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DECISION MAKING AND COORDINATION OF FRESH AGRICULTURE PRODUCT SUPPLY CHAIN CONSIDERING FAIRNESS CONCERNS

Bo Yan*, Yan-Ru Chen and Shi-You He

Abstract. This paper investigates decisions in a supply chain of fresh agricultural products considering fairness concerns. By considering a two-echelon supply chain consisting of a retailer and a manufacturer, this paper discusses the effect of the manufacturer's fairness concerns and the retailer's fairness concerns on the fresh agriculture product supply chain within the framework of Nash bargaining. Meanwhile, a revenue-sharing contract is designed to coordinate the supply chain with fairness concerns. The results show that the manufacturer's behavioral tendency of fairness concerns will reduce their fresh-keeping effort; thereby, the freshness of products and market demand will also decrease. The behavioral tendencies of fairness concerns of both sides reduce the overall effectiveness of the supply chain and adversely affect the stability of the fresh produce supply chain. Both the optimal retail price and the fresh-keeping effort can be achieved while all parties get higher utilities under the revenue-sharing contract in comparison to the case without coordination.

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1. Introduction

With the continuous improvement of people's standards of living, people have adopted higher requirements for quality of life. Fresh agricultural products are necessities of daily life, and our requirement for their quality and freshness is increasing. A highly efficient supply chain is essential for maintaining the freshness of fresh agricultural products, and it has gradually become a focus in the academia, government, and enterprises in recent years. The present studies related to fresh agricultural products are mostly based on the assumption that people are perfectly rational. However, in real life, decision makers in the supply chain are also concerned about the profit distribution. The behavioral tendencies of fairness concerns significantly affect the operation of the fresh agricultural supply chain. Thus, by considering the characteristic of fresh agricultural products, this article introduces the behavioral tendency of fairness concerns to study the fresh agricultural supply chain

Keywords. Fresh agricultural products, freshness-keeping effort level, fairness concerns, supply chain coordination, revenue sharing.

South China University of Technology, School of Economics and Commerce, South China University of Technology, Guangzhou Higher Education Mega Centre, Panyu District, Guangzhou 510006, PR China.
*Corresponding author: yanbo@scut.edu.cn

and the optimal decision-making problem. Then, this article analyzes the effects of the behavioral tendency of fairness concern, and future discusses the revenue-sharing contract that can facilitate the coordination between the manufacturer and the retailer.

2. Literature review

This paper mainly studies the coordination of fresh agriculture product supply chain with fairness concern. Therefore, we discuss the literature related to supply chain coordination for fresh agricultural products.

2.1. Fresh agricultural product supply chain

Scholars have conducted extensive research on the fresh agricultural product supply chain. Most of them have focused on pricing, inventory management and ordering strategies.

Dye [15] constructed an inventory model of deteriorating items with a deterioration rate in which the optimal selling price and replenishment schedule can be found. Akcay *et al.* [2] developed a joint dynamic pricing of perishable products by using a polynomial-time exact algorithm when considering consumer choice. Lee and Dye [26] discussed the optimal order quantity and preservation technology investment strategies in a situation in which demand is dependent on stock and shortages are allowed. To study the optimal ordering strategy in the supply chain of fresh agricultural products [33], further developed the previous studies of other researchers and established a multi-item economic order quantity model in which demand depends on the efforts of retailers. Lotfi *et al.* [25] proposed a model for retailers' replenish planning and space allocation of perishable products with certain constraints on space, holding time, and budget. Wang and Li [36] examined how to reduce food spoilage waste and maximize food retailers' profit and analyzed the product pricing policies. To minimize the total cost while maintaining the quality of food products above acceptable levels [30], developed a total cost model that included various costs incurred during transportation. Qin *et al.* [31] examined the joint pricing and inventory control for fresh produce and foods by simultaneously considering quality and physical quantity deterioration.

From the perspective of the whole fresh agricultural product supply chain [29], established an innovative and low-cost gapless traceability system of fresh vegetable products using RFID, NFC, and data matrix technologies. Atallah *et al.* [4] discussed the effects of the redistribution of fresh vegetable products on total cost, product flow, and consumer price, and further analyzed the localization effects for a fresh vegetable product supply chain. Ahmadi and Hoseinpour [1] studied the effects of a cooperative advertising model on the supply chain with one manufacturer and one retailer under the Stackelberg game and Nash game. Keizer *et al.* [20] presented a mixed integer linear programming formulation and found that logistic network was important for reducing decay rate and delivery lead time.

2.2. Supply chain coordination

Most literature about supply chain coordination has focused on non-perishable products. Xiao *et al.* [37] studied how to coordinate the supply chain consisting of one manufacturer and one retailer under a revenue-sharing contract and the utility of consumer was considered. Xu *et al.* [38] investigated the impact of constructing a dual-channel supply chain coordinating contract when the supply chain agents are risk averse via a mean–variance model. Govindan and Popiuc [16] proposed an analytical model for the two- and three-echelon reverse supply chain to explore the implications of recycling and coordinated the supply chain with a revenue sharing contract. Zhang *et al.* [39] investigated the impact of consumer environmental awareness on order quantities and channel coordination in a supply chain consisting of one manufacturer and one retailer and found that the return policy can coordinate a decentralized supply chain effectively. Li *et al.* [22] discussed the pricing and greening strategies for the chain members in both centralized and decentralized cases and found that a two-part tariff contract can coordinate the decentralized dual-channel green supply chain.

Considering the characteristics of fresh agricultural products [21], highlighted the importance of information sharing and centralized control in the supply chain of perishable products and identified the conditions under which benefits are realized. To coordinate the supply chain with perishable products and achieve value maximization [6], presented an appropriate model to minimize lost value in the supply chain, which is a hybrid of a responsive model from post-harvest to cooling, followed by an efficient model in the remainder of the chain. Lohmann [24] assumed that market demand is influenced by both price level and effort. On this basis, he studied the coordination problem of the supply chain of fresh agricultural products and conducted a comparative analysis of optical solutions under three different pricing strategies. Rong *et al.* [32] analyzed the process of decision making during production and distribution in a food supply chain and provided a methodology to model food quality degradation. Huang *et al.* [18] discussed how to reduce retailers' order lead time to reduce the value loss of fresh produce in the circulation process and proposed a price discount mechanism based on order lead time to achieve coordination in the fresh agricultural product supply chain. Cai *et al.* [8] proposed an incentive scheme to coordinate the fresh product supply chain consisting of a wholesale-market clearance contract and a wholesale-price-discount sharing contract which can eliminate the "double marginalization" in the three-tier supply chain.

2.3. Fairness concerns of supply chain members

Traditional studies usually ignore the influence of other relevant factors and assume a fully rational and egoist decision maker. Decision makers maximize their benefits and make the best choices. However, in recent years, behavioral research has shown that decision makers usually focus on fairness in real management activities. That is, they are not only concerned about their own benefits but also about the benefits of other participants. When decision makers tend to have the fairness concern behavior and feelings of being treated unfairly, they most likely punish other participants even at the expense of their own benefits [13]. Although contrary to the traditional hypothesis on rational people, the fairness concern behavior has been proved by many empirical and experimental studies. Loch and Wu [23] showed that manufacturers and retailers might sacrifice their own profits to improve their counterparts' margins and thus promote fairness in the chain by experimental evidence. Katok *et al.* [19] found that when the member information is incomplete, the efficiency of the supply chain is lower than that of all members who know the fairness preference. Ho *et al.* [17] found that the sales commission contract that considers fairness preference contributes to the voluntary cooperation between the manufacturer and the retailer. Caliskan-Demirag *et al.* [9] further studied how policy makers of fairness preference coordinate the supply chain. Chen *et al.* [10] studied the impact of fairness concerns on members' equilibrium strategies in a supply chain including one supplier and one retailer, and the result showed that the retailer's fairness concerns are beneficial for the supply chain to improve the performance when the retailer takes the risk of uncertain market solely.

Thus, by considering the characteristics of fresh agricultural products, this article introduces the behavioral tendency of fairness concerns to study the fresh agricultural supply chain and the optimal decision-making problem. Then, this article analyzes the effects of the behavioral tendency of fairness concern and discusses the revenue-sharing contract that can facilitate the coordination between the manufacturer and the retailer.

3. Decentralized decision making and coordination of a fresh agricultural product chain based on fairness concerns

3.1. Description of the model and symbols

We consider a two-stage fresh agricultural product supply chain that consists of a retailer and a manufacturer with fairness concerns on both sides. The manufacturer sells the product to the retailer with a wholesale price w, and the retailer sells the product to consumers with a retail price p. The manufacturer is responsible for providing the fresh agricultural products and keeping them fresh, and the retailer is responsible for selling. The manufacturer's freshness-keeping effort level is measured by a continuous variable e. Also, we introduce a variable θ to measure the level of freshness of the fresh agricultural products, and it is dependent on the manufacturer's freshness-keeping effort.

Table 1. Symbols and their descriptions.

p	Retail price per unit, where $p \in (c, p^l)$ and p^l is the highest
w	Wholesale price per unit
c	Cost of production per unit
c_d	Deterioration cost per unit
e	Level of freshness-keeping effort of the manufacturer, where
θ	Level of the freshness of fresh agricultural products
$C_t(e)$	Freshness-keeping cost of the manufacturer
$C_d(\gamma)$	Deterioration cost of the manufacturer
D	Market demand for fresh agricultural products
π_i	π_s, π_r, and π_{sc} represent the profit of the manufacturer, the retailer, and the whole supply chain, respectively
λ_s	$\lambda_s > 0$, coefficient of the manufacturer's fairness concerns
λ_r	$\lambda r > 0$, coefficient of the retailer's fairness concerns
U	Utility function

We assume that the manufacturer's fresh-keeping effort is meaning and realistic, the perishable fresh agricultural products will be less fresh if preservation measures are not taken throughout the transportation process. Less freshness of products affects consumers' desire to buy and reduces the market demand.

Assumptions:

– Both participants have symmetric information.
– The retailer's order quantity is equal to the market demand [28].
– The market demand of the fresh agricultural products is affected by level of freshness θ and price p. The retailer cannot enhance the freshness level after receiving the product.
– The residual value of the fresh agricultural products becomes zero after their expiry date because of their perishable nature. In addition, we assume no loss when the products are out of stock.
– The producing ability of the manufacturer can fully meet the market demand.

θ denotes a freshness index in the range of $[0, 1]$, with $\theta = 0$ representing the "completely decayed" and $\theta = 1$ representing the "fully fresh". The function of the level of freshness is $\theta = \theta_0 - \gamma$, where θ_0 is the initial level of freshness in the beginning of the transportation process, γ is the product's perishability rate. Furthermore, γ is a function of e, $\gamma = (1 - he)\gamma_0$ [12], where h is the coefficient of e, and $h \in (0, 1)$, $e \in (0, 1)$.

The function of freshness-keeping cost is $C_t(e) = \frac{1}{2}\beta e^2$ [28], and β is the coefficient of freshness-keeping cost. $C_t(e)$ meets the conditions that $C_t'(e) > 0$ and $C_t''(e) > 0$. The formula shows that the more freshness-keeping effort the manufacturer takes, the higher the cost he should undertake. Moreover, the increase trend is accelerating. The function of deterioration cost is $C_d(\gamma) = c_d \times D \times \gamma$ [35], where c_d is the deterioration cost per unit.

Generally, the market demand for fresh products is relevant to the freshness and retail prices. By referring to the related literature, we assume that the function of the market demand of fresh agricultural products is $D = D(p, \theta) + \eta$, where $D(p, \theta) = a - bp + k\theta$ [28]. $a > 0$ measures the market scale, and $b > 0$, $k > 0$ represent the sensitivity of demand to price and freshness, respectively.

The symbols are described in Table 1.

On the basis of the assumptions and definitions above, we obtain the profit function of the manufacturer:

$$\begin{aligned}\pi_s = (w - c)D(p, \theta) - C_t(e) - C_d(\gamma) = (w - c)[a - bp + k(\theta_0 - (1 - he)\gamma_0)] \\ - \frac{1}{2}\beta e^2 - c_d(1 - he)\gamma_0(a - bp + k(\theta_0 - (1 - he)\gamma_0)).\end{aligned} \tag{3.1}$$

The retailer's profit function is expressed as follows:

$$\pi_r = (p-w)D(p,\theta) = (p-w)[a-bp+k(\theta_0-(1-he)\gamma_0)]. \tag{3.2}$$

In constructing the model with fairness concerns using the Nash bargaining framework, we assume that $(\pi_s^{\otimes}, \pi_r^{\otimes})$ is a fair solution for Nash bargaining and the best solution for fairness. Such an assumption is introduced into the Nash bargaining framework as a fairness reference concern. Referring to the relevant literature [3, 11], the utility function of the retailer with fairness concerns is:

$$\cup_{(\pi_r)} = \pi_r + \lambda_r(\pi_r - \pi_r^{\otimes}) = (1+\lambda_r)\pi_r - \lambda_r\pi_r^{\otimes}, \tag{3.3}$$

the utility function of the manufacturer with fairness concerns is:

$$\cup_{(\pi_s)} = \pi_s + \lambda_s(\pi_s - \pi_s^{\otimes}) = (1+\lambda_s)\pi_s - \lambda_s\pi_s^{\otimes}, \tag{3.4}$$

where $\pi_s^{\otimes}$ and $\pi_r^{\otimes}$ are the fair solutions of both parties [34]. As the relative fairness references come from the psychological Nash bargaining for fair payoff distribution between two players [14], then $\pi_s^{\otimes} + \pi_r^{\otimes} = \pi$. In addition, $\pi_s + \pi_r = \pi$.

Game theory indicates that the optimal Nash bargaining solution is the fair solution that we seek. The objective function of Nash bargaining [5] is expressed as

$$\begin{aligned} &\max_{\pi_r,\pi_s} U_{(\pi_r)}U_{(\pi_s)} \\ &\quad \text{s.t. } \pi_s + \pi_r = \pi \\ &\qquad U_{(\pi_r)},\ U_{(\pi_s)} > 0. \end{aligned}$$

Based on the above equations, we can obtain $U_{(\pi_s)} = (1+\lambda_s)(\pi-\pi_r) - \lambda_s(\pi-\pi_r^{\otimes})$, $U_{(\pi_r)}U_{(\pi_s)} = [(1+\lambda_r)\pi_r - \lambda_r\pi_r^{\otimes}] \times [(1+\lambda_s)(\pi-\pi_r) - \lambda_s(\pi-\pi_r^{\otimes})]$. Given that $\frac{\partial^2(U_{(\pi_r)}U_{(\pi_s)})}{\partial\pi_r^2} = -2(1+\lambda_r)(1+\lambda_s) < 0$, then $U_{(\pi_r)}U_{(\pi_s)}(\pi,\ \pi_r)$ is concave. To find the optimal Nash bargaining solution π_r^*, we differentiate $U_{(\pi_r)}U_{(\pi_s)}$ with respect to π_r, and set it to 0. Furthermore, π_r^* is the fair solution for Nash bargaining.

$$\begin{cases} \frac{\partial U_{(\pi_r)}U_{(\pi_s)}(\pi_r^*)}{\partial \pi_r^*} = 0 \\ \pi_r^* = \pi_r^{\otimes}. \end{cases}$$

By solving the system of equations, we can obtain the following:

$$\pi_s^{\otimes} = \frac{1+\lambda_s}{2+\lambda_s+\lambda_r}\pi, \quad \pi_r^{\otimes} = \frac{1+\lambda_r}{2+\lambda_s+\lambda_r}\pi.$$

Substituting the solutions above into (3.3) and (3.4), we obtain the utility functions of the manufacturer and the retailer:

$$\cup_{(\pi_s)} = (1+\lambda_s)\pi_s - \frac{\lambda_s(1+\lambda_s)}{2+\lambda_s+\lambda_r}\pi = \frac{(\lambda_r+2)(1+\lambda_s)}{2+\lambda_s+\lambda_r}\pi_s - \frac{\lambda_s(1+\lambda_s)}{2+\lambda_s+\lambda_r}\pi_r, \tag{3.5}$$

$$\cup_{(\pi_r)} = (1+\lambda_r)\pi_r - \frac{\lambda_r(1+\lambda_r)}{2+\lambda_s+\lambda_r}\pi = \frac{(\lambda_s+2)(1+\lambda_r)}{2+\lambda_s+\lambda_r}\pi_r - \frac{\lambda_r(1+\lambda_r)}{2+\lambda_s+\lambda_r}\pi_s. \tag{3.6}$$

The total utility of the fresh agricultural supply chain is:

$$\cup_{(\pi_{sc})} = \cup_{(\pi_s)} + \cup_{(\pi_r)}. \tag{3.7}$$

The superscript symbol "∧" represents the optimal decisions in the centralized system with neutral fairness concerns, and the superscript symbol "#" denotes the optimal decisions in the Nash-bargaining decentralized model with fairness concerns.

3.2. Centralized decision making when both parties are fairness-neutral

The objective of coordination is to maximize the overall profit of the supply chain or to maximize the overall utility. Thus, we first analyze the situation in the centralized system, which is the basis of applying revenue-sharing contract to coordinate the supply chain.

Proposition 3.1. *In the case in which both manufacturer and retailer show no fairness concerns and make centralized decisions, the optimal decisions of the fresh agricultural product supply chain are given by* $p^\wedge = \frac{-\beta(a+b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))+h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0))}{-2b\beta+h^2(k+bc_d)^2\gamma_0^2}$ *and* $e^\wedge = \frac{h(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))}{2b\beta-h^2(k+bc_d)^2\gamma_0^2}$.

On the basis of Proposition 3.1, we can obtain the level of freshness and market demand when both parties are fairness-neutral, and they are expressed as follows:

$$\theta^\wedge = \frac{2b\beta(\theta_0-\gamma_0)+h^2\left(k+bc_d\right)\gamma_0^2\left(a-b(c+c_d\theta_0)\right)}{2b\beta-h^2\left(k+bc_d\right)^2\gamma_0^2},$$
$$D^\wedge = \frac{b\beta\left(-a+bc+\left(k+bc_d\right)\gamma_0-k\theta_0\right)}{-2b\beta+h^2\left(k+bc_d\right)^2\gamma_0^2}.$$

The optimal utility of the supply chain in the centralized decision-making system is:

$$\cup^\wedge_{(\pi_{sc})} = \frac{\beta\left(a-bc-\left(k+bc_d\right)\gamma_0+k\theta_0\right)^2}{2\left(2b\beta-h^2\left(k+bc_d\right)^2\gamma_0^2\right)}.$$

Corollary 3.1. *In the case in which both parties in a two-stage fresh agricultural product supply chain are fairness-neutral, the optimal freshness-keeping effort is* $e^\wedge = \frac{h(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))}{2b\beta-h^2(k+bc_d)^2\gamma_0^2}$ *when* $0 < (a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0)) < \frac{2b\beta-h^2(k+bc_d)^2\gamma_0^2}{h(k+bc_d)\gamma_0}$, *and remains "1" when* $(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0)) > \frac{2b\beta-h^2(k+bc_d)^2\gamma_0^2}{h(k+bc_d)\gamma_0}$.

Proof. In reality, the level of freshness-keeping effort should meet the condition that $e \in [0,1]$. Thus, when $(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0)) > \frac{2b\beta-h^2(k+bc_d)^2\gamma_0^2}{h(k+bc_d)\gamma_0}$, then the optimal freshness-keeping effort is "1," and when $0 < (a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0)) < \frac{2b\beta-h^2(k+bc_d)^2\gamma_0^2}{h(k+bc_d)\gamma_0}$, the optimal freshness-keeping effort is $e^\wedge = \frac{h(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))}{2b\beta-h^2(k+bc_d)^2\gamma_0^2}$, which can be obtained in the proving process in Proposition 3.1. □

3.3. Decentralized decision making based on fairness concerns

By combining the above, we obtain their objective functions as follows:

$$\max_{w,e}\cup_{(\pi_s)} = \frac{(\lambda_r+2)(\lambda_s+1)}{\lambda_r+\lambda_s+2}\left\{\begin{array}{l}(w-c)[a-bp+k(\theta_0-(1-he)\gamma_0)]\\ -\frac{1}{2}\beta e^2-c_d(1-he)\gamma_0[a-bp+k(\theta_0-(1-he)\gamma_0)]\end{array}\right\}$$
$$-\frac{\lambda_s(\lambda_s+1)}{\lambda_r+\lambda_s+2}(p-w)[a-bp+k(\theta_0-(1-he)\gamma_0)], \quad (3.8)$$

$$\max_{p}\cup_{(\pi_r)} = \frac{(\lambda_s+2)(\lambda_r+1)}{\lambda_r+\lambda_s+2}(p-w)[a-bp+k(\theta_0-(1-he)\gamma_0)] \quad (3.9)$$
$$-\frac{\lambda_r(\lambda_r+1)}{\lambda_r+\lambda_s+2}\left\{\begin{array}{l}(w-c)[a-bp+k(\theta_0-(1-he)\gamma_0)]\\ -\frac{1}{2}\beta e_2-c_d(1-he)\gamma_0[a-bp+k(\theta_0-(1-he)\gamma_0)]\end{array}\right\}.$$

Following their utility functions, we obtain the following proposition:

Proposition 3.2. *Considering the fairness concerns of both sides in the fresh agricultural product supply chain under a decentralized decision, the optimal solution of the retailer is* $p^{\#} = \frac{-2h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0)) + \beta(2+\lambda_r)(3a+bc+b\gamma_0 c_d+a\lambda_s+k(\theta_0-\gamma_0)(3+\lambda_s))}{-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)}$, *and the optimal solutions of the manufacturer are given by*

$$w^{\#} = \frac{\begin{pmatrix} -2h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0))(2+\lambda_r+\lambda_s) \\ +\beta(2+\lambda_r)\begin{pmatrix} k\theta_0(2+\lambda_s)^2 \\ +bc\lambda_r(4+\lambda_s)+(2+\lambda_s)(2a+2bc+a\lambda_s)\end{pmatrix} \\ +\beta\gamma_0(2+\lambda_r)\left(-k(2+\lambda_s)^2+bc_d(2(2+\lambda_s)+\lambda_r(4+\lambda_s))\right)\end{pmatrix}}{\left((2+\lambda_r+\lambda_s)\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)\right)}$$

and

$$e^{\#} = \frac{2h(k+bc_d)\gamma_0(-a+bc+(k+bc_d)\gamma_0-k\theta_0)}{2h^2(k+bc_d)^2\gamma_0^2-b\beta(2+\lambda_r)(4+\lambda_s)}.$$

We can obtain the corresponding level of freshness and the market demand:

$$\theta^{\#} = \theta_0 - \gamma_0\left(1+\frac{2h^2(k+bc_d)\gamma_0(a-bc-(k+bc_d)\gamma_0+k\theta_0)}{2h^2(k+bc_d)^2\gamma_0^2-b\beta(2+\lambda_r)(4+\lambda_s)}\right),$$

$$D^{\#} = \frac{b\beta(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))(2+\lambda_r)}{-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)}.$$

The optimal utility functions of the manufacturer and the retailer are:

$$\cup^{\#}_{(\pi_s)} = \frac{\beta(a-bc-(k+bc_d)\gamma_0+k\theta_0)^2(2+\lambda_r)(1+\lambda_s)}{(2+\lambda_r+\lambda_s)\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)},$$

$$\cup^{\#}_{(\pi_r)} = \frac{\beta\begin{pmatrix} a-bc \\ -(k+bc_d)\gamma_0 \\ +k\theta_0\end{pmatrix}^2(1+\lambda_r)\begin{pmatrix} 4b\beta(2+\lambda_s)+b\beta\lambda_r^2(2+\lambda_s) \\ +2\lambda_r\begin{pmatrix} h^2(k+bc_d)^2\gamma_0^2 \\ +2b\beta(2+\lambda_s)\end{pmatrix}\end{pmatrix}}{(2+\lambda_r+\lambda_s)\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)^2}.$$

Then, we obtain the optimal utility of the whole supply chain:

$$\cup^{\#}_{(\pi_{sc})} = \frac{\beta\begin{pmatrix} a-bc \\ -(k+bc_d)\gamma_0 \\ +k\theta_0\end{pmatrix}^2\begin{pmatrix} (2+\lambda_r)(1+\lambda_s)\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right) \\ +(1+\lambda_r)\begin{pmatrix} 4b\beta(2+\lambda_s)+b\beta\lambda_r^2(2+\lambda_s) \\ +2\lambda_r\left(h^2(k+bc_d)^2\gamma_0^2+2b\beta(2+\lambda_s)\right)\end{pmatrix}\end{pmatrix}}{(2+\lambda_r+\lambda_s)\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)^2}.$$

According to Proposition 3.2, we obtain the following corollaries.

Corollary 3.2. *In the decentralized supply chain with fairness concerns, the optimal freshness-keeping effort of the manufacturer is given by* $e^{\#} = \frac{2h(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))}{-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)}$ *when* $0 < a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0) < \frac{-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)}{2h(k+bc_d)\gamma_0}$, *and remains "1" when* $a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0) > \frac{-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)}{2h(k+bc_d)\gamma_0}$.

Proof. In reality, the level of freshness-keeping effort should meet the condition that $e \in [0,1]$. Thus, when $a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0) > \frac{-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)}{2h(k+bc_d)\gamma_0}$, the optimal freshness-keeping effort is "1," and when $0 < a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0) < \frac{-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)}{2h(k+bc_d)\gamma_0}$, the optimal freshness-keeping effort is $e^{\#} = \frac{2h(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))}{-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)}$, which can be obtained in the proving process in Proposition 3.2. □

Corollary 3.3. *Considering the fairness concerns in the fresh agricultural product supply chain under a decentralized decision, the freshness-keeping effort of the manufacturer is lower than that exerted when both parties are fairness-neutral ceteris paribus.*

Proof. $\Delta e = e^{\#} - e^{\wedge} = -\frac{bh\beta(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))(2(2+\lambda_s)+\lambda_r(4+\lambda_s))}{\left(2b\beta-h^2(k+bc_d)^2\gamma_0^2\right)\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)}$.

Given that $2b\beta - h^2(k+bc_d)^2\gamma_0^2 > 0$, $\lambda_s > 0$, and $\lambda_r > 0$, we can find that $\left(-2h^2(k+bc_d)^2\gamma_0^2 + b\beta(2+\lambda_r)(4+\lambda_s)\right) > 8b\beta - 2h^2(k+bc_d)^2\gamma_0^2 > 0$, where both the numerator and the denominator are larger than 0, thus $\Delta e < 0$, that is, $e^{\#} < e^{\wedge}$. □

Corollary 3.4. *Considering the fairness concerns in the fresh agricultural product supply chain under a decentralized decision, the retail price set by the retailer is lower than when both parties are fairness-neutral ceteris paribus.*

Proof.

$$\Delta p = p^{\#} - p^{\wedge} = \frac{\begin{pmatrix}\beta(a+b(c+c_d\gamma_0)+k(\theta_0-\gamma_0)) \\ -h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0))\end{pmatrix}\left(2h^2(k+bc_d)^2\gamma_0^2 - b\beta(2+\lambda_r)(4+\lambda_s)\right) + \left(-2b\beta+h^2(k+bc_d)^2\gamma_0^2\right)\begin{pmatrix}2h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0)) \\ -\beta(2+\lambda_r)(a(3+\lambda_s)+b(c_d\gamma_0+c)+k(\theta_0-\gamma_0)(3+\lambda_s))\end{pmatrix}}{\left(2h^2(k+bc_d)^2\gamma_0^2 - b\beta(2+\lambda_r)(4+\lambda_s)\right)\left(-2b\beta+h^2(k+bc_d)^2\gamma_0^2\right)}.$$

Given that $-\beta(a+b(c+c_d\gamma_0)+k(\theta_0-\gamma_0)) + h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0)) < 0$, the numerator is smaller than 0, whereas the denominator is larger than 0. Thus, $\Delta p < 0$, that is, $p^{\#} < p^{\wedge}$. □

3.4. Effect of fairness concerns on the fresh agricultural product supply chain

Subsequently, we focus on analyzing the effect of the fairness concerns on the fresh agricultural product supply chain. According to the above, we obtain the following corollaries.

Corollary 3.5. *In consideration of the fairness concerns in the fresh agricultural product supply chain under decentralized decision, the manufacturer's fairness concern λ_s and the retailer's fairness concern λ_r are both negatively correlated with the level of manufacturer's fresh-keeping effort e. That is, the more that the manufacturer is concerned about the fairness, the lower his level of fresh-keeping effort becomes. The retailers' fairness concerns also decrease the manufacturer's level of fresh-keeping effort.*

Proof. According to the formula of the optimal fresh-keeping effort $e^{\#}$, we can obtain the first-order derivative with respect to λ_s, λ_r, the formulas are expressed as following:

$$\frac{\partial e^{\#}}{\partial \lambda_r} = -\frac{2bh\beta(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))(4+\lambda_s)}{\left(2h^2(k+bc_d)^2\gamma_0^2 - b\beta(2+\lambda_r)(4+\lambda_s)\right)^2} < 0,$$

$$\frac{\partial e^{\#}}{\partial \lambda_s} = -\frac{2bh\beta(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))(2+\lambda_r)}{\left(2h^2(k+bc_d)^2\gamma_0^2 - b\beta(2+\lambda_r)(4+\lambda_s)\right)^2} < 0.$$

□

Corollary 3.6. *In consideration of the fairness concerns in the fresh agricultural product supply chain under a decentralized decisions, the wholesale pricew and retail pricep are both positively correlated with the manufacturer's fairness concerns λ_s. That is, the more that the manufacturer is concerned about fairness, the higher the wholesale price that he will set. The retail price also increases with the increase in the manufacturer's fairness* *concern. The wholesale pricewand retail pricep are both negatively correlated with the retailer's fairness concerns* λ_r*. That is, when the retailer is concerned about fairness, the manufacturer must reduce the wholesale price to meet the fairness concern behavior. Furthermore, the retailer reduces the retail price because of the decrease in wholesale price.*

Proof. According to the formulas of the optimal wholesale price $w^{\#}$and optimal retail price $p^{\#}$, we can obtain the first-order derivative with respect to λ_s and λ_r. The formulas are expressed as following:

$$\frac{\partial w^{\#}}{\partial \lambda_r} = \frac{\begin{pmatrix} -2h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0))(2+\lambda_r+\lambda_s) \\ +\beta(2+\lambda_r)\begin{pmatrix} k(\theta_0-\gamma_0)(2+\lambda_s)^2 \\ +b(c+c_d\gamma_0)\lambda_r(4+\lambda_s) \\ +(2+\lambda_s)(2a+2b(c+c_d\gamma_0)+a\lambda_s) \end{pmatrix} \end{pmatrix}\begin{pmatrix} -b\beta(4+\lambda_s)(2+\lambda_r+\lambda_s) \\ +2h^2(k+bc_d)^2\gamma_0^2 \\ -b\beta(2+\lambda_r)(4+\lambda_s) \end{pmatrix} + \begin{pmatrix} -2h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0)) \\ +\beta\begin{pmatrix} 4a+12bc+4a\lambda_s+4bc\lambda_s+a\lambda_s^2 \\ +k(\theta_0-\gamma_0)(2+\lambda_s)^2+2bc\lambda_r(4+\lambda_s) \\ +2bc_d\gamma_0(2(3+\lambda_s)+\lambda_r(4+\lambda_s)) \end{pmatrix} \end{pmatrix}(2+\lambda_r+\lambda_s)\begin{pmatrix} -2h^2(k+bc_d)^2\gamma_0^2 \\ +b\beta(2+\lambda_r)(4+\lambda_s) \end{pmatrix}}{(2+\lambda_r+\lambda_s)^2\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)^2} < 0,$$

$$\frac{\partial w^{\#}}{\partial \lambda_s} = \frac{\beta(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))(2+\lambda_r)\begin{pmatrix} b\beta(2+\lambda_r)(2+\lambda_s)(2(2+\lambda_s)+\lambda_r(6+\lambda_s)) \\ -2h^2\gamma_0^2(k+bc_d)(k(2+\lambda_s)(2+2\lambda_r+\lambda_s)-\lambda_r^2bc_d) \end{pmatrix}}{(2+\lambda_r+\lambda_s)^2\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)^2} > 0,$$

$$\frac{\partial p^{\#}}{\partial \lambda_r} = -\frac{2h^2\beta(k+bc_d)\gamma_0^2(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))(k(3+\lambda_s)-bc_d)}{\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)^2} < 0,$$

$$\frac{\partial p^{\#}}{\partial \lambda_s} = \frac{\beta(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))(2+\lambda_r)\left(b\beta(2+\lambda_r)-2h^2k(k+bc_d)\gamma_0^2\right)}{\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)^2} > 0.$$

□

3.5. Coordination of the fresh agricultural product supply chain based on two parties' fairness concerns

The revenue-sharing contract (w^o, ϕ) is adopted in this paper to coordinate the fresh agricultural product supply chain, $w^o$is the wholesale price after coordination while ϕ is the revenue share coefficient of manufacturer. We can obtain the profit functions of the two participants in the supply chain:

$$\begin{aligned} \pi_s &= (\phi p + w^o - c)D(p,\theta) - C_t(e) - C_d(\gamma) \\ &= (\phi p + w^o - c)[a - bp + k(\theta_0 - (1-he)\gamma_0)] \\ &\quad - \frac{1}{2}\beta e^2 - c_d(1-he)\gamma_0[a - bp + k(\theta_0 - (1-he)\gamma_0)], \end{aligned} \tag{3.10}$$

$$\begin{aligned} \pi_r &= [(1-\phi)p - w^o]D(p,\theta) \\ &= [(1-\phi)p - w^o][a - bp + k(\theta_0 - (1-he)\gamma_0)]. \end{aligned} \tag{3.11}$$

Correspondingly, the utility functions of the manufacturer and the retailer are:

$$\begin{aligned} \cup_{(\pi_s)} &= \frac{(\lambda_r+2)(\lambda_s+1)}{\lambda_r+\lambda_s+2}\left\{\begin{array}{l} (\phi p + w^o - c)[a - bp + k(\theta_0 - (1-he)\gamma_0)] \\ -\frac{1}{2}\beta e^2 - c_d(1-he)\gamma_0[a - bp + k(\theta_0 - (1-he)\gamma_0)] \end{array}\right\} \\ &\quad - \frac{\lambda_s(\lambda_s+1)}{\lambda_r+\lambda_s+2}[(1-\phi)p - w^o][a - bp + k(\_0 - (1-he)\gamma_0)], \end{aligned} \tag{3.12}$$

$$\cup_{(\pi_r)} = \frac{(\lambda_s+2)(\lambda_r+1)}{\lambda_r+\lambda_s+2}[(1-\phi)p-w^o][a-bp+k(\theta_0-(1-he)\gamma_0)] - \frac{\lambda_r(\lambda_r+1)}{\lambda_r+\lambda_s+2}\left\{\begin{array}{l}(\phi p+w^o-c)[a-bp+k(\theta_0-(1-he)\gamma_0)]\\ -\frac{1}{2}\beta e^2-c_d(1-he)\gamma_0[a-bp+k(\theta_0-(1-he)\gamma_0)]\end{array}\right\}. \tag{3.13}$$

By maximizing the value of equation (3.13), we obtain the response function of the retail pricep' on the wholesale price w^o and the freshness-keeping effort of the manufacturer e:

$$p' = \frac{a+k(\theta_0-(1-he)\gamma_0)}{2b} + \frac{[\lambda_r(c+c_d\gamma_0-(w^o+hec_d\gamma_0))]-w^o(2+\lambda_s)}{2\left(\phi\lambda_r+(-1+\phi)\left(2+\lambda_s\right)\right)}. \tag{3.14}$$

After adopting the revenue-sharing contract, since the demand is a linear function of price, if the price of the fresh agricultural product supply chain under the decentralized decision-making model is the same as that under the centralized decision-making model, then the optimal sales of the two decision-making models are the same. To make the strategy in the decentralized system the same as that in the centralized system, we let $p' = p^\wedge$ and $e = e^\wedge$ in equation (3.14), and obtain the wholesale price under the revenue-sharing contract:

$$w^o = \frac{(-1+\phi)\left(\begin{array}{c}c\left(2b\beta-h^2k^2\gamma_0^2\right)-bh^2c_d^2\gamma_0^2\left(a+k\theta_0\right)\\ -c_d\gamma_0\left(-2b\beta+h^2k\gamma_0\left(a+bc+k\theta_0\right)\right)\end{array}\right)}{-2b\beta+h^2\left(k+bc_d\right)^2\gamma_0^2}.$$

In order to stimulate two parties in the supply chain to implement the revenue sharing contract, the following constraints should be met in addition to determining the revenue distribution coefficient ϕ:

$$\cup_{(\pi_s)} \geq \cup^{\#}_{(\pi_s)}, \cup_{(\pi_r)} \geq \cup^{\#}_{(\pi_r)}. \tag{3.15}$$

By solving the inequalities system, the range of ϕ can be obtained.

$$\phi = \left[\frac{\begin{array}{l}4b\beta\left(2+\lambda_s\right)^2\\ +h^2\left(k+bc_d\right)^2\gamma_0^2\lambda_r^2\left(4+\lambda_s\right)\\ +2\lambda_r\left(2+\lambda_s\right)\left(\begin{array}{l}2h^2\left(k+bc_d\right)^2\gamma_0^2\\ +b\beta\left(2+\lambda_s\right)\end{array}\right)\end{array}}{2\left(2+\lambda_r+\lambda_s\right)\left(\begin{array}{l}-2h^2\left(k+bc_d\right)^2\gamma_0^2\\ +b\beta\left(2+\lambda_r\right)\left(4+\lambda_s\right)\end{array}\right)}, \frac{\begin{array}{l}2b^2\beta^2\left(2+\lambda_r\right)^2\left(2+\lambda_s\right)^2\left(6+\lambda_s\right)\\ +bh^2\beta\left(k+bc_d\right)^2\gamma_0^2\left(4+\lambda_r\right)\left(\begin{array}{l}8\lambda_r\left(2+\lambda_s\right)\\ -4\left(2+\lambda_s\right)^2+\lambda_r^2\left(4+\lambda_s\right)^2\end{array}\right)\\ -2h^4\left(k+bc_d\right)^4\gamma_0^4\lambda_r\left(8\left(2+\lambda_s\right)+\lambda_r\left(10+3\lambda_s\right)\right)\end{array}}{2\left(2+\lambda_r+\lambda_s\right)\left(\begin{array}{l}-2h^2\left(k+bc_d\right)^2\gamma_0^2\\ +b\beta\left(2+\lambda_r\right)\left(4+\lambda_s\right)\end{array}\right)^2}\right].$$

According to the range of ϕ, the variable ϕ can be any value within the above range, and it is determined by the two parties' coordination.

Substituting $\phi_1 = \frac{\begin{array}{l}4b\beta\left(2+\lambda_s\right)^2+h^2\left(k+bc_d\right)^2\gamma_0^2\lambda_r^2\left(4+\lambda_s\right)\\ +2\lambda_r\left(2+\lambda_s\right)\left(2h^2\left(k+bc_d\right)^2\gamma_0^2+b\beta\left(2+\lambda_s\right)\right)\end{array}}{2(2+\lambda_r+\lambda_s)\left(-2h^2(k+bc_d)^2\gamma_0^2+b\beta(2+\lambda_r)(4+\lambda_s)\right)}$ into equations (3.12) and (3.13), we derive the optimal utility of the manufacturer as follows:

$$U_{(\pi_s)} = \frac{\beta\left(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0)\right)^2\left(2+\lambda_r\right)\left(1+\lambda_s\right)}{\left(2+\lambda_r+\lambda_s\right)\left(-2h^2\left(k+bc_d\right)^2\gamma_0^2+b\beta\left(2+\lambda_r\right)\left(4+\lambda_s\right)\right)}.$$

The optimal utility of the retailer is given by

$$U_{(\pi_r)} = \frac{\beta\left(a-bc-\left(k+bc_d\right)\gamma_0+k\theta_0\right)^2\left(1+\lambda_r\right)\left(2b\beta\left(2+\lambda_s\right)+\lambda_r\left(h^2\left(k+bc_d\right)^2\gamma_0^2+b\beta\left(2+\lambda_s\right)\right)\right)}{\left(-2b\beta+h^2\left(k+bc_d\right)^2\gamma_0^2\right)\left(2+\lambda_r+\lambda_s\right)\left(2h^2\left(k+bc_d\right)^2\gamma_0^2-b\beta\left(2+\lambda_r\right)\left(4+\lambda_s\right)\right)}.$$

The total utility of the supply chain under the revenue-sharing contract is expressed as

$$U_{(\pi_{\text{sc}})}=\frac{\beta\left(a-bc-\left(k+bc_{d}\right)\gamma_{0}+k\theta_{0}\right)^{2}\begin{pmatrix}h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\left(\lambda_{r}^{2}-\lambda_{r}\lambda_{s}-2\left(1+\lambda_{s}\right)\right)\\+b\beta\left(2+\lambda_{r}\right)\left(4+3\lambda_{s}+\lambda_{r}\left(2+\lambda_{s}\right)\right)\end{pmatrix}}{\left(-2b\beta+h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\right)\left(2+\lambda_{r}+\lambda_{s}\right)\left(2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}-b\beta\left(2+\lambda_{r}\right)\left(4+\lambda_{s}\right)\right)}.$$

Comparing the utilities above with utility of parties in the supply chain without the revenue-sharing contract, we obtain

$$U_{(\pi_{s})}-U_{(\pi_{s})}^{\#}=0,$$

$$U_{(\pi_{r})}-U_{(\pi_{r})}^{\#}=\frac{b\beta^{2}\begin{pmatrix}a-bc\\-\left(k+bc_{d}\right)\gamma_{0}\\+k\theta_{0}\end{pmatrix}^{2}\left(1+\lambda_{r}\right)\begin{pmatrix}4b\beta\left(2+\lambda_{s}\right)^{2}+4\lambda_{r}\left(2+\lambda_{s}\right)\begin{pmatrix}h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\\+b\beta\left(2+\lambda_{s}\right)\end{pmatrix}\\+\lambda_{r}^{2}\left(b\beta\left(2+\lambda_{s}\right)^{2}+2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\left(3+\lambda_{s}\right)\right)\end{pmatrix}}{\left(2b\beta-h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\right)\left(2+\lambda_{r}+\lambda_{s}\right)\left(-2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}+b\beta\left(2+\lambda_{r}\right)\left(4+\lambda_{s}\right)\right)^{2}}\geq 0.$$

Substituting

$$\phi_{2}=\frac{\begin{matrix}2b^{2}\beta^{2}\left(2+\lambda_{r}\right)^{2}\left(2+\lambda_{s}\right)^{2}\left(6+\lambda_{s}\right)+bh^{2}\beta\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\left(4+\lambda_{r}\right)\begin{pmatrix}8\lambda_{r}\left(2+\lambda_{s}\right)\\-4\left(2+\lambda_{s}\right)^{2}+\lambda_{r}^{2}\left(4+\lambda_{s}\right)^{2}\end{pmatrix}\\-2h^{4}\left(k+bc_{d}\right)^{4}\gamma_{0}^{4}\lambda_{r}\left(8\left(2+\lambda_{s}\right)+\lambda_{r}\left(10+3\lambda_{s}\right)\right)\end{matrix}}{2\left(2+\lambda_{r}+\lambda_{s}\right)\left(-2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}+b\beta\left(2+\lambda_{r}\right)\left(4+\lambda_{s}\right)\right)^{2}}$$ into

equations (3.12) and (3.13), we derive the manufacturer's optimal utility

$$U_{(\pi_{s})}=\frac{\beta\begin{pmatrix}a-bc\\-\left(k+bc_{d}\right)\gamma_{0}\\+k\theta_{0}\end{pmatrix}^{2}\left(1+\lambda_{s}\right)\begin{pmatrix}2h^{4}\left(k+bc_{d}\right)^{4}\gamma_{0}^{4}\left(2+\lambda_{r}\right)\\+b^{2}\beta^{2}\left(2+\lambda_{r}\right)^{2}\left(12+6\lambda_{s}+\lambda_{s}^{2}\right)\\+bh^{2}\beta\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\left(\lambda_{r}^{2}\left(2+\lambda_{s}\right)-12\lambda_{r}+-4\left(6+\lambda_{s}\right)\right)\end{pmatrix}}{\left(2b\beta-h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\right)\left(2+\lambda_{r}+\lambda_{s}\right)\left(-2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}+b\beta\left(2+\lambda_{r}\right)\left(4+\lambda_{s}\right)\right)^{2}}.$$

The retailer's optimal utility is expressed as

$$U_{(\pi_{r})}=\frac{\beta\left(a-bc-\left(k+bc_{d}\right)\gamma_{0}+k\theta_{0}\right)^{2}\left(1+\lambda_{r}\right)\begin{pmatrix}4b\beta\left(2+\lambda_{s}\right)+b\beta\lambda_{r}^{2}\left(2+\lambda_{s}\right)\\+2\lambda_{r}\left(h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}+2b\beta\left(2+\lambda_{s}\right)\right)\end{pmatrix}}{\left(2+\lambda_{r}+\lambda_{s}\right)\left(-2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}+b\beta\left(2+\lambda_{r}\right)\left(4+\lambda_{s}\right)\right)^{2}}.$$

The total utility of the supply chain under the revenue-sharing contract is given by

$$U_{(\pi_{\text{sc}})}=\frac{\beta\left(a-bc-\left(k+bc_{d}\right)\gamma_{0}+k\theta_{0}\right)^{2}\begin{pmatrix}2h^{4}\left(k+bc_{d}\right)^{4}\gamma_{0}^{4}\left(\lambda_{r}^{2}-\lambda_{r}\lambda_{s}-2\left(1+\lambda_{s}\right)\right)\\-b^{2}\beta^{2}\left(2+\lambda_{r}\right)^{2}\left(16+20\lambda_{s}+7\lambda_{s}^{2}+\lambda_{s}^{3}+2\lambda_{r}\left(2+\lambda_{s}\right)\right)\\+bh^{2}\beta\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\begin{pmatrix}\lambda_{r}^{3}\left(2+\lambda_{s}\right)+4\lambda_{r}\left(6+5\lambda_{s}\right)\\+\lambda_{r}^{2}\left(4+2\lambda_{s}-\lambda_{s}^{2}\right)+4\left(8+8\lambda_{s}+\lambda_{s}^{2}\right)\end{pmatrix}\end{pmatrix}}{\left(-2b\beta+h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\right)\left(2+\lambda_{r}+\lambda_{s}\right)\left(-2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}+b\beta\left(2+\lambda_{r}\right)\left(4+\lambda_{s}\right)\right)^{2}}.$$

Comparing the utilities above with utility of parties in the supply chain without the revenue-sharing contract, we obtain

$$U_{(\pi_{s})}-U_{(\pi_{s})}^{\#}=\frac{b\beta^{2}\begin{pmatrix}a-bc\\-\left(k+bc_{d}\right)\gamma_{0}\\+k\theta_{0}\end{pmatrix}^{2}\left(1+\lambda_{s}\right)\begin{pmatrix}4b\beta\left(2+\lambda_{s}\right)^{2}\\+4\lambda_{r}\left(2+\lambda_{s}\right)\begin{pmatrix}h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\\+b\beta\left(2+\lambda_{s}\right)\end{pmatrix}\\+\lambda_{r}^{2}\begin{pmatrix}b\beta\left(2+\lambda_{s}\right)^{2}\\+2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\left(3+\lambda_{s}\right)\end{pmatrix}\end{pmatrix}}{\left(2b\beta-h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}\right)\left(2+\lambda_{r}+\lambda_{s}\right)\left(-2h^{2}\left(k+bc_{d}\right)^{2}\gamma_{0}^{2}+b\beta\left(2+\lambda_{r}\right)\left(4+\lambda_{s}\right)\right)^{2}}\geq 0,$$

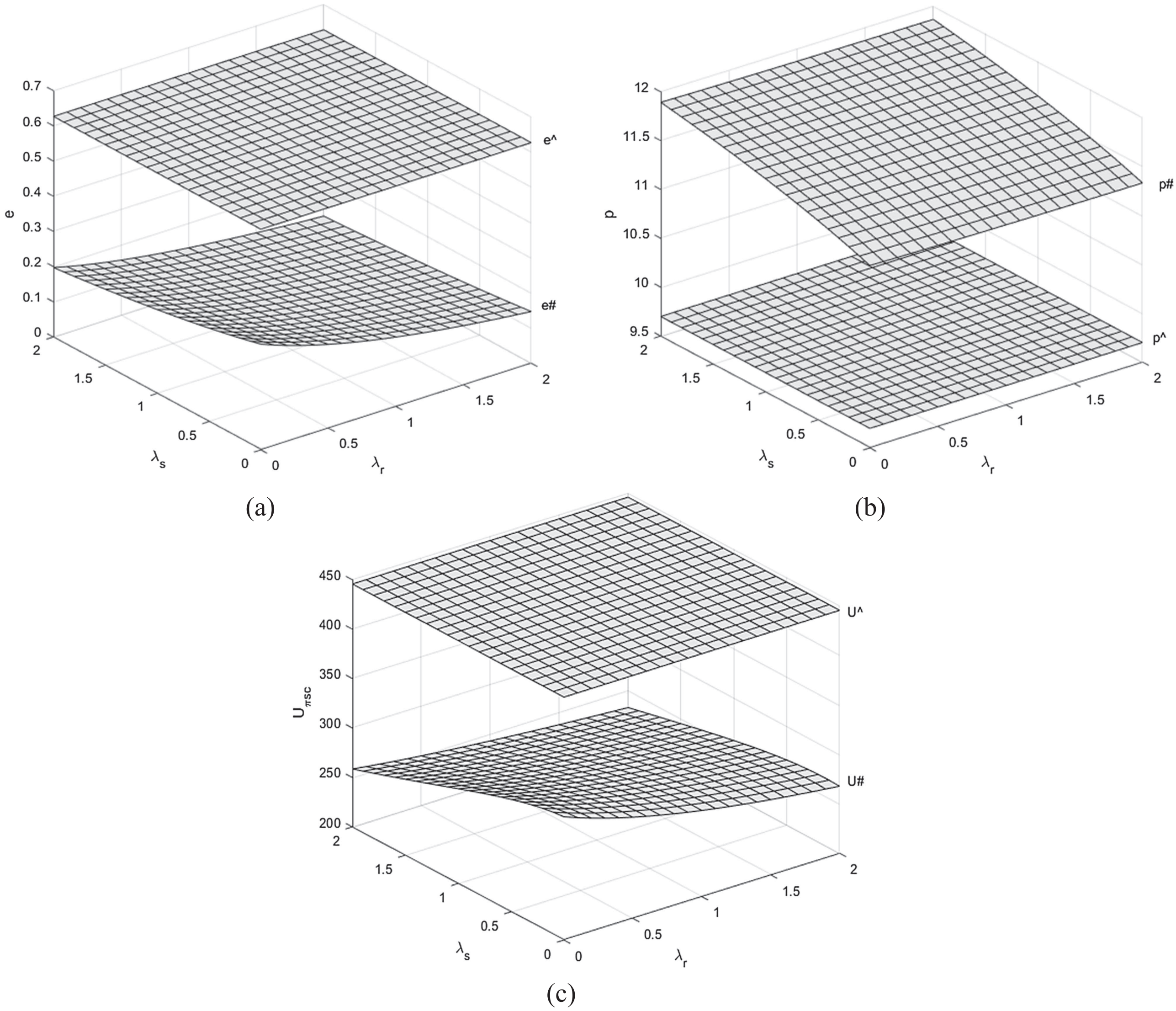

Figure 1. (a) Effect of fairness concerns on the freshness-keeping effort. (b) Effect of fairness concerns on the retail price. (c) Effects of fairness concerns on the overall utility of the fresh agricultural product supply chain.

$$U_{(\pi_r)} - U^{\#}_{(\pi_r)} = 0.$$

We can find that all parties get higher utilities under the revenue-sharing contract in comparison with the case without coordination. Consequently, the retailer and the manufacturer have enough motivation to accept the revenue-sharing contract.

4. Case study

In this paper, we use the historical sale data, and the market research information about tilapia in May 2015 provided by our cooperative unit Foshan Jushi Agricultural Development Co. Ltd. in China to determine the value of the parameters in the model. Then, to analyze the data.

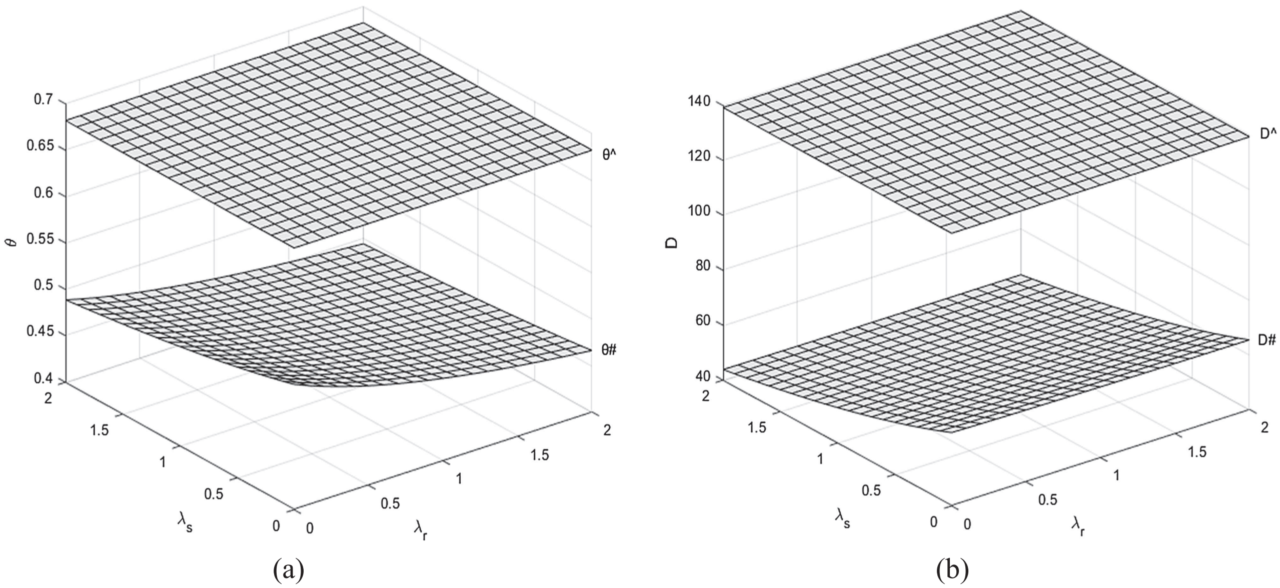

FIGURE 2. (a) Effect of fairness concerns on freshness (b) Effect of fairness concerns on market demand.

To maintain the freshness of tilapia during transport to the retailer, the company chooses to use refrigerated trucks, and doing so incurs a certain cost that is mainly borne by this company. By combining the existing data and the relevant literature [7, 28], we can obtain the parameter values in the model, which are $c = 6$, $c_d = 1$, $\beta = 200$, $\theta_0 = 0.9$, $\gamma_0 = 0.5$, $h = 0.9$; In addition, the market research data indicate that the lowest degree of freshness consumers are willing to accept is 0.3, and that the effect of the freshness level on the market demand is linear when it is over 0.3. From historical data, we obtain the parameter values of the demand function: $a = 500$, $b = 40$, and $k = 40$. In this paper, we assume that the coefficient value of the fairness concerns λ_r and λ_s starts from 0 to 2 with an equal interval of 0.1.

To fully illustrate how the fairness concerns of both the manufacturer and the retailer affect the fresh agricultural product supply chain, this article introduces the centralized decision with fairness-neutrality to compare with the decentralized decision with fairness concerns within the Nash bargaining framework.

The results in Figure 1 verify Corollaries 3.3–3.5.

Figure 1(a) describes that compared with centralized decisions with fairness-neutrality, the manufacturer's level of fresh-keeping effort is lower than that in the decentralized decision making with fairness concern. Also, the fairness concerns negatively affect the manufacturer's freshness-keeping effort. Figure 1(b) illustrates that the retailer's price decreases with the increase of the retailer's fairness concern. The retail price increases with the increase of the manufacturer's fairness concern and decreases with the increase of the retailer's fairness concern; the behavioral tendency of the retailer's fairness concern has little effect on retail price. Figure 1(c) demonstrates that the overall utility in a centralized supply chain is greater than that in a decentralized supply chain. Also, the increase in the manufacturer's fairness concerns and retailer's fairness concerns both result in the decrease in the overall utility of the fresh agricultural product supply chain. In sum, the decisions in the centralized supply chain are better that those in the decentralized supply chain.

The results in Figure 2 indicate that both freshness and market demand decrease as the two parties' levels of fairness concern increase.

The results in Figure 3 show the relationships among the wholesale price, the retailer and the manufacturer's utility and the level of fairness concerns.

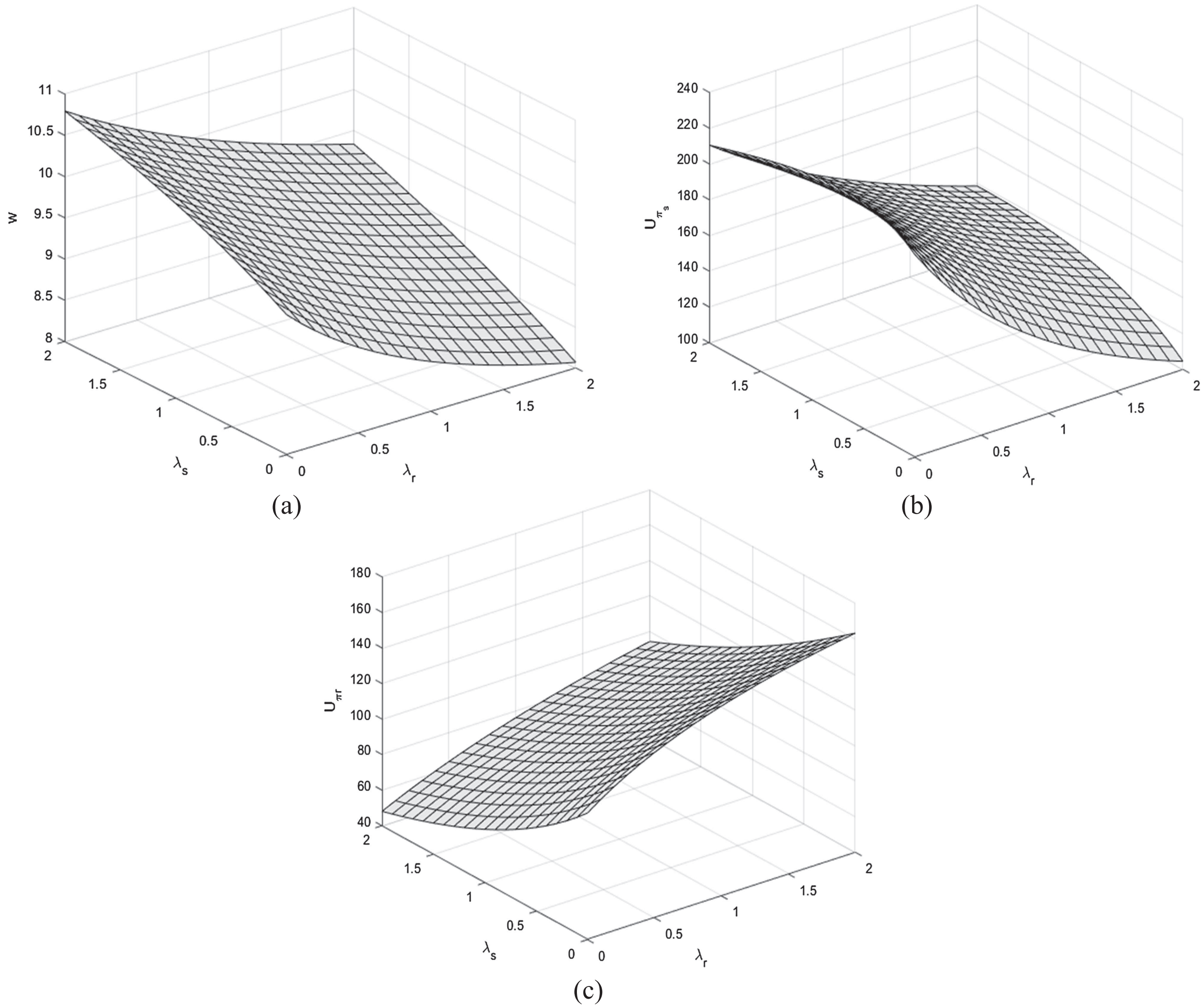

FIGURE 3. (a) Effect of fairness concerns on the wholesale price (b) Effect of fairness concerns on the utility of the manufacturer (c) Effect of fairness concerns on the utility of the retailer.

Figure 3(a) indicates that the manufacturer sets a higher wholesale price to maintain his personal utility. Figure 3(b) indicates that the manufacturer's utility increases with the increase in his fairness concerns when $\lambda_s > 1$, whereas it decreases with the increase in his fairness concerns when $0 < \lambda_s < 1$. The manufacturer's utility is negatively correlated with retailer's fairness concerns and decreases with the increase in retailer's fairness concerns. Figure 3(c) presents the effect of two parties' fairness concerns on the retailer's utility. The figure indicates that the utility of the retailer is negatively correlated with the manufacturer's level of fairness concerns and is positively correlated with the level of the retailer's fairness concerns.

5. Conclusions

In this paper, we discuss the effect of the behavioral tendency of fairness concerns on the optimal fresh-keeping efforts and optimal pricing decisions of the fresh agricultural product supply chain within the Nash bargaining framework. Furthermore, we compare the different situations of fairness concerns and fairness-neutrality. Then, we adopt the revenue-sharing contract to coordinate the fresh agricultural product supply chain, and we obtain the contract parameter and its range. We intuitively investigate the effect of fairness concerns on the fresh agricultural product supply chain through an empirical analysis.

The research results indicate that the fresh-keeping efforts decrease progressively with two parties' fairness concerns and that the retailer's fairness concerns considerably influence the manufacturer's decision making. Correspondingly, the increase in two parties' fairness concerns reduces freshness and market demand of fresh agricultural products provided by manufacturers. The wholesale price and retail price increase progressively with the increase in the manufacturer's fairness concerns and decrease progressively with the increase in the retailer's fairness concerns. When the manufacturer's fairness concern is relatively high, his utility decreases progressively with the increase in his fairness concerns and conversely increases. The behavioral tendency of the retailer's fairness concern reduces the manufacturer's utility, and the retailer's utility decreases with the increase in the manufacturer's fairness concerns and increase with the increase in the retailer's fairness concerns. The retailer's fairness concerns intensify the game during the operation of the fresh agricultural product supply chain. The profit of two parties is redistributed according to the result of the game. The fairness concerns lead to the reduction of the overall utility of the fresh agricultural product supply chain.

Appendix

Proof of Proposition. Based on equations (3.1) and (3.2), we obtain the function of the expected utility of the whole supply chain, which is as follows:

$$\begin{aligned} U_{(\pi_{\text{sc}})} &= \pi_{\text{sc}} = \pi_s + \pi_r \\ &= (p-c)[a - bp + k(\theta_0 - (1-he)\gamma_0)] \\ &\quad -\tfrac{1}{2}\beta e^2 - c_d(1-he)\gamma_0(a - bp + k(\theta_0 - (1-he)\gamma_0)). \end{aligned}$$

We differentiate $U_{(\pi_{\text{sc}})}$ with respect to the retail price p and the level of freshness-keeping effort e, setting them to 0.

$$\begin{cases} \frac{\partial U_{(\pi_{\text{sc}})}}{\partial p} = a - 2bp + bc + k\theta_0 - (1-he)\gamma_0(k - bc_d) = 0 \\ \frac{\partial U_{(\pi_{\text{sc}})}}{\partial e} = -e\beta - 2h\left(1-eh\right)kc_d\gamma_0^2 + h\gamma_0\left(k\left(p-c\right) + c_d\left(a - bp + k\theta_0\right)\right) = 0. \end{cases}$$

We can find the optimal retail price p and the level of freshness-keeping effort e by solving the above equation.

$$\begin{cases} p^{\wedge} = \frac{-\beta(a+b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))+h^2(k+bc_d)\gamma_0^2(ck+c_d(a+k\theta_0))}{-2b\beta+h^2(k+bc_d)^2\gamma_0^2} \\ e^{\wedge} = \frac{h(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))}{2b\beta-h^2(k+bc_d)^2\gamma_0^2}. \end{cases}$$

From the model description above and the reality, $p > c + c_d\gamma_0$. In addition, even though the manufacture's fresh-keeping effort is 0, the market demand for fresh agricultural products cannot be negative. Thus, we obtain $(a - b(c + c_d\gamma_0) + k(\theta_0 - \gamma_0)) > 0$. The manufacturer's fresh-keeping effort cannot be negative, that is, $e^{\wedge} = \frac{h(k+bc_d)\gamma_0(a-b(c+c_d\gamma_0)+k(\theta_0-\gamma_0))}{2b\beta-h^2(k+bc_d)^2\gamma_0^2} > 0$. Thus, we obtain $2b\beta - h^2\left(k+bc_d\right)^2\gamma_0^2 > 0$.

Given that $p^{\wedge} > 0$, $-2b\beta + h^2\left(k+bc_d\right)^2\gamma_0^2 < 0$, thus we can get $-\beta\left(a + b(c + c_d\gamma_0) + k(\theta_0 - \gamma_0)\right) + h^2\left(k+bc_d\right)\gamma_0^2\left(ck + c_d\left(a + k\theta_0\right)\right) < 0$.

The Hessian Matrix of $U_{(\pi_{\text{sc}})}$ is expressed as

$$H = \begin{bmatrix} \frac{\partial^2 U_{(\pi_{\text{sc}})}}{\partial p^2} & \frac{\partial^2 U_{(\pi_{\text{sc}})}}{\partial p \partial e} \\ \frac{\partial^2 U_{(\pi_{\text{sc}})}}{\partial e \partial p} & \frac{\partial^2 U_{(\pi_{\text{sc}})}}{\partial e^2} \end{bmatrix} = \begin{bmatrix} -2b & h\left(k - bc_d\right)\gamma_0 \\ h\left(k - bc_d\right)\gamma_0 & -\beta + 2h^2kc_d\gamma_0^2 \end{bmatrix}.$$

We can find that $|H| = 2b\beta - h^2\left(k+bc_d\right)^2\gamma_0^2$, as $2b\beta - h^2\left(k+bc_d\right)^2\gamma_0^2 > 0$, $|H| > 0$. Furthermore, the first order leading principal minor is $|H_1| = -2b < 0$. Therefore, the Hessian Matrix is negative definite. In addition, $p^{\wedge}$ and $e^{\wedge}$ are the optimal results. □

Proof of Proposition. Backward induction indicate that the second-order derivative on $\cup_{(\pi_{\mathrm{sc}})}$ with respect to the p is $\partial^2\cup_{(\pi_r)}/\partial p^2 = \frac{-2b(\lambda_s+2)(\lambda_r+1)}{\lambda_s+\lambda_r+2} < 0$; thus, $\cup_{(\pi_r)}$ has the maximum value with respect to p. Then, we take the first-order derivative on $\cup_{(\pi_{\mathrm{sc}})}$ with respect to p. By letting this equation be equal to zero, we obtain the response function of p to the wholesale price w and the freshness-keeping effort e as follows:

$$p' = \frac{2a + 2bw - bc\lambda_r + bw\lambda_r + a\lambda_s + bw\lambda_s + k\theta_0\left(2+\lambda_s\right) + \left(-1+eh\right)\gamma_0\left(bc_d\lambda_r + k\left(2+\lambda_s\right)\right)}{2b\left(2+\lambda_s\right)}.$$

By combining equation (3.10) and the above equation, we obtain the Hessian matrix of $\cup_{(\pi_s)}$.

$$H = \begin{bmatrix} \frac{\partial^2\cup_{(\pi_s)}}{\partial w^2} & \frac{\partial^2\cup_{(\pi_s)}}{\partial w\partial e} \\ \frac{\partial^2\cup_{(\pi_s)}}{\partial e\partial w} & \frac{\partial^2\cup_{(\pi_s)}}{\partial e^2} \end{bmatrix}$$

$$= \begin{bmatrix} -\frac{b(1+\lambda_s)(4+\lambda_s)(2+\lambda_r+\lambda_s)}{2(2+\lambda_s)^2} & \frac{h\gamma_0(1+\lambda_s)\left(k(2+\lambda_s)^2 - bc_d(2(2+\lambda_s)+\lambda_r(4+\lambda_s))\right)}{2(2+\lambda_s)^2} \\ \frac{h\gamma_0(1+\lambda_s)\left(\begin{array}{c} k\left(2+\lambda_s\right)^2 \\ -bc_d\left(2\left(2+\lambda_s\right)+\lambda_r\left(4+\lambda_s\right)\right)\end{array}\right)}{2(2+\lambda_s)^2} & -\left(\begin{array}{l}\left(\left(1+\lambda_s\right)\left(\begin{array}{c} -2bh^2kc_d\gamma_0^2\left(2+\lambda_r\right)\left(2+\lambda_s\right)^2 + \left(2+\lambda_s\right)^2\left(4b\beta + 2b\beta\lambda_r + h^2k^2\gamma_0^2\lambda_s\right) \\ +b^2h^2c_d^2\gamma_0^2\lambda_r\left(4\left(2+\lambda_s\right)+\lambda_r\left(4+\lambda_s\right)\right)\end{array}\right)\right) \\ /\left(2b\left(2+\lambda_s\right)^2\left(2+\lambda_r+\lambda_s\right)\right)\end{array}\right) \end{bmatrix}.$$

From the formula above, we obtain $|H| = \frac{(1+\lambda_s)^2\left(-2h^2(k+bc_d)^2\gamma_0^2 + b\beta(2+\lambda_r)(4+\lambda_s)\right)}{2(2+\lambda_s)^2}$. Combining this with $2b\beta - h^2\left(k+bc_d\right)^2\gamma_0^2 > 0$, we can conclude that $|H| > 0$. Furthermore, $|H_1| = -\frac{b(1+\lambda_s)(4+\lambda_s)(2+\lambda_r+\lambda_s)}{2(2+\lambda_s)^2} < 0$; hence, the Hessian matrix is negative, and $\cup_{(\pi_s)}$ is a joint concave function of e and w. Taking the first-order derivative on $\cup_{(\pi_{\mathrm{sc}})}$ with respect to e and w, and letting them be 0, i.e., $\partial\cup_{(\pi_s)}/\partial w = 0$ and $\partial\cup_{(\pi_s)}/\partial e = 0$, we obtain the optimal freshness-keeping effort $e^{\#}$ and the optimal wholesale price $w^{\#}$.

$$e^{\#} = \frac{2h\left(k+bc_d\right)\gamma_0\left(a - b(c + c_d\gamma_0) + k(\theta_0 - \gamma_0)\right)}{-2h^2\left(k+bc_d\right)^2\gamma_0^2 + b\beta\left(2+\lambda_r\right)\left(4+\lambda_s\right)},$$

$$w^{\#} = \frac{\left(\begin{array}{l} -2h^2\left(k+bc_d\right)\gamma_0^2\left(ck + c_d\left(a + k\theta_0\right)\right)\left(2+\lambda_r+\lambda_s\right) \\ +\beta\left(2+\lambda_r\right)\left(k\theta_0\left(2+\lambda_s\right)^2 + bc\lambda_r\left(4+\lambda_s\right) + \left(2+\lambda_s\right)\left(2a+2bc+a\lambda_s\right)\right) \\ +\beta\gamma_0\left(2+\lambda_r\right)\left(-k\left(2+\lambda_s\right)^2 + bc_d\left(2\left(2+\lambda_s\right)+\lambda_r\left(4+\lambda_s\right)\right)\right)\end{array}\right)}{\left(\left(2+\lambda_r+\lambda_s\right)\left(-2h^2\left(k+bc_d\right)^2\gamma_0^2 + b\beta\left(2+\lambda_r\right)\left(4+\lambda_s\right)\right)\right)}.$$

We can obtain the optimal retail price $p^{\#}$ as follows:

$$p^{\#} = \frac{\begin{array}{l} -2h^2\left(k+bc_d\right)\gamma_0^2\left(ck + c_d\left(a+k\theta_0\right)\right) \\ +\beta\left(2+\lambda_r\right)\left(3a + bc + b\gamma_0c_d + a\lambda_s + k(\theta_0-\gamma_0)\left(3+\lambda_s\right)\right)\end{array}}{-2h^2\left(k+bc_d\right)^2\gamma_0^2 + b\beta\left(2+\lambda_r\right)\left(4+\lambda_s\right)}.$$

□

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