APEM journal
Advances in Production Engineering & Management
Volume 13 | Number 3 | September 2018 | pp 345–357
https://doi.org/10.14743/apem2018.3.295
ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Decision-making strategies in supply chain management with a waste-averse and stockout-averse manufacturer

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A B S T R A C T

Behavioral preferences is an important factor that affects the decision-making strategies of enterprises. Usually, the behavioral preferences will lead to decision-making that deviates from profit maximization. In this study, we investigate the influence of a dominant manufacturer's behavioral preferences on decision-making and subsequent impact on profits. This study looks at the profits of the manufacturer, retailer and the system as a whole. We construct a two-stage supply chain involving a retailer and a manufacturer who may have risk-neutral (RN), stockout-aversion (SA), waste-aversion (WA), and stockout- and waste-aversion (SW) preferences. Through a comparison and analysis of the four cases, we find that the manufacturer's wholesale price increases (decreases) with the SA (WA) coefficient, while the retailer's order quantity is completely the opposite. The manufacturer's wholesale price is the highest in the WA model, followed by the RN, SA and SW models, in that order. The retailer's order quantity is the largest and smallest in the SA and WA models, respectively, while the size of the order quantity between the RN and SW models depends on the ratio m (the ratio of the SA to the WA). Moreover, we also explore the changing trends of the decision-making and profits of the participants and the system profit with the degree of SA and WA, comparing the profits of the four cases.

A R T I C L E I N F O

Keywords:
Decision-making strategy;
Supply chain management;
Waste-averse preferences;
Stockout-averse preferences

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Article history:
Received 6 July 2018
Revised 20 August 2018
Accepted 22 August 2018

1. Introduction

The supply chain decision-making is a very important problem in supply chain (SC) management and therefore is also a very difficult problem for enterprises. In practice, many retailers must look at overordering cost, underordering cost and predicted demand to determine their ordering decisions before a sales season [1]. In addition, the manufacturer also must decide the pricing strategy for its products according to its own business interests. Traditional research on decision-making strategies are based mainly on risk neutrality, as in [2-3]. However, we know from behavioral economics that decision-makers in the real world may have behavioral preferences, which is also an important reason for the existence of "decision bias" [1]. Therefore, it is more practical to study the decision-making strategies of decision-makers by integrating behavior preferences into the SC.

In the existing literature, behavioral preferences research focuses mainly on loss aversion and risk aversion. A study of loss aversion by Niu *et al.* [4] considers the sustainability of the with alternative power structures, and the impact of the supplier's attitudes to loss on the 's sustainability and profitability. Choi [5] studies the newsboy problem, where the decision-maker is loss-averse under carbon emission constraints. When there is competition between manufacturers, research by Li and Li [6] show an ordering decision problem in the case of a supply disruption. Xu *et al.* [7] study the optimal order quantity in the loss-averse newsvendor model with backordering. In the two-period game, research by Yang and Xiao [8] study the pricing, ordering and quality of retailers' service decisions when loss-averse consumers are sensitive to service quality. They also construct a SC coordination mechanism.

A study of risk aversion by Giri [9] simultaneously considers the case of a retailer ordering from a manufacturer with random output and a manufacturer with a fixed output and studies the inventory decision problem of a risk-averse retailer. Zhu *et al.* [10] consider the global optimization problem when the manufacturer has two sales channels. Wu *et al.* [11] study the influence of capacity uncertainty on the order decision of risk-averse managers. Additionally, Oh *et al.* [12] consider the impact of uncertainty in service cost on the product pricing decision when the service provider of the downstream SC is risk-averse. Egging *et al.* [13] discuss the influence of risk aversion on gas investment decisions. Xiao *et al.* [14] consider the retailer's service and pricing decisions when both system members and consumers are risk-averse. Zhou *et al.* [15] study a coordination problem when chain members and service provider are risk-averse. Zheng *et al.* [16] study the pricing decisions of two competitive shipping companies, one of which is risk-averse. Liu [17] analyzes the influence of risk aversion on the decision-making and expected profits of dual-channel members when information asymmetry exists in the risk aversion. For more research on risk aversion, see [18-20].

However, there are few studies available on the decision-making strategy problems that arise when decision makers have SA or WA preferences. Schweitzer and Cachon [1] study the ordering decision when the decision-maker in the downstream SC has either a SA or WA preferences. In contrast to the previous literature cited, in this paper, we introduce the SA and WA coefficients under the manufacturer-led Stackelberg game. We also consider that the manufacturer may have RN, SA, WA, and SW preferences. This paper mainly studies the following three problems:

- How will the four different behavioral preferences of the manufacturer affect the decision-making and expected profits of the chain members, as well as the expected profit of the system?
- How will the change in the manufacturer's SA and WA preferences affect the decisions of the chain members?
- How will the change in the manufacturer's SA and WA preferences affect the expected profits of the chain members and system?

To solve these problems, we build a Stackelberg game model composed of a retailer and a manufacturer, who is the leader and assume the demand is random. The retailer pursues its own expected profit maximization by making order decisions, while the manufacturer pursues its own expected utility maximization by setting wholesale pricing. We compare the decision-making behavior and expected profits of the chain members, and the expected profit of the system, under the four different behavioral preferences. At the same time, we also analyze the influence of the change in the SA and WA coefficients on the decision-making and expected profits of the chain members, as well as the expected profit of the system. The above conclusions can be used to some extent to guide decision-makers on how to adjust their decision-making strategies according to the manufacturer's SA and WA preferences.

This paper is organized as follows. Section 2 provides the assumptions and notations of the model. Section 3 presents the model analysis under the four kinds of behavioral preferences. Section 4 offers the comparison and analysis of the four cases. Section 5 provides the numerical study, and Section 6 summarizes the full text.

2. Assumptions and notations

2.1 Model assumptions

The mathematical model presented in this paper is based on the following assumptions:

Assumption 1: The entire SC consists of a manufacturer and a retailer, in which the manufacturer is the leader and the retailer is the follower.

Assumption 2: The cumulative distribution function and probability density function of random demand D are $F(x)$ and $f(x)$, respectively, and the expected demand is $E(x) = \mu$.

Assumption 3: Because market demand D is random, the retailer may overorder or underorder. To simplify the model, we ignore any salvage value or shortage loss. This assumption is common in the existing literature (e.g., [1, 4, 16, 20]) and does not have any effect on the conclusions.

Assumption 4: The manufacturer may have four behavioral preferences: RN, SA, WA, and SW.

Assumption 5: $p > w > c$.

2.2 Notations

The meanings of the other symbols used in this article are in Table 1.

Table 1 The listing of notations ($j \in \{RN, WA, SA, SW\}$)

Symbol	Meaning	Symbol	Meaning
w	Wholesale price	c	Production cost
p	Retail price	q	Order quantity
β	WA coefficient	λ	Stockout-aversion coefficient
RN	Risk-neutral	WA	Waste-averse
SA	Stockout-averse	SW	Stockout- and waste-averse
SC	Supply chain	π_R^j	The retailer's expected profit in case j
π_S^j	The supplier's expected profit in case j	π_C^j	The expected profit of supply chain in case j
U_S^j	The supplier's expected utility in case j	*	Optimal value

3. Model analysis

In this section, we will study the optimal decisions of the participants under the four behavioral preferences models. In the manufacturer-led Stackelberg game, the manufacturer has priority decision-making power and first determines the wholesale price w to maximize its expected utility. Then, the retailer determines its order quantity q in response to the manufacturer's decision-making and the predicted market demand D.

The expected profits of the manufacturer and the retailer are as follows:

$$\pi_S^j = (w - c)q \tag{1}$$

$$\pi_R^j(q) = pEmin(q, D) - wq = (p - w)q - p\int_0^q F(x)dx \tag{2}$$

where $j \in \{RN, WA, SA, SW\}$. Superscripts RN, WA, SA and SW indicate that the manufacturer has risk-neutral, waste-aversion, stockout-aversion and stockout- and waste-aversion preferences, respectively.

Case 1 With reference to Schweitzer and Cachon [1], when the manufacturer has SW preferences, the manufacturer's expected utility function is

$$U_S^{SW}(w) = wq - cq - E\{\beta(q - D)^+ - \lambda(D - q)^+\}$$
$$= (w - c + \lambda)q - \lambda\mu + (\beta + \lambda)\int_0^q F(x)dx \tag{3}$$

In the Eq. 3, wq is the product sales income of the manufacturer, cq is the production cost of the product, $\beta(q - D)^+$ is the waste penalty loss and $\lambda(D - q)^+$ is the shortage penalty loss. Among these variables, higher values of coefficients β and λ indicate higher degrees of WA and SA, respectively, by the manufacturer.

The inverse induction method is used to solve the model. From Eq. 2, we have $\frac{\partial^2 \pi_R^{SW}}{\partial q^2} = -pf(q) < 0$; then, π_R^{SW} is concave in q. Let $\frac{\partial \pi_R^{SW}}{\partial q} = 0$, and we can obtain the following:

$$q^{SW*} = F^{-1}\left(\frac{p-w}{p}\right) \tag{4}$$

By substituting q^{SW*} into Eq. 3, the manufacturer's expected utility optimization problem is

$$\max_{w} U_S^{SW} = (w-c+\lambda)q^{SW*} - \lambda\mu + (\beta+\lambda)\int_0^{q^{SW*}} F(x)dx \tag{5}$$

Let $\frac{\partial U_S^{SW}}{\partial q} = 0$, and we can obtain the following:

$$F^{-1}\left(\frac{p-w}{p}\right) - \frac{(w-c+\lambda)(p-v)+(p-w)(\lambda+\beta)}{(p-v)^2 f\left[F^{-1}\left(\frac{p-w}{p}\right)\right]} = 0 \tag{6}$$

Eq. 6 is too complex to obtain intuitionistic results, in order to gain more valuable conclusions, we follow prior literature [10, 20] and assume that the random demand variable obeys a uniform distribution, that is, $x \sim U(0, B)$. Through Eqs. 4 and 6, we can now obtain the following:

$$w^{SW*} = \frac{p(p+c+\beta)}{2p+\beta+\lambda},\ q^{SW*} = \frac{B(p-c+\lambda)}{2p+\beta+\lambda} \tag{7}$$

By substituting Eq. 7 into Eqs. 1 and 2, we can obtain the following:

$$\pi_S^{SW*} = \frac{B(p-c+\lambda)[p(p+\beta)-c(p+\beta+\lambda)]}{(2p+\beta+\lambda)^2}, \pi_R^{SW*} = \frac{Bp(p-c+\lambda)^2}{2(2p+\beta+\lambda)^2} \tag{8}$$

$$\pi_C^{SW*} = \pi_S^{SW*} + \pi_R^{SW*} = \frac{B(p-c+\lambda)[p(3p+2\beta+\lambda)-c(3p+2\beta+2\lambda)]}{2(2p+\beta+\lambda)^2} \tag{9}$$

Case 2 When the manufacturer has only WA preferences, that is, $\lambda = 0$, then the optimal decisions and expected profits of the participants are shown in the third row of Table 2.

Case 3 When the manufacturer has only SA preferences, that is, $\beta = 0$, then the optimal decisions and expected profits of the participants are shown in the fourth row of Table 2.

Case 4 When the manufacturer has RN preferences, that is, $\lambda = 0$ and $\beta = 0$, then the optimal decisions and expected profits of the participants are shown in the fifth row of Table 2.

Table 2 Optimal decisions and expected profits of the manufacturer and retailer ($j \in \{RN, WA, SA, SW\}$)

Preferences	q^{j*}	w^{j*}	π_S^{j*}	π_R^{j*}
RN	$\frac{B(p-c)}{2p}$	$\frac{p+c}{2}$	$\frac{B(p-c)^2}{4p}$	$\frac{B(p-c)^2}{8p}$
WA	$\frac{B(p-c)}{2p+\beta}$	$\frac{p(p+c+\beta)}{2p+\beta}$	$\frac{B(p-c)^2(p+\beta)}{(2p+\beta)^2}$	$\frac{Bp(p-c)^2}{2(2p+\beta)^2}$
SA	$\frac{B(p-c+\lambda)}{2p+\lambda}$	$\frac{B(p+c)}{2p+\lambda}$	$\frac{B(p-c+\lambda)[p^2-c(p+\lambda)]}{(2p+\lambda)^2}$	$\frac{Bp(p-c+\lambda)^2}{2(2p+\lambda)^2}$
SW	$\frac{B(p-c+\lambda)}{2p+\beta+\lambda}$	$\frac{B(p+c+\beta)}{2p+\beta+\lambda}$	$\frac{B(p-c+\lambda)[(p-c)(p+\beta)-c\lambda]}{(2p+\beta+\lambda)^2}$	$\frac{Bp(p-c+\lambda)^2}{2(2p+\beta+\lambda)^2}$

Table 3 Optimal expected profit of the SC

π_C^{RN*}	$\frac{3B(p-c)^2}{8p}$
π_C^{WA*}	$\frac{B(p-c)^2(3p+2\beta)}{2(2p+\beta)^2}$
π_C^{SA*}	$\frac{B(p-c+\lambda)[p(3p+\lambda)-c(3p+2\lambda)]}{2(2p+\lambda)^2}$
π_C^{SW*}	$\frac{B(p-c+\lambda)[p(3p+2\beta+\lambda)-c(3p+2\lambda+2\beta)]}{2(2p+\lambda+\beta)^2}$

4. Comparison and analysis of the four behavioral preferences mode

This section mainly analyzes the conclusions obtained in the previous section. We analyze the influence of the change in SA coefficient λ and WA coefficient β on the decisions and expected profits of the participants, as well as the expected profit of the system. Additionally, the decisions and expected profits of the participants and the expected profit of the system are compared and analyzed under the four cases. The equilibrium results in the four cases are summarized in Tables 2 and 3.

We first analyze the effect of λ and β on the q^{SW*} and w^{SW*}. From Eq. 7, we can obtain

$$\frac{\partial q^{SW*}(\lambda,\beta)}{\partial \lambda}=\frac{B(p+\beta+c)}{(2p+\beta+\lambda)^2}>0,\frac{\partial q^{SW*}(\lambda,\beta)}{\partial \beta}=-\frac{B(p+\lambda-c)}{(2p+\beta+\lambda)^2}<0 \tag{10}$$

$$\frac{\partial w^{SW*}(\lambda,\beta)}{\partial \lambda}=-\frac{p(p+\beta+c)}{(2p+\beta+\lambda)^2}<0,\frac{\partial w^{SW*}(\lambda,\beta)}{\partial \beta}=\frac{p(p+\lambda-c)}{(2p+\beta+\lambda)^2}>0 \tag{11}$$

Therefore, we can obtain Proposition 1.

Proposition 1 (1) The retailer's order quantity increases with the λ, while it decreases with the β. (2) The manufacturer's wholesale price decreases with the λ, while it increases with the β.

Proposition 1 shows that the SA (WA) preferences motivates (weakens) the retailer's ordering enthusiasm. As λ (β) increases, the order quantity will increase (decrease). On the other hand, the dominant manufacturer will adjust the price of the product according to the ordering decisions of the retailer in order to maximize its expected utility. So as λ (β) increases, the wholesale price will decrease (increase).

Next, we will analyze the influence of λ and β on the expected profits of the participants. From Table 2, we can obtain

$$\frac{\partial \pi_R^{SW*}(\lambda,\beta)}{\partial \beta}=-\frac{Bp(p-c+\lambda)^2}{(2p+\beta+\lambda)^3}<0,\frac{\partial \pi_R^{SW*}(\lambda,\beta)}{\partial \lambda}=\frac{Bp(p-c+\lambda)(p+c+\beta)}{(2p+\beta+\lambda)^3}>0 \tag{12}$$

$$\frac{\partial \pi_S^{SA*}(\lambda)}{\partial \lambda}=-\frac{B\lambda(p+c)^2}{(2p+\lambda)^3}<0,\frac{\partial \pi_S^{WA*}(\beta)}{\partial \beta}=-\frac{B\beta(p-c)^2}{(2p+\beta)^3}<0 \tag{13}$$

$$\frac{\partial \pi_S^{SW*}(\lambda,\beta)}{\partial \beta}=\frac{B(p-c+\lambda)[p(\lambda-\beta)+c(\lambda+\beta)]}{(2p+\beta+\lambda)^3} \tag{14}$$

$$\frac{\partial \pi_S^{SW*}(\lambda,\beta)}{\partial \lambda}=\frac{B(p+c+\beta)[p(\beta-\lambda)-c(\lambda+\beta)]}{(2p+\beta+\lambda)^3} \tag{15}$$

From Eq. 14, there are $\frac{\partial \pi_S^{SW*}}{\partial \beta}>0$ when $\lambda>\lambda_1$ and $\frac{\partial \pi_S^{SW*}}{\partial \beta}<0$ when $0\le\lambda<\lambda_1$, where $\lambda_1=\frac{\beta(p-c)}{p+c}$. From Eq. 15, there are $\frac{\partial \pi_S^{SW*}}{\partial \lambda}>0$ when $\beta>\beta_1$ and $\frac{\partial \pi_S^{SW*}}{\partial \lambda}<0$ when $0\le\beta<\beta_1$, where $\beta_1=\frac{\lambda(p-c)}{p+c}$.

Through the above analysis, we can obtain the following proposition.

Proposition 2 (1) The retailer's expected profit decreases and increases with the β and the λ, respectively. (2) When the manufacturer has only WA (SA) preferences, the manufacturer's expected profit is decreases with the β and the λ. (3) When the manufacturer has SW preferences, the relationship between the manufacturer's expected profit and the β (λ) is determined by the λ (β): there is a threshold λ_1 (β_1), and when the value of λ (β) is large, that is, $\lambda>\lambda_1$ ($\beta>\beta_1$), the manufacturer's expected profit increases with the β (λ); conversely, the manufacturer's expected profit decreases with the β (λ).

As λ (β) increases, the retailer's expected profit increases (decreases), which is due to an increase (decrease) in order volume. When the manufacturer has only WA (SA) preferences, it is understandable that the manufacturer's expected profit decreases as the order quantities decrease. However, the manufacturer's expected profit decreases as order volume increases, which seems counterintuitive; this is because the gains from the increase in order quantity are not sufficient to compensate for the loss caused by the reduction in product price. In addition, the relationship between manufacturer's expected profit and the λ (β) is related to the β (λ) in the SW model.

From Table 3, we can obtain

$$\frac{\partial \pi_C^{SW*}(\lambda,\beta)}{\partial \lambda}=\frac{B(p+c+\beta)[p(\beta+p)-c(p+\lambda+\beta)]}{(2p+\beta+\lambda)^3} \tag{16}$$

$$\frac{\partial \pi_C^{SW*}(\lambda,\beta)}{\partial \beta}=-\frac{B(p-c+\lambda)[p(\beta+p)-c(p+\lambda+\beta)]}{(2p+\beta+\lambda)^3} \tag{17}$$

From Eq. 16, there are $\frac{\partial \pi_C^{SW*}}{\partial \lambda}\geq 0$ when $\beta\geq\beta_2$ and $\frac{\partial \pi_C^{SW*}}{\partial \lambda}<0$ when $0\leq\beta<\beta_2$, where $\beta_2=\frac{c(p+\lambda)-p^2}{p-c}$. From Eq. 17, there are $\frac{\partial \pi_C^{SW*}}{\partial \beta}\geq 0$ when $\lambda\geq\lambda_2$ and $\frac{\partial \pi_C^{SW*}}{\partial \beta}<0$ when $0<\lambda<\lambda_2$, where $\lambda_2=\frac{(p-c)(p+\beta)}{c}$.

Since the decisions and profits of the participants must be positive, the following inequalities are established:

$$\begin{cases} p(p+\beta)-c(p+\beta+\lambda)>0 \\ p^2-c(p+\lambda)>0 \end{cases} \tag{18}$$

$$\frac{\partial \pi_C^{SA*}}{\partial \lambda}=\frac{B(p+c)[p^2-c(p+\lambda)]}{(2p+\lambda)^3}>0, \frac{\partial \pi_C^{WA*}}{\partial \beta}=-\frac{B(p-c)^2(p+\beta)}{(2p+\lambda)^3}<0 \tag{19}$$

From the above analysis, we can obtain Proposition 3.

Proposition 3 (1) When the manufacturer has only *SA (WA)* preferences, the expected profit of SC increases (decreases) with the *λ (β).* (2) When the manufacturer has SW preferences, the relationship between the expected profit of SC and the *β (λ)* is determined by *λ(β).* There is a threshold *λ_2 ($\beta>\beta_2$),* and when the value of *λ (β)* is large, that is, *$\lambda>\lambda_2$ ($\beta>\beta_2$),* the expected profit of SC increases with the *β (λ)*; in contrast, the expected profit of SC decreases with the *β (λ).*

Proposition 3 shows that the system profit is increasing (decreasing) with the λ (β) in the SA (WA) model. Because for the whole system, the order quantity increases (decreases) with the increase (decrease) in λ (β), which can (cannot) satisfy the potential market demand as much as possible. In addition, if λ (β) is larger, there will be a risk of overordering or underordering in the SW model. Therefore, reducing (increasing) the order amount is beneficial to increase the profit of the system.

From Eqs. 10 and 11, we can obtain

$$\left.\begin{aligned} \frac{\partial w^{SW*}(\lambda,\beta)}{\partial \lambda}<0 \Rightarrow \begin{cases} w^{SW*}(\lambda,\beta)<w^{SW*}(0,\beta)=w^{WA*}(\beta) \\ w^{SW*}(\lambda,0)=w^{SA*}(\lambda)<w^{SA*}(0)=w^{RN*} \end{cases} \\ \frac{\partial w^{SW*}(\lambda,\beta)}{\partial \beta}>0 \Rightarrow \begin{cases} w^{SW*}(\lambda,\beta)<w^{SW*}(\lambda,0)=w^{SA*}(\lambda) \\ w^{SW*}(0,\beta)=w^{WA*}(\beta)>w^{WA*}(0)=w^{RN*} \end{cases} \end{aligned}\right\}$$

$$\Rightarrow w^{SW*}<w^{SA*}<w^{RN*}<w^{WA*}$$

$$\left.\begin{aligned} \frac{\partial q^{SW*}(\lambda,\beta)}{\partial \lambda}>0 \Rightarrow \begin{cases} q^{SW*}(\lambda,\beta)>q^{SW*}(0,\beta)=q^{WA*}(\beta) \\ q^{SW*}(\lambda,0)=q^{SA*}(\lambda)>q^{SA*}(0)=q^{RN*} \end{cases} \\ \frac{\partial q^{SW*}(\lambda,\beta)}{\partial \beta}<0 \Rightarrow \begin{cases} q^{SW*}(\lambda,\beta)<q^{SW*}(\lambda,0)=q^{SA*}(\lambda) \\ q^{SW*}(0,\beta)=q^{WA*}(\beta)<q^{WA*}(0)=q^{RN*} \end{cases} \end{aligned}\right\}$$

$$\Rightarrow q^{WA*}<q^{SW*}\ or\ q^{RN*}<q^{SA*}$$

Let $m=\lambda/\beta$, then

$$q^{SW*} - q^{RN*} = \frac{B\beta[c(1+m) + p(m-1)]}{2p(2p + m\beta + \beta)} \tag{20}$$

From Eq. 20, there are $q^{SW*} > q^{RN*}$ when $m > m_1$ and $q^{SW*} < q^{RN*}$ when $0 \leq m < m_1$, where $m_1 = \frac{p-c}{p+c}$.

From the above analysis, we can obtain Proposition 4.

Proposition 4

(1) $w^{SW*} < w^{SA*} < w^{RN*} < w^{WA*}$; (2) $\begin{cases} q^{WA*} < q^{RN*} < q^{SW*} < q^{SA*}, m > m_1 \\ q^{WA*} < q^{SW*} < q^{RN*} < q^{SA*}, 0 \leq m < m_1 \end{cases}$

where $m_1 = \frac{p-c}{p+c}$.

Proposition 4 indicates that (1) the manufacturer's wholesale price is the highest in the WA model, followed by the RN, SA and SW models, in that order. (2) As shown in Fig. 1, the retailer's order quantity is the largest and the smallest in the SA and WA models respectively. However, the size of the order quantity between the RN and SW models depends on the ratio m. There is a threshold m_1, and when the ratio m is large, that is, $m > m_1$, the order quantity is larger in the SW model; otherwise, the order quantity is larger in the RN model.

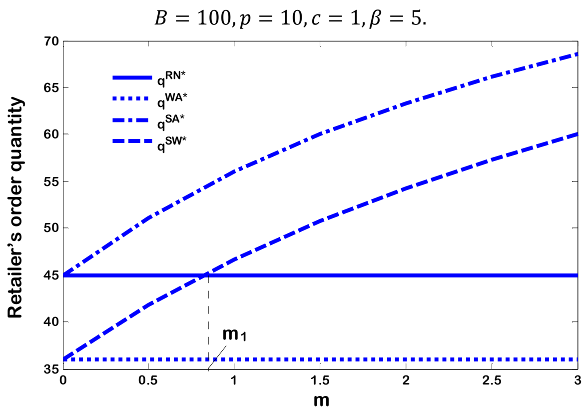


Fig. 1 The effect of ratio m on the retailer's order quantity

From the Eq. 12, we can obtain the following:

$$\left. \begin{array}{l} \dfrac{\partial \pi_R^{SW*}(\lambda,\beta)}{\partial \beta} < 0 \Rightarrow \begin{cases} \pi_R^{SW*}(\lambda,\beta) < \pi_R^{SW*}(\lambda,0) = \pi_R^{SA*} \\ \pi_R^{SW*}(0,\beta) = \pi_R^{WA*}(\beta) < \pi_R^{WA*}(0) = \pi_R^{RN*} \end{cases} \\ \dfrac{\partial \pi_R^{SW*}(\lambda,\beta)}{\partial \lambda} > 0 \Rightarrow \begin{cases} \pi_R^{SW*}(\lambda,\beta) > \pi_R^{SW*}(0,\beta) = \pi_R^{WA*}(\beta) \\ \pi_R^{SW*}(\lambda,0) = \pi_R^{SA*}(\lambda) > \pi_R^{SA*}(0) = \pi_R^{RN*} \end{cases} \end{array} \right\}$$

$$\Rightarrow \pi_R^{WA*} < \pi_R^{RN*} \ or \ \pi_R^{SW*} < \pi_R^{SA*}$$

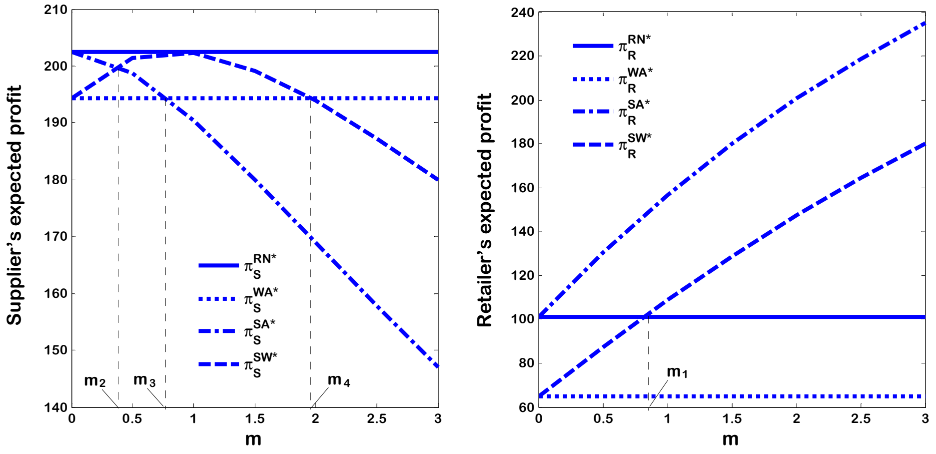
Let $m = \lambda/\beta$, then

$$\pi_R^{SW*} - \pi_R^{RN*} = \frac{4Bp^2(p-c+m\beta)^2 - B(p-c)^2(2p+\beta+m\beta)^2}{8p(2p+m\beta+\beta)^2} \tag{21}$$

From Eq. 21, there are $\pi_R^{SW*} > \pi_R^{RN*}$ when $m > m_1$ and $\pi_R^{SW*} < \pi_R^{RN*}$ when $0 \leq m < m_1$, where $m_1 = \frac{p-c}{p+c}$.

Proposition 5 $\begin{cases} \pi_R^{WA*} < \pi_R^{RN*} < \pi_R^{SW*} < \pi_R^{SA*}, \ m > m_1 \\ \pi_R^{WA*} < \pi_R^{SW*} < \pi_R^{RN*} < \pi_R^{SA*}, \ 0 \leq m < m_1 \end{cases}$

As shown in Fig. 2(b), Proposition 5 shows that the retailer's expected profit is the highest and lowest in the SA and WA models respectively. However, the size of the expected profit between the RN and SW models depends on the ratio m. There is a threshold m_1, and when the ratio m is large, that is, $m > m_1$, the expected profit is larger in the SW model; conversely, the expected profit is larger in the RN model.



(a) (b)

Fig. 2 The effect of ratio m on the expected profit of manufacturer (a) and retailer (b)

Proposition 6 $\begin{cases} \pi_S^{WA*} < \pi_S^{SW*} < \pi_S^{SA*} < \pi_S^{RN*}, \ 0 \le m < m_2 \\ \pi_S^{WA*} < \pi_S^{SA*} < \pi_S^{SW*} < \pi_S^{RN*}, \ m_2 < m < m_3 \\ \pi_S^{SA*} < \pi_S^{WA*} < \pi_S^{SW*} < \pi_S^{RN*}, \ m_3 < m < m_4 \\ \pi_S^{SA*} < \pi_S^{SW*} < \pi_S^{WA*} < \pi_S^{RN*}, \ m > m_4 \end{cases}$

where $m_2 = \frac{-2p^2-c(2p+\beta)+\sqrt{4p^3(p+\beta)+4cp^2(2p+\beta)+c^2(4p^2+\beta^2)}}{2\beta(p+c)}$, $m_3 = \frac{p(p-c)}{p^2+c(p+\beta)}$, $m_4 = \frac{(2p+\beta)(p-c)}{p^2+c(p+\beta)}$.

The proof for Preposition 6 is in Appendix A.

As shown in Fig. 2(a), Proposition 6 indicates that the manufacturer's expected profit is highest in the RN model. However, the expected profit difference between the *WA*, *SW* and *SA* models depends on the ratio m. There are three thresholds, m_2, m_3 and m_4, where $m_2 < m_3 < m_4$. When $0 \le m < m_2$, the expected profit is the highest and lowest in the *SA* and *WA* models, respectively. When $m_2 < m < m_3$, the expected profit is the highest and lowest in the *SW* and *WA* models, respectively. When $m_3 < m < m_4$, the expected profit is the highest and lowest in the *SW* and *SA* models, respectively. When $m > m_4$, the expected profit is the highest and lowest in the *WA* and *SA* models, respectively.

Proposition 7 $\begin{cases} \pi_C^{WA*} < \pi_C^{SW*} < \pi_C^{RN*} < \pi_C^{SA*}, \ 0 \le m < m_5 \\ \pi_C^{WA*} < \pi_C^{RN*} < \pi_C^{SW*} < \pi_C^{SA*}, \ m_5 < m < m_6 \\ \pi_C^{WA*} < \pi_C^{RN*} < \pi_C^{SA*} < \pi_C^{SW*}, \ m > m_6 \end{cases}$

where $m_5 = \frac{p-c}{p+c}$ and $m_6 = \frac{2p^2+p\beta-2c(3p+\beta)+\sqrt{p^2(2p+\beta)^2+4cp(2p^2+p\beta-\beta^2)+4c^2(p^2+\beta^2)}}{4c\beta}$.

The proof for Preposition 7 is in Appendix A.

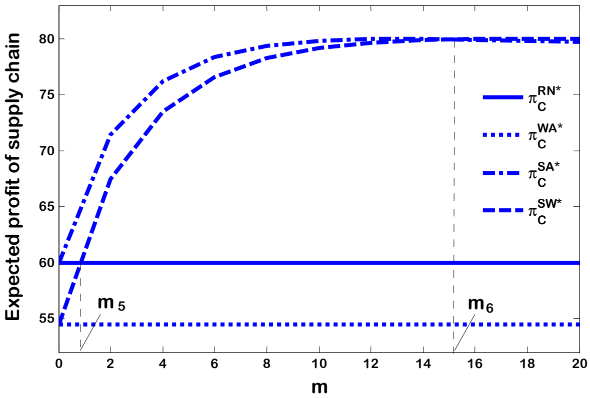


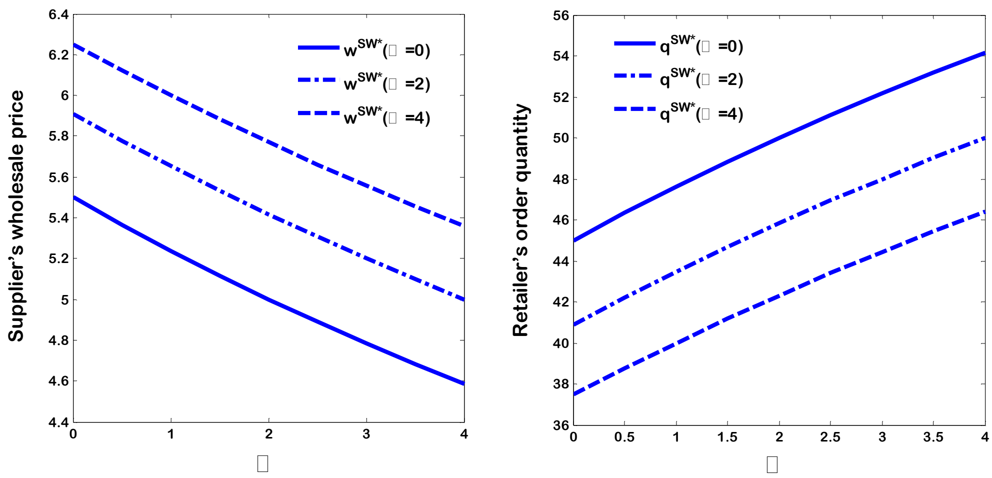
Fig. 3 The effect of ratio m on the expected profit of *SC*

As shown in Fig. 3, Proposition 7 shows that the expected profit of SC is lowest in the WA model. However, the expected profit difference between the RN, SW and SA models depends on the ratio m. There are two thresholds, m_5 and m_6, where $m_5 < m_6$. When $0 \leq m < m_5$, the expected profit is the highest and lowest in the SA and SW models, respectively. When $m_5 < m < m_6$, the expected profit is the highest and lowest in the SA and RN models, respectively. When $m > m_6$, the expected profit is the highest and lowest in the SW and RN models, respectively.

5. Results and discussion

A numerical simulation was used to intuitively show the impact of the λ and the β on the decisions and expected profits of the chain members and the expected profit of the system. At the same time, we also want to verify the correctness of the above conclusions. Therefore, this section uses a numerical simulation method for further analysis. Without the loss of generality, the parameters are set as follows: $B = 100, p = 10, c = 1$.

From Fig. 4(a), we can see that the manufacturer's wholesale price is decreasing with the λ and increasing with the β. It can be seen from Fig. 4(b) that the retailer's order quantity is increasing with the λ and decreasing with the β.



(a) (b)

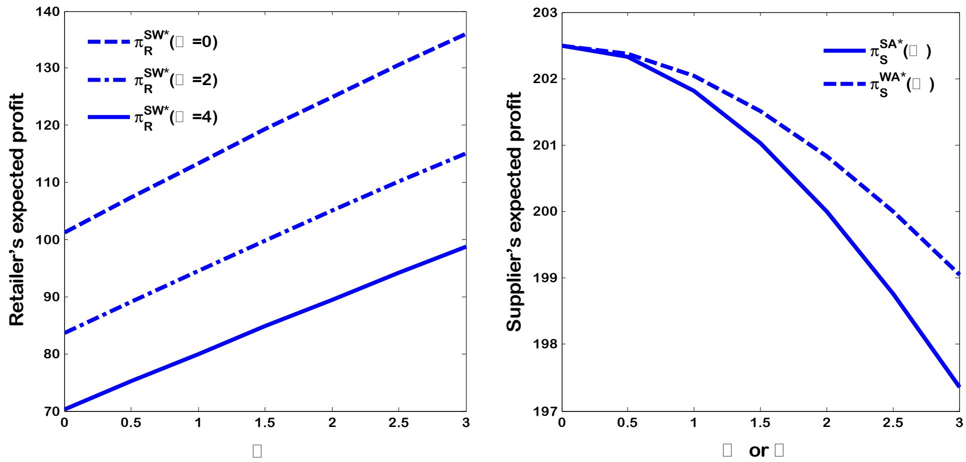
Fig. 4 The effect of λ and β on wholesale price (a), and order quantity (b)

From Fig. 5(a), we can see that the retailer's expected profit is increasing with the λ and decreasing with the β. Fig. 5(b) shows that when the manufacturer has only SA (WA) preferences, the manufacturer's expected profit is decreasing with the λ (β).

From Figs. 6(a) and 7(a), we can see that when the manufacturer has SW preferences, the relationship between the expected profit of the manufacturer (SC) and the λ depends on the β. If β is large, that is, $\beta = 4.0$, then the expected profit is increasing with λ; in contrast, if β is small, that is, $\beta = 0.5$, then the expected profit is decreasing with λ.

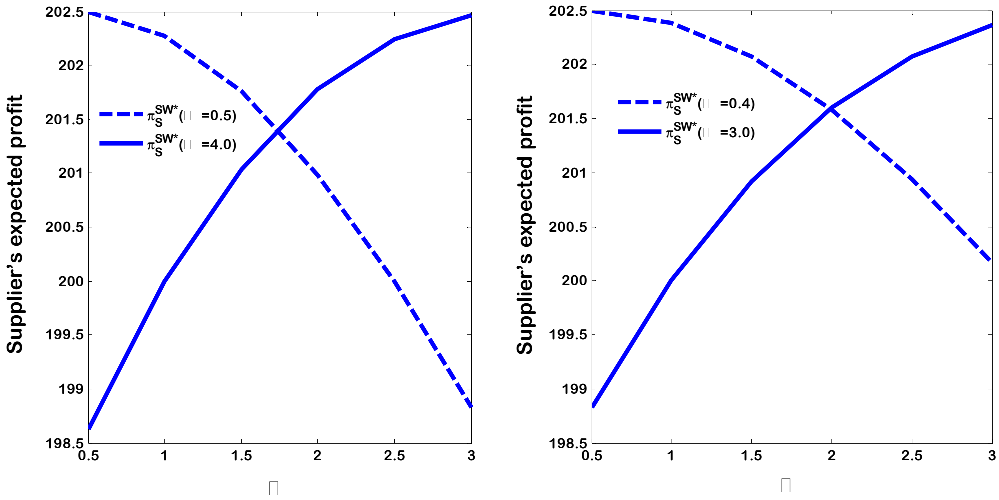
Figs. 6(b) and 7(b) show that the relationship between the expected profit of the manufacturer (SC) and the β depends on the λ. If λ is large, that is, $\lambda = 3.0$, then the expected profit is increasing with β; in contrast, if λ is small, that is, $\lambda = 0.4$, then the expected profit is decreasing with β.

Fig. 8 shows that when the manufacturer has only the SA (WA) preferences, the expected profit of the SC is increasing (decreasing) with the λ (β).



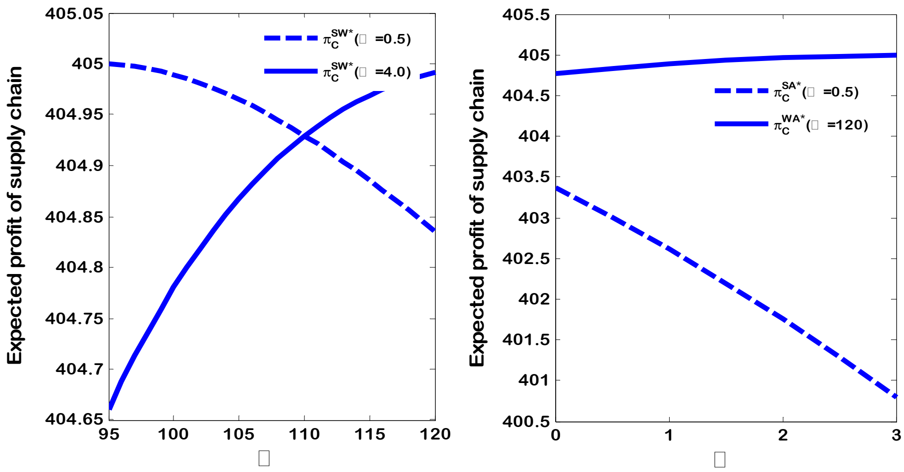
(a) (b)

Fig. 5 The effect of λ and β on the expected profits of retailer (a) and manufacturer (b)



(a) (b)

Fig. 6 The effect of λ and β on the expected profit of the manufacturer



(a) (b)

Fig. 7 The effect of λ and β on the expected profit of the *SC*

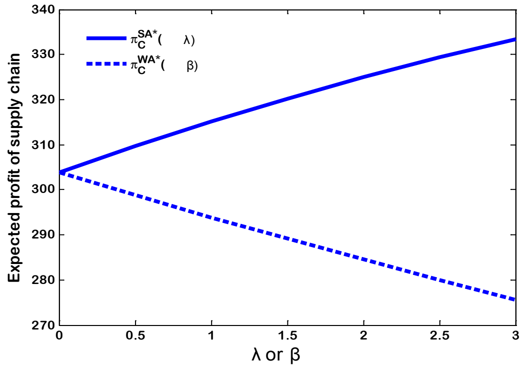


Fig. 8 The effect of λ or β on the expected profit of the SC

6. Conclusion

This paper studies the influence of a dominant manufacturer's behavioral preferences on the decision-making and expected profits of the chain members, as well as the expected profit of the system. The behavioral preferences investigated include RN, SA, WA and SW preferences. Through the analysis of this paper, we can draw the following conclusions:

- The manufacturer's wholesale price is increasing (decreasing) with the SA (WA) coefficient, while the retailer's order quantity (expected profit) is the opposite;
- When the manufacturer has only the SA (WA) preferences, the manufacturer's expected profit decreases with the SA (WA) coefficient;
- When the manufacturer has the SW preferences, the relationship between the expected profit of the manufacturer (SC) and the SA coefficient depends on the WA coefficient. The relationship between the expected profit of the manufacturer (SC) and the WA coefficient depends on the SA coefficient;
- The manufacturer's wholesale price is the highest in the WA model, followed by the RN, SA and SW models, in that order;
- The retailer's order quantity (expected profit) is the largest and smallest in the SA and WA models, respectively, while the size of the order quantity (expected profit) between the RN and SW models depends on the ratio m, and there is a ratio threshold of m_1;
- The manufacturer's expected profit is the largest in the RN model. However, the size of the expected profit among the WA, SW and SA models depends on the ratio m, and there are three ratio thresholds of m_2, m_3 and m_4, where $m_2 < m_3 < m_4$;
- The expected profit of the SC is the lowest in the WA model. However, the size of the expected profit among the RN, SW and SA models depends on the ratio m, and there are two ratio thresholds of m_5 and m_6, where $m_5 < m_6$.

Acknowledgement

This work was supported by the Natural Social Science Foundation of China (18BGL104).

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Appendix A

Proof of Proposition 6

Let $m = \lambda/\beta$; from Eq. 13 and Table 2, we can obtain

$$\left.\begin{array}{r}\dfrac{\partial \pi_S^{SA*}(\lambda)}{\partial \lambda} < 0 \Rightarrow \pi_S^{SA*}(\lambda) < \pi_S^{SA*}(0) = \pi_S^{RN*} \\ \dfrac{\partial \pi_S^{WA*}(\beta)}{\partial \beta} < 0 \Rightarrow \pi_S^{WA*}(\beta) < \pi_S^{WA*}(0) = \pi_S^{RN*} \\ \pi_S^{SW*} - \pi_S^{RN*} = -\dfrac{B\beta^2[c(1+m) - p(1-m)]^2}{4p(2p+\beta+m\beta)^2} < 0\end{array}\right\} \tag{A1}$$

$$\Rightarrow max\{\pi_S^{SA*}, \pi_S^{WA*}, \pi_S^{SW*}, \pi_S^{RN*}\} = \pi_S^{RN*}$$

$$\pi_S^{SW*} - \pi_S^{SA*} = -\frac{B\beta^2(p - c + m\beta)\{p[p(2m-1) + m\beta^2] + c[p + 2mp + m\beta(1+m)]\}}{(2p+m\beta)^2(2p+m\beta+\beta)^2} \tag{A2}$$

$$\pi_S^{WA*} - \pi_S^{SA*} = \frac{B(p-c)^2(p+\beta)}{(2p+\beta)^2} - \frac{B(p-c+m\beta)[p^2 - c(p+m\beta)]}{(2p+m\beta)^2} \tag{A3}$$

$$\pi_S^{SW*} - \pi_S^{WA*} = \frac{B(p-c+m\beta)[(p-c)(p+\beta) - cm\beta]}{(2p+\beta+m\beta)^2} - \frac{B(p-c)^2(p+\beta)}{(2p+\beta)^2} \tag{A4}$$

From Eqs. A1 to A4, we can obtain Proposition 6. Where m_2, m_3, and m_4 satisfy Eqs. A2, A3, and A4, respectively.

Additionally, $m_3 = \frac{p(p-c)}{p^2+c(p+\beta)}$, $m_2 = \frac{-2p^2-c(2p+\beta)+\sqrt{4p^3(p+\beta)+4cp^2(2p+\beta)+c^2(4p^2+\beta^2)}}{2\beta(p+c)}$, and $m_4 = \frac{(2p+\beta)(p-c)}{p^2+c(p+\beta)}$.

Proof of Proposition 7

Let $m = \lambda/\beta$; from Eqs. 19 and Table 3, we can obtain

$$\pi_C^{WA*} - \pi_C^{SW*} = \frac{B(p-c)^2(3p+2\beta)}{2(2p+\beta)^2} - \frac{B(p-c+m\beta)[p(3p+2\beta+m\beta)-c(3p+2m\beta+2\beta)]}{2(2p+m\beta+\beta)^2}$$

$$\frac{\partial(\pi_C^{WA*} - \pi_C^{SW*})}{\partial m} = -\frac{B\beta(p+c+\beta)[p(p+\beta)-c(p+m\beta+\beta)]}{(2p+m\beta+\beta)^3} < 0$$

$$\Rightarrow max\{\pi_C^{WA*} - \pi_C^{SW*}\} = \left(\pi_C^{WA*} - \pi_C^{SW*}\right)_{m=0} = 0 \Rightarrow \pi_C^{WA*} < \pi_C^{SW*} \tag{A5}$$

$$\left.\begin{array}{l} \dfrac{\partial \pi_C^{SA*}(\lambda)}{\partial \lambda} > 0 \Rightarrow \pi_C^{SA*}(\lambda) > \pi_C^{SA*}(0) = \pi_C^{RN*} \\ \dfrac{\partial \pi_C^{WA*}(\beta)}{\partial \beta} < 0 \Rightarrow \pi_C^{WA*}(\beta) < \pi_C^{WA*}(0) = \pi_C^{RN*} \end{array}\right\} \Rightarrow \pi_C^{WA*} < \pi_C^{RN*} < \pi_C^{SA*} \tag{A6}$$

$$\pi_C^{RN*} - \pi_C^{SW*} = \frac{B\beta[c(1+m)-p(1-m)]\{c[4p+3\beta(1+m)]-p[4p+\beta(3+m)]\}}{8p(2p+m\beta+\beta)^2} \tag{A7}$$

$$\pi_C^{SA*} - \pi_C^{SW*} = \frac{\begin{bmatrix} B\beta(p-c+m\beta)\{p[4p^2+p\beta(3+2m)+m\beta^2] \\ -c[4p^2+2m\beta^2(1+m)+3p(\beta+2m\beta)]\} \end{bmatrix}}{2(2p+m\beta)^2(2p+m\beta+\beta)^2} \tag{A8}$$

From Eqs. A5 to A8, we can obtain

$$\begin{cases} \pi_C^{WA*} < \pi_C^{SW*} < \pi_C^{RN*} < \pi_C^{SA*}, \ 0 \le m < m_5 \\ \pi_C^{WA*} < \pi_C^{RN*} < \pi_C^{SW*} < \pi_C^{SA*}, \ m_5 < m < m_6 \\ \pi_C^{WA*} < \pi_C^{RN*} < \pi_C^{SA*} < \pi_C^{SW*}, \ m > m_6 \end{cases}$$

Where m_5 and m_6 satisfy Eqs. A7 and A8, respectively. Additionally, $m_5 = \frac{p-c}{p+c}$ and $m_6 = \frac{2p^2+p\beta-2c(3p+\beta)+\sqrt{p^2(2p+\beta)^2+4cp(2p^2+p\beta-\beta^2)+4c^2(p^2+\beta^2)}}{4c\beta}$.