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The Coordination Mechanism of Fresh Agricultural Products Supply Chain: A Game-Theoretic Approach Considering Retailer's Fairness Concern and Price Competition

Abstract. *As consumers place a growing emphasis on the freshness of agricultural products, effective freshness-keeping strategies have become crucial for improving product quality and boosting supply chain profitability. This study aims to analyse how the retailer's fairness concerns affect freshness-keeping efforts and pricing strategies in the fresh agricultural products supply chain and to explore effective supply chain coordination mechanisms to increase overall profits. This study explores a fresh agricultural products supply chain with a dominant supplier and a retailer, analysing three decision-making scenarios: centralised, decentralised with retailer fairness neutrality, and fairness concern. The research findings indicate: (1) the prices, freshness-keeping efforts, and the profit of both parties all increase as the coefficient of consumer freshness preference increases; (2) the retailer's fairness concern negatively affects supplier prices, freshness efforts, and profits, while enhancing retailer profit; (3) introducing a cost-sharing contract can promote the freshness of agricultural products, increasing sales; (4) The price difference between competing fresh products positively influences the market share of product 1. Numerical analysis results corroborate these conclusions.*

Keywords: *fresh agricultural products supply chain, retailer's fairness concern, price competition, cost-sharing contract.*

JEL Classification: C51, C70.

1. Introduction

Fresh agricultural products are necessities in people's daily lives. However, these perishable goods are prone to decay, which impacts the market demand and

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sellers' pricing (Moon, 2020). Significant freshness-keeping efforts incur high costs (Cat et al., 2009; Yan et al., 2020). Suppliers and retailers often experience double marginal effects, resulting in inadequate freshness efforts and decreased quality (Dye & Hsieh, 2012), highlighting the need for better coordination in the supply chain.

Several studies have addressed the optimisation of freshness-keeping efforts. Cao et al. (2019) found that total supply chain profits increase with retailers' freshness efforts, proposing incentives to limit supplier free-riding. Xu et al. (2020) showed that origin grading improves pricing, freshness strategies, demand, and profits. Li et al. (2023) revealed that increased loss rates hurt supply chain profits in a three-tier fresh agricultural product supply chain. While these studies contribute valuable insight, they often assume rational "economic agents," neglecting the complexities of real-world decision-making.

Supply chain members are influenced by factors beyond profit maximisation, such as risk aversion, overconfidence, and fairness concerns. Behavioural economics emphasises that individuals consider the fairness of income distribution. Cui et al. were the first to introduce the concept of fairness into the supply chain and highlighted fairness in supply chain dynamics, while Zhang et al. (2017) found that increased retailer fairness concerns lead to suppliers conceding profits. Bo Yan (2020) and Zhang et al. (2016) examined the effects of fairness on revenue-sharing contracts and pricing strategies, respectively.

Research on fresh agricultural products supply chain coordination typically examines how profits are influenced by freshness and pricing. Yan et al. (2020) compared supplier decisions in traditional and Nash bargaining frameworks, using a revenue-sharing contract to coordinate the supply chain to achieve Pareto improvement. Furthermore, some studies have addressed consumer behaviour's impact, suggesting revenue-sharing and wholesale price strategies for coordination (Yan, 2020). However, many focus on a single retail price. Wei et al. (2023) investigated dual-channel supply chain coordination with retailers' fairness concerns, while Zhang et al. (2021) analysed coordination for the same product with different retail prices in two channels. However, these studies often overlook how competition between various products affects supply chain profits.

In summary, this paper examines a two-level fresh agricultural products supply chain with a supplier and retailer, considering their simultaneous freshness-keeping efforts and price competition. The paper aims to address the following questions: (1) How do retailer's fairness concern and consumer freshness preference coefficients affect the supplier's and retailer's optimal freshness-keeping efforts, pricing, and profits? (2) To mitigate the impact of the retailer's fairness concern behaviour on the profits of both parties, the paper studies whether the use of a cost-sharing contract can achieve Pareto improvement in the fresh agricultural products supply chain.

2. Model Description and Assumptions

This study examines a two-level fresh agricultural products supply chain with a single supplier (S) and retailer (R) selling two products at different prices (p_1, p_2).

Consumer demand (D) is influenced by freshness and prices, along with the supplier's wholesale price (w) and production cost (c). The fresh agricultural products supply chain structure is shown in Figure 1.

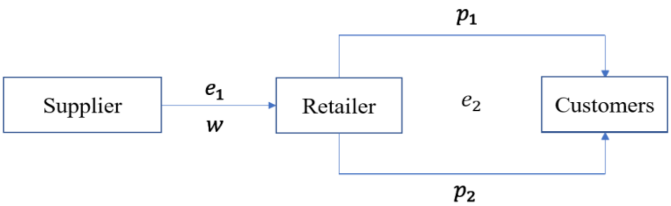

Figure 1. Supply chain structure of fresh agricultural retailers under agricultural product price competition model
Source: Authors' own creation.

Assumption 1. The freshness of agricultural products depends on the supplier's freshness-keeping efforts, like packaging and cold chain transport, and the retailer's use of storage equipment and freshness technology (Yan et al., 2020), we assume a freshness function as follows:

$$\theta = \theta_0 + \gamma_1 e_1 + \gamma_2 e_2$$

θ_0 denotes the initial freshness level of agricultural products without any efforts. e_1、e_2 represent the freshness-keeping efforts by the supplier and retailer respectively. while γ_1 and γ_2 represent the sensitivity coefficient of freshness-keeping efforts for the supplier and the retailer respectively. For the simplicity of the model, let $\gamma_1 = \gamma_2 = 1$.

Assumption 2. Referring to the literature (Chambers et al., 2006), we assume that the freshness-keeping costs of the supplier and the retailer have a quadratic relationship with freshness-keeping efforts, respectively, with the following functions:

$$c_1 = \frac{1}{2}\mu_1 e_1^2$$
$$c_2 = \frac{1}{2}\mu_2 e_2^2$$

Where, c_1 and c_2 respectively represent the freshness-keeping costs of the supplier and the retailer, μ_1 and μ_2 represent the coefficient of the freshness-keeping cost of the supplier and the retailer, respectively.

Assumption 3. In the fresh agricultural products supply chain, the retailer sales equal the order quantity from the supplier. D_1 and D_2 denote demands for products

1 and 2, influenced by prices and freshness levels (Mukhopadhyay et al., 2008; Gurnani et al., 2010).

$$D_1 = \eta a + \alpha\theta - p_1 + bp_2$$

$$D_2 = (1-\eta)a + \alpha\theta - p_2 + bp_1$$

Where η represents the market share of product 1, $(1 - \eta)$ represents the market share of product 2, a represents the basic market demand, α represents the coefficient of consumer freshness preference, b represents the cross-price elasticity coefficient, and $0 < b < 1$.

In the following text, π represents the profit of decision maker and U represents the utility of the decision maker. The superscripts $*, c, d, n,$ and $+$ respectively represent optimal state, centralised decision-making, decentralised decision-making when the retailer has fairness neutrality, decentralised decision-making when the retailer has fairness concern and the use of cost-sharing contract.

3. Model specification

3.1 Centralised decision-making

The supplier and the retailer are consistent main bodies under centralised decision-making, so the profit of the fresh agricultural products supply chain is:

$$U^c = \pi^c = (p_1 - c)D_1 + (p_2 - c)D_2 - (c_1 + c_2) \tag{1}$$

Proposition 1. Under centralised decision-making, the fresh agricultural products supply chain can make equilibrium decisions that achieve its optimum:

$$p_1^{c*} = \frac{2\mu_1\mu_2[ab + \alpha\theta_0(1+b)] + 2c(1+b)[\mu_1\mu_2(1-b) - 2\alpha^2(\mu_1+\mu_2)] + a\alpha^2(\mu_1+\mu_2) + 2Aa\eta}{4A(1+b)}$$

$$p_2^{c*} = \frac{2\mu_1\mu_2[a + \alpha\theta_0(\mu_1+\mu_2)] + 2c(1+b)[\mu_1\mu_2(1-b) - 2\alpha^2(\mu_1+\mu_2)] - a\alpha^2(\mu_1+\mu_2) - 2Aa\eta}{4A(1+b)}$$

$$e_1^{c*} = \frac{\alpha\mu_2[a - 2c(1-b) + 2\alpha\theta_0]}{2A}$$

$$e_2^{c*} = \frac{\alpha\mu_1[a - 2c(1-b) + 2\alpha\theta_0]}{2A}$$

where, $A = \mu_1\mu_2(1-b) - \alpha^2(\mu_1+\mu_2)$.

Proof: By taking the first-order derivative on p_1 and p_2 with respect to equation (1), we obtain the following:

$$\frac{\partial U^c}{\partial p_1} = \eta a + \alpha(\theta_0 + e_1 + e_2) - (2p_1 - c) + b(2p_2 - c) \tag{2}$$

$$\frac{\partial U^c}{\partial p_2} = (1-\eta)a + \alpha(\theta_0 + e_1 + e_2) - (2p_2 - c) + b(2p_1 - c) \tag{3}$$

We determine the conditions for the existence of the optimal solution by constructing the Hessian matrix:

$$H_1 = \begin{pmatrix} \frac{\partial^2 U^c}{\partial p_1^2} & \frac{\partial^2 U^c}{\partial p_1 \partial p_2} \\ \frac{\partial^2 U^c}{\partial p_2 \partial p_1} & \frac{\partial^2 U^c}{\partial p_2^2} \end{pmatrix} = \begin{pmatrix} -2 & 2b \\ 2b & -2 \end{pmatrix}$$

We can find that $|H_1| = 4 - 4b > 0$,and the first-order principal minor is $-2 < 0$. Therefore, the second-order Hessian matrix H_1 of U^c with respect to p_1 and p_2 is negative definite. That is, U^c is a joint concave function with respect top_1 and p_2 with a unique optimal solution p_1^{c*} and p_2^{c*}.

Letting $\frac{\partial U^c}{\partial p_1} = 0$, $\frac{\partial U^c}{\partial p_2} = 0$, we can obtain the following:

$$p_1 = \frac{ab + c(1-b^2) + \alpha(1+b)(e_1+e_2) + a\eta(1-b) + \alpha\theta_0(1+b)}{2(1-b^2)} \tag{4}$$

$$p_2 = \frac{a + c(1-b^2) + \alpha(1+b)(e_1+e_2) - a\eta(1-b) + \alpha\theta_0(1+b)}{2(1-b^2)} \tag{5}$$

By taking the first-order derivative on e_1 and $e_2$with respect to equation (1), we can obtain the following:

$$\frac{\partial U^c}{\partial e_1} = \alpha(p_1 + p_2 - 2c) - \mu_1 e_1 \tag{6}$$

$$\frac{\partial U^c}{\partial e_2} = \alpha(p_1 + p_2 - 2c) - \mu_2 e_2 \tag{7}$$

Similarly, we can conclude that the Hessian matrix H_2 is negative definite, indicating that U^c is a joint concave function about e_1 and e_2 , and thus there exits unique optimal solutions e_1^{c*} and e_2^{c*}.When $\frac{\partial U^c}{\partial e_1} = 0$, $\frac{\partial U^c}{\partial e_2} = 0$, we can obtain:

$$e_1 = \frac{\alpha(p_1+p_2-2c)}{\mu_1} \tag{8}$$

$$e_2 = \frac{\alpha(p_1+p_2-2c)}{\mu_2} \tag{9}$$

By combining with the above equations, we can obtain:

$$e_1^{c*} = \frac{\alpha\mu_2[a - 2c(1-b) + 2\alpha\theta_0]}{2A} \tag{10}$$

$$e_2^{c*} = \frac{\alpha\mu_1[a - 2c(1-b) + 2\alpha\theta_0]}{2A} \tag{11}$$

$$p_1^{c*} = \frac{2\mu_1\mu_2[ab + \alpha\theta_0(1+b)] + 2c(1+b)[\mu_1\mu_2(1-b) - 2\alpha^2(\mu_1+\mu_2)] + a\alpha^2(\mu_1+\mu_2) + 2Aa\eta}{4A(1+b)} \tag{12}$$

$$p_2^{c*} = \frac{2\mu_1\mu_2[a + \alpha\theta_0(\mu_1+\mu_2)] + 2c(1+b)[\mu_1\mu_2(1-b) - 2\alpha^2(\mu_1+\mu_2)] - a\alpha^2(\mu_1+\mu_2) - 2Aa\eta}{4A(1+b)} \tag{13}$$

Proposition 1 is proven.

Substituting the solutions above into equation (1), we obtain the optimal profit of the fresh agricultural products supply chain under centralised decision-making.

Corollary 1. Under the centralised decision-making, the retail price and freshness-keeping efforts of products are affected by α, and they increase as α increases; Additionally, the price difference between product 1 and product 2 is positively correlated with η. When $\eta > 0.5$, the price difference is negatively correlated with b. When $\eta < 0.5$, the price difference is positively correlated with b. When $\eta = 0.5$, there is no correlation between price difference and b.

Proof: When $\frac{\partial p_1^{C*}}{\partial \alpha} = \frac{\partial p_2^{C*}}{\partial \alpha} = \frac{\mu_1\mu_2\{\alpha(\mu_1+\mu_2)[a-2c(1-b)]+\theta_0[\mu_1\mu_2(1-b)+\alpha^2(\mu_1+\mu_2)]\}}{2A^2}$, we can conclude that $\frac{\partial p_1^{C*}}{\partial \alpha} = \frac{\partial p_2^{C*}}{\partial \alpha} > 0$ .That is, under the centralised decision-making, the retail price of products will increase with the increase of consumer freshness preference coefficient.

When $\frac{\partial e_1^{C*}}{\partial \alpha} = \frac{\mu_2\{[\mu_1\mu_2(1-b)+2\alpha^2(\mu_1+\mu_2)][a-2c(1-b)]+4\alpha\mu_1\mu_2\theta_0(1-b)\}}{2A^2}$, $\frac{\partial e_2^{C*}}{\partial \alpha} = \frac{\mu_1\{[\mu_1\mu_2(1-b)+2\alpha^2(\mu_1+\mu_2)][a-2c(1-b)]+4\alpha\mu_1\mu_2\theta_0(1-b)\}}{2A^2}$， we can conclude that $\frac{\partial e_1^{C*}}{\partial \alpha} > 0$、$\frac{\partial e_2^{C*}}{\partial \alpha} > 0$. This indicates that under centralised decision-making, the freshness-keeping efforts of both the supplier and the retailer have a positive relationship with consumer freshness preference coefficient.

In the fresh agricultural products supply chain, market demand is closely related to retail price and freshness levels. As consumers show a higher preference for freshness, it indicates that the higher the freshness level of fresh agricultural products, the greater the attraction to consumers. This suggests that with the increase in the consumer's freshness preference coefficient, the impact of the freshness of agricultural products on market demand can offset the impact of the decline in market demand due to the rise in retail prices.

Under the centralised decision-making, the price difference between product 1 and product 2 is $\Delta p = p_1^{C*} - p_2^{C*} = \frac{a(2\eta-1)}{2(1+b)}$. First of all, we take the first-order derivative of Δp with respect to η and we can obtain $\frac{\partial \Delta p}{\partial \eta} = \frac{a}{1+b}$.Therefore it can be inferred that the price difference between two different fresh agricultural products is positively correlated with η. If the market share of product 1 is larger, the retail price will be higher, and vice versa.

Second, by calculating the first derivative of Δp with respect to b ,we can obtain $\frac{\partial \Delta p}{\partial b} = \frac{-(2\eta-1)a}{2(1+b)^2}$. When $\eta > 0.5$, Δp is negatively correlated with b; when $\eta < 0.5$, Δp is positively correlated; and when $\eta = 0.5$, there is no correlation between p and b. The cross-price elasticity coefficient between two different fresh agricultural products of the retailer represents the substitution effect between two different products. When the market share of product 1 is greater, the substitutability of product 2 for product 1 is smaller, leading to a higher price for product 1.

3.2 Decentralised decision-making when the retailer is fairness-neutral

Under decentralised decision-making, the supply chain members pursue the maximisation of their profits. The supplier and the retailer will engage in a Stackelberg game, while the game process is dominated by the supplier. Therefore, the profit functions of the supplier and the retailer are as follows:

$$U_s^d = \pi_s = (w-c)(D_1+D_2) - c_1(e_1) \quad (14)$$
$$U_r^d = \pi_r = (p_1-w)D_1 + (p_2-w)D_2 - c_2(e_2) \quad (15)$$

Proposition 2. Under decentralised decision-making when the retailer is fairness neutral, both the supplier and the retailer can formulate equilibrium decisions that achieve optimal outcomes:

$$w^{d*} = \frac{2Ac(1-b) + B(a + 2\alpha\theta_0)}{2(1-b)(A+B)}$$

$$p_1^{d*} = \frac{\begin{pmatrix} a\mu_1\mu_2(1-b)(1+5b) + a\alpha^2[\mu_2(1-b) - 4b] + 2a\eta(1-b)(A+B) \\ +2\alpha\theta_0(1+b)(3B - \alpha^2\mu_1) + 2c(1-b^2)[\mu_1\mu_2(1-b) - 2\alpha^2(\mu_1+\mu_2)] \end{pmatrix}}{4(1-b^2)(A+B)}$$

$$p_2^{d*} = \frac{\begin{pmatrix} a\mu_1\mu_2(1-b)(5+b) - a\alpha^2[4\mu_1 + \mu_2(1-b)] - 2a\eta(1-b)(A+B) \\ +2c(1-b^2)[\mu_1\mu_2(1-b) - 2\alpha^2(\mu_1+\mu_2)] + 2\alpha\theta_0(1+b)(3B - \alpha^2\mu_1) \end{pmatrix}}{4(1-b^2)(A+B)}$$

$$e_1^{d*} = \frac{\alpha\mu_2[a - 2c(1-b) + 2\alpha\theta_0]}{2(A+B)}$$

$$e_2^{d*} = \frac{\alpha\mu_1[a - 2c(1-b) + 2\alpha\theta_0]}{2(A+B)}$$

where, $B = \mu_1\mu_2(1-b) - \alpha^2\mu_1 > 0$.

Proof: By taking the second-order derivative of U_r^d with respect to p_1、p_2 and e_2, we can obtain the following:

$$\frac{\partial U_r^d}{\partial p_1} = a\eta + \alpha(\theta_0 + e_1 + e_2) + b(2p_2 - w) - (2p_1 - w) \tag{16}$$

$$\frac{\partial U_r^d}{\partial p_2} = a(1-\eta) + \alpha(\theta_0 + e_1 + e_2) + b(2p_1 - w) - (2p_2 - w) \tag{17}$$

$$\frac{\partial U_r^d}{\partial e_2} = \alpha(p_1 - w) + \alpha(p_2 - w) - \mu_2 e_2 \tag{18}$$

Calculating its Hessian matrix:

$$H_3 = \begin{pmatrix} \frac{\partial^2 U_r^d}{\partial p_1^2} & \frac{\partial^2 U_r^d}{\partial p_1 \partial p_2} & \frac{\partial^2 U_r^d}{\partial p_1 \partial e_2} \\ \frac{\partial^2 U_r^d}{\partial p_2 \partial p_1} & \frac{\partial^2 U_r^d}{\partial p_2^2} & \frac{\partial^2 U_r^d}{\partial p_2 \partial e_2} \\ \frac{\partial^2 U_r^d}{\partial e_2 \partial p_1} & \frac{\partial^2 U_r^d}{\partial e_2 \partial p_2} & \frac{\partial^2 U_r^d}{\partial e_2^2} \end{pmatrix} = \begin{pmatrix} -2 & 2b & \alpha \\ 2b & -2 & \alpha \\ \alpha & \alpha & -\mu_2 \end{pmatrix}$$

We can find that $B = \mu_1\mu_2(1-b) - \alpha^2\mu_1 > 0$, $|H_3| = -4(1+b)[\mu_1(1-b) - \alpha^2] < 0$. Additionally, the first-order principal minor is $-2 < 0$ and the second-order principal minor is $4 - 4b > 0$. Therefore, the third-order Hessian matrix is negative definite indicating the existence of a unique optimal solution under decentralised decision-making.

Letting the first-order derivative of equation (16-18) equal to zero, and obtain:

$$p_1 = \frac{a[(1-2\eta)\alpha^2 + 2\mu_2(b + \eta - b\eta)]}{4(1+b)[\mu_2(1-b) - \alpha^2]} + \frac{w[\mu_2(1-b) - 2\alpha^2] + \alpha(\theta_0 + e_1)}{2[\mu_2(1-b) - \alpha^2]} \tag{19}$$

$$p_2 = \frac{a[(2\eta-1)\alpha^2 + 2\mu_2(1 - \eta + b\eta)]}{4(1+b)[\mu_2(1-b) - \alpha^2]} + \frac{w[\mu_2(1-b) - 2\alpha^2] + \alpha\mu_2(\theta_0 + e_1)}{2[\mu_2(1-b) - \alpha^2]} \tag{20}$$

$$e_2 = \frac{\alpha[a - 2w(1-b) + 2\alpha(\theta_0 + e_1)]}{2[\mu_2(1-b) - \alpha^2]} \tag{21}$$

Substituting (19), (20) and (21) into U_s^d ,taking the first-order derivative of w and e_1 as follows:

$$\frac{\partial U_s^d}{\partial w} = \frac{(-1+b)(a+2c-2bc-4w+4bw+2\alpha e_1+2\alpha\theta_0}{2[\mu_2(1-b)-\alpha^2]} \tag{22}$$

$$\frac{\partial U_s^d}{\partial e_1} = -\mu_1 e_1 - \frac{(-1+b)(c-w)\alpha}{[\mu_2(1-b)-\alpha^2]} \tag{23}$$

Calculating its Hessian matrix:

$$H_4 = \begin{pmatrix} \frac{\partial^2 U_s^d}{\partial w^2} & \frac{\partial^2 U_s^d}{\partial w \partial e_1} \\ \frac{\partial^2 U_s^d}{\partial e_1 \partial w} & \frac{\partial^2 U_s^d}{\partial e_1^2} \end{pmatrix} = \begin{pmatrix} -\frac{2\mu_2(1-b)^2}{\mu_2(1-b)-\alpha^2} & \frac{\alpha\mu_2(1-b)}{\mu_2(1-b)-\alpha^2} \\ \frac{\alpha\mu_2(1-b)}{\mu_2(1-b)-\alpha^2} & -\mu_1 \end{pmatrix}$$

Since $A = \mu_1\mu_2(1-b) - \alpha^2(\mu_1+\mu_2)$， $B = \mu_1\mu_2(1-b) - \alpha^2\mu_1 > 0$, we can conclude that $|H_4| = \frac{\mu_2(1-b)^2(A+B)}{[\mu_2(1-b)-\alpha^2]^2} > 0$. Additionally ,the first-order principal minor $-\frac{2\mu_2(1-b)^2}{\mu_2(1-b)-\alpha^2} < 0$, therefore the second-order Hessian matrix H_4 of U_s^d with respect to w and e_1 is negative definite, so U_s^d is a joint concave function with respect to w and e_1 and there exists a unique optimal solution w^{d*} and e_1^{d*}. Letting $\frac{\partial U_s^d}{\partial w} = 0$、$\frac{\partial U_s^d}{\partial e_1} = 0$, we can obtain:

$$w^{d*} = \frac{2Ac(1-b)+B(a+2\alpha\theta_0)}{2(1-b)(A+B)} \tag{24}$$

$$e_1^{d*} = \frac{\alpha\mu_2[a-2c(1-b)+2\alpha\theta_0]}{2(A+B)} \tag{25}$$

Substituting the above equation into equation (19-21), we can obtain:

$$p_1^{d*} = \frac{\begin{pmatrix} a\mu_1\mu_2(1-b)(1+5b)+a\alpha^2[\mu_2(1-b)-4b]+2a\eta(1-b)(A+B) \\ +2\alpha\theta_0(1+b)(3B-\alpha^2\mu_1)+2c(1-b^2)[\mu_1\mu_2(1-b)-2\alpha^2(\mu_1+\mu_2)] \end{pmatrix}}{4(1-b^2)(A+B)} \tag{26}$$

$$p_2^{d*} = \frac{\begin{pmatrix} a\mu_1\mu_2(1-b)(5+b)-a\alpha^2[4\mu_1+\mu_2(1-b)]-2a\eta(1-b)(A+B) \\ +2c(1-b^2)[\mu_1\mu_2(1-b)-2\alpha^2(\mu_1+\mu_2)]+2\alpha\theta_0(1+b)(3B-\alpha^2\mu_1) \end{pmatrix}}{4(1-b^2)(A+B)} \tag{27}$$

$$e_2^{d*} = \frac{\alpha\mu_1[a-2c(1-b)+2\alpha\theta_0]}{2(A+B)} \tag{28}$$

Proposition 2 is proven.

Substituting the solution above into equations (14) and (15), we can obtain the respective optimal profits for the supplier and the retailer under decentralised decision-making when the retailer is fairness neutral.

Corollary 2. Under decentralised decision-making when the retailer is fairness neutral, the retail price and freshness-keeping efforts of products are affected by α and-increase as α increases; The price difference between product 1 and product 2 is positively correlated with η. When $\eta > 0.5$, the price difference is negatively correlated with b. When $\eta < 0.5$, the price difference is positively correlated with b. When $\eta = 0.5$, there is no correlation between price difference and b.

Proof: When $\frac{\partial w^{d*}}{\partial \alpha} = \frac{\alpha\mu_1\mu_2^2(1-b)[a-2c(1-b)]+\theta_0\{2B^2+\alpha^2\mu_2[\mu_1\mu_2(1-b)+\alpha^2\mu_1]\}}{(1-b)(A+B)^2}$, it can be known that $\frac{\partial w^{d*}}{\partial \alpha} > 0$.That is, under the decentralised decision, the wholesale price of the supplier increase with the increase of the consumer freshness preference coefficient. The remaining proofs are similar to Corollary 1, and we will not further elaborate here.

Corollary 3. When $\mu_1\mu_2(1-b)-2\alpha^2(\mu_1+\mu_2)>0$, $p_1^{c*}<p_1^{d*}$, $p_2^{c*}<p_2^{d*}$, and if $\mu_1\mu_2(1-b)-2\alpha^2(\mu_1+\mu_2)<0$, then $p_1^{c*}>p_1^{d*}$, $p_2^{c*}>p_2^{d*}$; $e_1^{c*}>e_1^{d*}$, $e_2^{c*}>e_2^{d*}$.

Proof: Supposing that $\mu_1\mu_2(1-b)-2\alpha^2(\mu_1+\mu_2)>0$,

$$p_1^{c*}-p_1^{d*}=p_2^{c*}-p_2^{d*}=-\frac{B[\mu_1\mu_2(1-b)-2\alpha^2(\mu_1+\mu_2)][a-2c(1-b)+2\alpha\theta_0]}{4A(1-b)(A+B)}<0$$

$$e_1^{c*}-e_1^{d*}=\frac{B\alpha\mu_2[a-2c(1-b)+2\alpha\theta_0]}{2A(A+B)}>0$$

$$e_2^{c*}-e_2^{d*}=\frac{B\alpha\mu_1[a-2c(1-b)+2\alpha\theta_0]}{2A(A+B)}>0$$

According to Corollary 3, with certain constraints, we can obtain that $p_1^{c*}<p_1^{d*}$, $p_2^{c*}<p_2^{d*}$; $e_1^{c*}>e_1^{d*}$, $e_2^{c*}>e_2^{d*}$. The above results indicate that under decentralised decision-making, the supplier and retailer are often prone to have double marginal effect, resulting in lower freshness-keeping efforts and costs. Consequently, it reduces the overall freshness level of fresh agricultural products, resulting in a continuous decline in consumer demand. As a result, the profit of the supply chain under decentralised decision-making will be lower than that under centralised decision-making. Coordinating the supply chain through incentive mechanisms can help maintain cooperation among members.

3.3 Decentralised decision-making when the retailer has fairness concern

3.3.1 Nash Bargaining Fairness Concern Framework

When the retailer has fairness concern, it considers both its profit and the fairness of profit distribution. Its utility depends on the actual profit and the difference from a fairness reference point, which is derived from Nash bargaining with the supplier. The fairness reference solution is denoted as $(\overline{\pi_s},\ \overline{\pi_r})$, satisfying $\overline{\pi_s}+\overline{\pi_r}=\pi_s+\pi_r=\pi$, where π represents the overall supply chain profit under Nash bargaining.

$$U_r=\pi_r+\lambda(\pi_r-\overline{\pi_r}) \tag{29}$$
$$U_s=\pi_s \tag{30}$$

Where, λ represents the fairness concern coefficient of the retailer, and $\lambda>0$.

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

$$Max\Psi=U_sU_r \tag{31}$$

$$s.t.\begin{cases}\pi_s+\pi_r=\pi\\ \pi_s,\ \pi_r\in[0,\pi]\end{cases}$$

When $\frac{\partial^2 \Psi}{\partial \pi_r^2} = -2(1+\lambda) < 0$, we can conclude that Ψ is a strictly concave function with respect to π_r. Therefore, there exists a unique optimal solution π_r^*.We let the first derivative of Ψ with respect to π_r equal to 0, we can obtain:

$$\frac{\partial \Psi(\pi,\pi_r^*)}{\partial \pi_r} = (1+\lambda)\pi - 2(1+\lambda)\pi_r^* + \lambda\overline{\pi_r} = 0 \tag{32}$$

According to the fixed-point theorem, we can know that the Nash bargaining solution is the desired fairness reference solution, namely $\pi_r^* = \overline{\pi_r}$. Therefore, by substituting this into the above equation, we can obtain the Nash bargaining fairness reference solution for the retailer as follow:

$$\overline{\pi_r} = \frac{1+\lambda}{2+\lambda}\pi \tag{33}$$

The retailer's utility function under the Nash bargaining fairness concern framework is as follows:

$$U_r = \frac{2(1+\lambda)}{2+\lambda}\pi_r - \frac{\lambda(1+\lambda)}{2+\lambda}\pi_s \tag{34}$$

3.3.2 Decision making when the retailer has fairness concern

When the retailer has a fairness concern in decision-making, the utility functions of the retailer and the supplier are as follows:

$$U_r^n = \frac{2(1+\lambda)}{2+\lambda}\pi_r - \frac{\lambda(1+\lambda)}{2+\lambda}\pi_s \tag{35}$$

$$U_s^n = \pi_s \tag{36}$$

Proposition 3. Under decentralised decision-making when the retailer has fairness concern, both the supplier and the retailer can formulate equilibrium decisions that achieve optimal outcomes:

$$w^{n*} = \frac{2c(1-b)(A+B\lambda)+B(a+2\alpha\theta_0)}{2(1-b)[2(A+B)+B\lambda]} \tag{37}$$

$$p_1^{n*} = \frac{\begin{pmatrix} a\mu_1\mu_2(1+5b)(1-b)(2+\lambda)+2a\alpha^2\mu_2(1-b)(1-2\eta)-4ab\alpha^2\mu_1(2+\lambda) \\ +4c(1-b^2)[\mu_1\mu_2(1-b)-2\alpha^2(\mu_1+\mu_2)]+4Ba\eta(1-b)(2+\lambda) \\ +2\alpha\theta_0(1+b)(2+\lambda)(B-\alpha^2\mu_1)+2c\lambda(1-b^2)[\mu_1\mu_2(1-b)-2\alpha^2\mu_1] \end{pmatrix}}{8(1-b^2)[A+B(1+\lambda)]} \tag{38}$$

$$p_2^{n*} = \frac{\begin{pmatrix} a\mu_1\mu_2(5+b)(1-b)(2+\lambda)-4Ba\eta(1-b)(2+\lambda)-4a\alpha^2\mu_1(2+\lambda) \\ +2c(1-b^2)(2+\lambda)[\mu_1\mu_2(1-b)-2\alpha^2\mu_1]-8c\alpha^2\mu_2(1-b^2) \\ +2\alpha\theta_0(1+b)(2+\lambda)(3B+\alpha^2\mu_1)-2a\alpha^2\mu_2(1-b)(1-2\eta) \end{pmatrix}}{8(1-b^2)[A+B(1+\lambda)]} \tag{39}$$

$$e_1^{n*} = \frac{\alpha\mu_2[a-2c(1-b)+2\alpha\theta_0]}{2[(A+B)+B\lambda]} \tag{40}$$

$$e_2^{n*} = \frac{\alpha\mu_1(2+\lambda)[a-2c(1-b)+2\alpha\theta_0]}{4[(A+B)+B\lambda]} \tag{41}$$

Proof: The proof of Proposition 3 is similar to that of Proposition 2, so it will not be repeated here.

Corollary 4. Under decentralised decision-making with the retailer's fairness concern, a as consumer freshness preference coefficient increases, the wholesale price, retail price and the freshness-keeping efforts on both parties of the fresh agricultural products supply chain increase. Additionally, Δp is positively correlated with η:when $\eta > 0.5$, Δp is negatively correlated with b; when $\eta < 0.5$, Δp is positively correlated with b; and when $\eta = 0.5$, there is no correlation. This proof is similar to Corollaries 1 and 2 and we will not further elaborate here.

Corollary 5. When the retailer has fairness concern, the freshness-keeping efforts of supply chain members are negatively correlated with the degree of fairness concern of the retailer. Therefore , the more concerned the retailer is about fairness, the lower the level of freshness-keeping efforts input by both parties.

Proof: $\frac{\partial e_1^{n*}}{\partial \lambda} = -\frac{B\alpha\mu_2[a-2c(1-b)+2\alpha\theta_0]}{2[A+B(1+\lambda)]^2}$, $\frac{\partial e_2^{n*}}{\partial \lambda} = -\frac{\alpha^3\mu_1\mu_2[a-2c(1-b)+2\alpha\theta_0]}{4[A+B(1+\lambda)]^2}$, according to the assumption ,we can know that $\frac{\partial e_1^{n*}}{\partial \lambda} < 0$, $\frac{\partial e_2^{n*}}{\partial \lambda} < 0$. When the retailer has fairness concern, the freshness-keeping efforts of both parties in the supply chain are negatively related to the degree of fairness concern of the retailer. If the retailer can alleviate these concerns and improve its efforts, the retailer can offer higher quality products, which will boost consumer demand and benefit both the retailer and the supplier.

Corollary 6. When the retailer has fairness concern, the wholesale price is negatively correlated with its degree of fairness concern, and the retail price is also negatively correlated with its degree of fairness concern.

Proof: By taking the first-order derivative on w^{n*} , p_1^{n*} and p_2^{n*} with respect to λ , we obtain the following:

$$\frac{\partial w^{n*}}{\partial \lambda} = -\frac{B^2[a-2c(1-b)+2\alpha\theta_0]}{2(1-b)[A+B(1+\lambda)]^2} \tag{42}$$

$$\frac{\partial p_1^{n*}}{\partial \lambda} = \frac{\partial p_2^{n*}}{\partial \lambda} = -\frac{\alpha^2\mu_2(3B+\alpha^2\mu_2)[a-2c(1-b)+2\alpha\theta_0]}{8(1-b)[A+B(1+\lambda)]^2} \tag{43}$$

It can be known from the conditions that $\frac{\partial w^{n*}}{\partial \lambda} < 0$, $\frac{\partial p_1^{n*}}{\partial \lambda} = \frac{\partial p_2^{n*}}{\partial \lambda} < 0$, which indicates a negative correlation between the wholesale price and the retailer's fairness concern, and the fairness concern also exerts a negative impact on the retail price. The results show that, as the retailer becomes more concerned about fairness, the wholesale prices set by the supplier continuously decrease. The level of freshness input by the supplier for the fresh agricultural products also decreases as a way of reducing their investment in freshness-keeping costs.

Corollary 7. $e_1^{n*} < e_1^{d*}$, $e_2^{n*} < e_2^{d*}$; $w^{n*} < w^{d*}$; $p_1^{n*} < p_1^{d*}$, $p_2^{n*} < p_2^{d*}$.

Proof:

$$\Delta e = e_1^{n*} - e_1^{d*} = -\frac{B\alpha\lambda\mu_1[a-2c(1-b)+2\alpha\theta_0]}{2(A+B)[A+B(1+\lambda)]}$$

$$e_2^{n*} - e_2^{d*} = -\frac{\alpha^2\lambda\mu_1\mu_2[a-2c(1-b)+2\alpha\theta_0]}{4(A+B)[A+B(1+\lambda)]}$$

$$\Delta w = w^{n*} - w^{d*} = -\frac{B\lambda[a-2c(1-b)+2\alpha\theta_0]}{2(1-b)(A+B)[A+B(1+\lambda)]}$$

$$\Delta p = p_1^{n*} - p_1^{d*} = p_2^{n*} - p_2^{d*} = -\frac{\alpha^2\lambda\mu_2(3B + \alpha^2\mu_1)[a - 2c(1-b) + 2\alpha\theta_0]}{8(1-b)(A+B)[A+B(1+\lambda)]}$$

It can be observed that $e_1^{n*} < e_1^{d*}$, $e_2^{n*} < e_2^{d*}$, $w^{n*} < w^{d*}$, $p_1^{n*} < p_1^{d*}$, $p_2^{n*} < p_2^{d*}$. The retailer's fairness concern forces the supplier to lower wholesale prices, which results in a reduction in the supplier's utility. Therefore, both parties in supply chain will reduce freshness-keeping costs, which will lead to decrease freshness-keeping efforts and lower market demand. To address the problem of optimal decision-making, the supplier should share freshness-keeping costs with the retailer through a coordination mechanism.

3.3 Coordination decision-making based on the retailer with fairness concern

The retailer's fairness concerns can negatively impact both its own and the supplier's utility, affecting overall freshness-keeping efforts. Where τ represents the proportion of the fresh agricultural products freshness-keeping efforts that the supplier shares for the retailer, and $1-\tau$ represents the proportion of the fresh agricultural products freshness-keeping efforts that the retailer bears on its own. Where, $0 < \tau < 1$.

At this point, we can obtain the profit functions for the retailer and the supplier:

$$\pi_r^+ = [p_1 - w]D_1 + [p_2 - w]D_2 - (1-\tau)c_2(e_2) \quad (44)$$

$$\pi_s^+ = (w - c)(D_1 + D_2) - c_1(e_1) - \tau c_2(e_2) \quad (45)$$

The utility function of the retailer and the supplier is:

$$U_r^+ = \frac{2+2\lambda}{2+\lambda}\pi_r^+ - \frac{\lambda(1+\lambda)}{2+\lambda}\pi_r \quad (46)$$

$$U_s^+ = \pi_s^+ \quad (47)$$

The optimal decision-making function of the supplier and the retailer can be obtained by maximising the utility function. To effectively implement cost-sharing among supply chain members, the sharing proportion τ should also meet the following requirements:

$$U_s^+ \geq U_s \quad (48)$$

$$U_r^+ \geq U_r \quad (49)$$

Combining the above equation, the range of the cost-sharing coefficient τ will be discussed in the numerical analysis.

4. Numerical analysis

This section verifies the impact of fairness concerns on supply chain decision-making through numerical analysis and assesses whether a cost-sharing contract can coordinate the supply chain, as shown in Table 1.

Table 1. Assignment of parameters

a	b	c	θ_0	η
30	0.3	2	0.4	0.6

Source: Defined by author.

4.1 The influence of retailers' fairness concern and consumer freshness preference on the supply chain

From Table 2, it can be observed that:(1) As the consumer freshness preference coefficient (α) increases, both product prices and freshness-keeping efforts improve under centralised and decentralised decision-making. When α = 0.5, prices are higher under centralised decision-making ($p_1^{c*} > p_1^{d*} > p_1^{n*}$、 $p_2^{c*} > p_2^{d*} > p_2^{n*}$). When α < 0.5, $p_1^{c*} < p_1^{n*} < p_1^{d*}$、 $p_2^{c*} < p_2^{n*} < p_2^{d*}$.(2) As the retailer's fairness concern increases, both price and freshness-keeping efforts decrease, as the retailer focuses on profits. The supplier reduces wholesale prices and reduces freshness-keeping efforts, while the retailer makes similar adjustments to enhance profits. Therefore, the above propositions are valid.

Table 2. Impact of λ and α on Supply Chain Decision

	λ	α	p_1	p_2	e_1	e_2	w
Centralised decision-making model	0	0.3	15.30	12.99	3.64	7.28	-
		0.4	18.11	15.80	5.98	11.97	-
		0.5	22.08	22.08	10.62	21.23	-
Decentralised decision making model	0	0.3	19.37	16.86	1.75	3.50	12.18
		0.4	20.65	18.34	2.75	5.50	12.61
		0.5	23.50	21.20	4.45	8.90	13.45
	0.5	0.3	19.05	16.74	1.39	3.48	10.08
		0.4	20.37	18.07	2.17	5.42	10.36
		0.5	22.87	20.65	3.45	8.63	10.87
	1	0.3	18.97	16.66	1.15	3.46	8.70
		0.4	20.19	17.89	1.79	5.36	8.89
		0.5	22.47	20.16	2.82	8.45	9.24
	1.5	0.3	18.91	16.60	0.98	3.45	7.72
		0.4	20.07	17.76	1.52	5.32	7.86
		0.5	22.18	19.88	2.38	8.33	8.12
	2	0.3	18.87	16.56	0.86	3.44	6.99
		0.4	19.98	17.76	1.32	5.29	7.10
		0.5	21.99	19.68	2.06	8.24	7.30

Source: calculated by authors.

From Table 3, it can be inferred that: (1) The profits for both the supplier and the retailer are positively correlated with consumer freshness preferences. That indicates that as consumers' preference for the freshness of fresh agricultural products increases, the profits of all members in the supply chain also increase. (2) The retailer's fairness concern behaviour has a positive correlation with its profit, while it is negatively correlated with the supplier's profit. This is because when the retailer has fairness concern behaviour, the price keeps falling with the deepening of such behaviour, and the purchase cost also decreases. However, when the retailer's fairness concern exceeds a certain level ($\lambda > 0.53$), its profits will surpass the supplier's. Thus, the supplier should share freshness-keeping costs to address these concerns and enhance cooperation.

Table 3. Impact of λ and α on profits of supply chain members

λ	α	π_s	π_r
0	0.3	80.10	45.05
	0.4	94.67	54.58
	0.5	122.87	74.80
0.5	0.3	63.59	60.80
	0.4	75.54	72.79
	0.5	95.22	97.19
1	0.3	52.73	71.03
	0.4	61.47	84.29
	0.5	71.73	110.54
1.5	0.3	45.03	78.22
	0.4	52.30	92.21
	0.5	65.67	119.37
2	0.3	39.30	93.53
	0.4	45.51	97.99
	0.5	56.85	125.64

Source: Authors' own creation.

4.2 The impact of the cost-sharing contract on supply chain profits under fairness concern

Analysing the effect of freshness-keeping cost-sharing coefficient τ on the profits of supply chain members reveals that when $\alpha = 0.4$ and $\lambda = 0.5$, the effect of adopting cost sharing contract on the profit function of the supplier and the retailer when the retailer has fairness concern is illustrated in Figure 2 below.

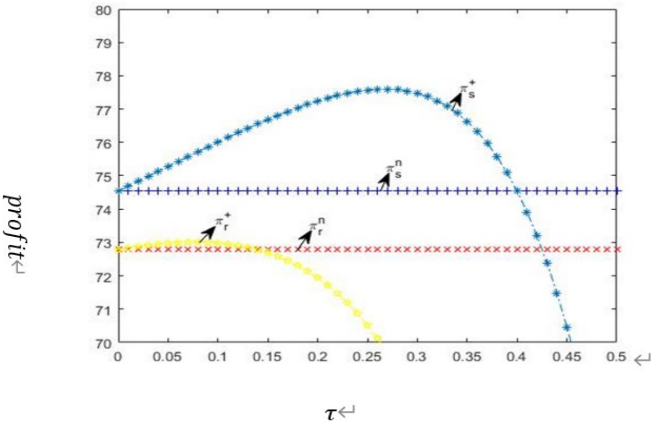

Figure 2. Impact of cost-sharing coefficient on profit under fairness concern
Source: Authors' own creation.

Figure 2 shows that when the retailer exits fairness concern and adopts a freshness-keeping cost-sharing contract, the profits of both the supplier and retailer display an inverted U-shaped relationship with the cost-sharing coefficient τ. From Figure 2, it can be observed that τ_1=0.14, τ_2=0.4, which indicates that when the freshness-keeping cost-sharing coefficient τ meets 0<τ<min (τ_1, τ_2), that is, when τ ∈ (0, 0.14), it can improve the profits of each member in the supply chain by implementing the cost-sharing contract when the retailer has fairness concern.. In addition, under the cost-sharing contract, the magnitude of profit growth for the supplier is significantly higher than that for the retailer. This is mainly because the supplier, as the dominant member of the game, has stronger bargaining power.

5. Conclusions

This paper addresses the coordination issues in the fresh agricultural products supply chain, focusing on joint investments in freshness-keeping costs and product price competition. It examines how the retailer's fairness concern and price competition affect the freshness-keeping efforts, pricing, and profits, and proposes a cost-sharing contract to coordinate supply chain profits. The research results showed that:

(1) The wholesale price, retail price, and freshness-keeping efforts of supply chain members are positively related to consumers' freshness preference. With the increase in the consumers' freshness preference coefficient, the profits of the retailer and the supplier also increase. However, the comparison of retail prices between different agricultural products depends on the consumers' freshness preference coefficient. (2) As the fairness concern deepens, the supplier tends to lower wholesale prices and reduce freshness-keeping efforts, which will lead to a decline in product freshness and consumer demand. Coordination contracts can address this issue. (3) The retailer's fairness concern behaviour has a positive correlated with its

profit. With the deepening of this behaviour, the price of the fresh agricultural products decreases, and the purchase cost also decreases. The supplier should focus on long-term cooperation and reduce fairness concerns to foster mutual profitability. (4) When the retailer has fairness concern, the freshness-keeping cost-sharing contract adopted by the supplier can achieve the fresh agricultural products supply chain coordination. The numerical analysis reveals that the cost-sharing coefficient τ within a certain value range, which can increase the profits of both the supplier and the retailer. (5) The price difference between competitive fresh agricultural products correlates with their market share. A product with a larger market share for results in less substitution and a higher price, while a smaller market share necessitates competitive pricing or discounts to draw consumer interest.

However, this paper has several limitations: (1) it only considered the retailer's fairness concern behaviour while neglected the supplier's fairness concern behaviour;(2) it only considered the determined market demand situation while neglected the uncertain market demand situation. In the future, researchers can expand from the following aspects: (1) to explore how the fairness concern from both the supplier and the retailer affects the decision-making of the fresh agricultural products supply chain; (2)to consider the fresh agricultural products supply chain decision-making under the stochastic market demand condition; (3) to introduce the factor of time awareness and explore how they impact on the fresh agricultural products supply chain decision-making, such as pricing and freshness-keeping efforts; (4)to consider the impact of time-varying freshness and consumer utility on the supply chain(Hu et al., 2024; Fang et al., 2024; Vora et al., 2024), (5) to perform decision modelling and simulation of market demand to determine the retailer's actual procurement demand from suppliers(Fang et al., 2024; He, 2024).(6) to consider more supply chain coordination contract designs(Wang et al., 2022) , such as goal-profit-based supply chain contract design(Jian et al., 2022)， resource-sharing decisions (Xu et al., 2024).

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