{ri}]$ from equation (21) with respect to $q_i$, and we get

$$
\frac{\partial E[\mu_{ri}]}{\partial q_i} = [(v - \omega)F(y_i) + (\omega - p_i - s)(F(y_i) - 1)]
- \frac{\lambda_m}{3 + \lambda_{ri} + \lambda_{rj} + \lambda_m} [(v - \omega)F(y_i) + (\omega - p_i - s)(F(y_i) - 1) + (\omega - c)]
$$

We take second-order partial derivative of $E[\mu_{ri}]$ from equation (21) with respect to $q_i$, and we get

$$
\frac{\partial^2 E[\mu_{ri}]}{\partial q_i^2} = (3 + \lambda_{rj} + \lambda_m)(v - p_i - s)f'(y_i) < 0,
\frac{\partial^2 E[\mu_{ri}]}{\partial q_1 \partial q_2} = 0
$$

So that the expected utility of the $i$th retailer $E[\mu_{ri}]$ is a jointly concave function with respect to $q_i$. From the first-order conditions, we get

$$
\frac{\partial E[\mu_{ri}]}{\partial q_i} = -(3 + \lambda_{rj} + \lambda_m)(\omega - p_i - s) + (3 + \lambda_{rj} + \lambda_m)(v - p_i - s)F(y_i) - \lambda_{ri}(\omega - c) = 0
$$

we obtain the optimal order quantity $q_{0ri}$ subject to

$$
F(q_{0ri} - a_i + b_ip_i - \theta p_j) = \frac{(3 + \lambda_{rj} + \lambda_m)(p_i - \omega + s) - \lambda_{ri}(\omega - c)}{(3 + \lambda_{rj} + \lambda_m)(p_i - v + s)}
$$

where $y_i = q_i - (a_i - b_ip_i + \theta p_j)$. 

Appendix E. Proof of Proposition 7

For a given $p_i$, the optimal order quantity $q_{fr_i}^0$ satisfies

$$q_{fr_i}^0 = (a_i - b_i p_i + \theta p_j) + F^{-1} \left[ \frac{(p_i - \omega + s) - \frac{\lambda_{ri}}{1 + \lambda_m + \lambda_{ij}} (\omega - c)}{(p_i - v + s)} \right], \quad j = 3 - i$$

Since $F(x)$ is a increasing function with respect to $x$ in $[A, B]$, then $F^{-1}(x)$ is a increasing function. Then,

$$\frac{\partial q_{fr_i}^0}{\partial c} = \left[ \frac{\lambda_{ri}}{1 + \lambda_m + \lambda_{ij}} \right] (F^{-1})' \left[ \frac{(p_i - \omega + s) - \frac{\lambda_{ri}}{1 + \lambda_m + \lambda_{ij}} (\omega - c)}{(p_i - v + s)} \right] > 0$$

$$\frac{\partial q_{fr_i}^0}{\partial s} = \left[ \frac{c - v}{(p_i - v + s)} \right] (F^{-1})' \left[ \frac{(p_i - \omega + s) - \frac{\lambda_{ri}}{1 + \lambda_m + \lambda_{ij}} (\omega - c)}{(p_i - v + s)} \right] < 0$$

$$\frac{\partial q_{fr_i}^0}{\partial v} = \left[ \frac{1}{(p_i - v + s)} \right] (F^{-1})' \left[ \frac{(p_i - \omega + s) - \frac{\lambda_{ri}}{1 + \lambda_m + \lambda_{ij}} (\omega - c)}{(p_i - v + s)} \right] > 0$$

$$\frac{\partial q_{fr_i}^0}{\partial a_i} = 1 > 0, \quad \frac{\partial q_{fr_i}^0}{\partial b_i} = p_j - p_i$$

When $p_j > p_i$, we have $\frac{\partial q_{fr_i}^0}{\partial b_i} > 0$; when $p_j = p_i$, we have $\frac{\partial q_{fr_i}^0}{\partial b_i} = 0$; when $p_j < p_i$, we have $\frac{\partial q_{fr_i}^0}{\partial b_i} < 0$.

When $\lambda_{ri} \not<$, we have $-\frac{\lambda_{ri}}{1 + \lambda_m + \lambda_{ij}} \not<; \quad \text{when} \; \lambda_{ij}, \lambda_m \not\ge, \quad \text{we have} -\frac{\lambda_{ri}}{1 + \lambda_m + \lambda_{ij}} \not\ge$. So that we get the above conclusions.

Appendix F. Proof of Proposition 8

We get $q_{fr_i}^0 < q_{ri}^0$ from equations (24) and (25), obviously.

For $(\lambda_m \ge \lambda_{ij}) \iff \frac{\lambda + \lambda_m}{\lambda + \lambda_{ij}} > 1$, we can get $q_{fr_i}^0 < q_{ri}^*$ from equations (19) and (20).

For $(\lambda_m = \lambda_{ij}) \iff \frac{\lambda + \lambda_m}{\lambda + \lambda_{ij}} = 1$, we can get $q_{fr_i}^0 = q_{ri}^*$ from equations (19) and (20).

For $(\lambda_m \le \lambda_{ij}) \iff \frac{\lambda + \lambda_m}{\lambda + \lambda_{ij}} < 1$, we can get $q_{fr_i}^0 < q_{ri}^*$ from equations (19) and (20).