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ORIGINAL PAPER

Investment and coordination decisions in a supply chain of fresh agricultural products

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Abstract This paper investigates investment decisions in a supply chain of fresh agricultural products. Based on investment decisions of supply chain members, three different scenarios are considered, and the corresponding results are compared by considering the impact of fairness indices. In the decentralized scenario, joint investment in maintaining product freshness is profitable for both the manufacturer and retailer; however, the manufacturer utility decreases progressively with an increase in the retailer fairness index. To coordinate and achieve a win–win outcome, and maintain fairness for each member, revenue sharing coupled with investment cost sharing is proposed. To enforce this contract, the manufacturer may need to charge negative wholesale prices, but as a result, the highest utility for the supply chain cannot be achieved. In an alternative approach, an incremental quantity discount contract may encourage the manufacturer to charge a wholesale price greater than the marginal cost such that both members of the supply chain achieve the highest utility possible. Extended numerical investigation provides insights on ways to manage an efficient joint-investment strategy for a sustainable fresh agricultural products supply chain.

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1 Introduction

Because of evolving attitudes toward increased health-consciousness and better informed consumers, the freshness of agricultural products, such as fruits, vegetables, meat, fish, dairy, and so forth, has become a key driver for retaining customer loyalty and maintaining store traffic. Therefore, every member of an agricultural-product supply chain must take responsibility for maintaining the quality and freshness of the goods. Consumers consider color, odor, and texture as indicators of overall quality and freshness of food. To preserve these quality indicators, temperature-controlled transportation and storage systems, specialty material-handling equipment and packaging types, and specific shelf-space allocation strategies are required by both the manufacturer and retailer for harvested goods. For example, reusable plastic containers may be used to deliver lettuce and greens; however, paper pint or quart containers are typically preferred for delivering berries, cherries, and tomatoes. Furthermore, carrots and peaches should never be stocked on the same shelf. To accommodate preferences and freshness criteria, retailers and manufacturers should rigorously monitor their associates and their own workforce to meet challenges in delivering and storing agricultural products. However, these interrelations create significant imbalances in bargaining power within the agricultural-product supply chain, which can lead to unfair trading practices.

This study contributes to better understanding of the investment decisions made in an agricultural-product supply chain. First, we analyzed the investment decisions of an agricultural-product manufacturer and the decisions related to preserving product freshness of a retailer. Three different scenarios of a decentralized environment were investigated to identify the impact of the investment decision: manufacturer-only investment, retailer-only investment, and joint investment of the manufacturer and retailer that we refer to as *Scenario M*, *Scenario R*, and *Scenario MR*, respectively. We used the corresponding centralized scenarios as benchmarks to compare critical findings. Second, the impact of fairness concerns of both supply chain members was explored from the perspective of the profitability of each member. Third, two hybrid coordination mechanisms were used to achieve supply chain coordination: revenue sharing coupled with investment cost sharing (RSIS) and an incremental quantity discount (IQD) contract. To the best of our knowledge, the investment, pricing, and coordination of agricultural products have not been studied with respect to supply chain member fairness. We found that the joint investment decision generates higher profits for each supply chain member and produces a product with the greatest freshness. If the processing cost for the retailer is high, the RSIS contract fails to coordinate the supply chain; however, in this case, the IQD contract can coordinate the chain. The results demonstrated that the fairness index of the retailer was an important parameter for the successful implementation of a coordination mechanism in a supply chain of fresh agricultural products. The retailer investment decisions were largely influenced by the parameter associated with the freshness-keeping efforts of the manufacturer. Regardless of the fairness indices, the retailer invests to maintain the high freshness of the agricultural products that the manufacturer delivers.

The paper is organized as follows. Literature review is conducted in Sect. 2. The models are developed and results are compared for three decentralized and corresponding centralized scenarios in Sect. 3. Behaviors of supply chain members under different contract mechanisms are analyzed with numerical illustrations in Sect. 4. Finally, conclusions and suggestions for future studies are discussed in Sect. 5.

2 Literature review

Supply chain coordination and fairness concern formed the foundation of the problem studied in this paper. Therefore, we discuss the literature that highlighted issues related to supply chain management for agricultural products.

2.1 Supply chain of the agricultural products

In recent years, researchers have analyzed various aspects of the agricultural-product supply chain. For example, Rong et al. (2011) investigated decision-making processes in a food supply chain during production and distribution. Qin et al. (2014) examined joint pricing and inventory controls for fresh foods by taking physical quantity deterioration into account. Handayati et al. (2015) studied the operational aspects of inventory management of a food supply chain. An overview of a food supply chain can be seen in the review article of Fredriksson and Liljestrand (2015). Ge et al. (2015) developed simulation models to explore the complex internal optimization issues associated with food security in agricultural supply chains. These authors also validated the model by considering a case study of the Canadian wheat-handling system. Borodin et al. (2016) discussed the latest developments of operations research methodologies to mitigate some challenging problems in agricultural supply chain management. Moreover, to reduce the environmental and human health impacts of conventional agricultural-production systems, integrated and organic farming has been developed to reduce inefficient or unsustainable consumption of natural resources, such as water, fertilizer, and fossil fuels (Tasca et al. 2017). Yan et al. (2017) found that traceability rate was an important factor to measure the competitiveness of agricultural-product supply chains. They used extension theory and fuzzy comprehensive methods. Rueda et al. (2017) discussed the merits of commonly used instruments adopted by food companies to promote sustainability in agricultural-product supply chains. Keizer et al. (2017) formulated an analytical model using mixed integer linear programming formulation for fresh agricultural products. They found that an optimal logistic network was essential for reducing delivery lead times and decay. Thorlakson et al. (2018) studied the impact of the *Farming for the Future* program in South Africa and concluded that the long-term relationship among supply chain members could encourage more sustainable agricultural practices.

2.2 Fairness concerns of supply chain members

Behavioral research into supply chain management has advanced in recent years. Theoretical and experimental studies on social preferences show the positive effects of fairness on retailers and manufacturers (Cui et al. 2007; Demirag et al. 2010; Wu et al. 2011; Du et al. 2014; Chen et al. 2016; Wang et al. 2016; Du et al. 2016; Beitzen-Heineke et al. 2017; Qin et al. 2017). Evidence indicates that decision makers pay attention not only to their own profits but also to the profits of other chain participants. The comparison of profits among members is referred to as *fairness concern*(Yang et al. 2013). Chen and Dan (2009) analyzed the cooperation based on a benefit-sharing contract used within a two-level supply chain with random production and demand. In a recent study, Debove et al. (2016) found that when decision makers feel that they have been treated unfairly, they try to punish other participants even if their actions negatively affect their own businesses. For example, the Lego Group rejected Walmart Canadas demand for a price reduction designed to maintain a fair pricing structure in Canadian and U.S. markets, and eventually this decision broke up their business relationship (Georgiades 2008). Many empirical and experimental studies show that manufacturers and retailers might sacrifice their own profits to improve their counterparts margins and thus promote fairness in the chain (Loch and Wu 2008). Demirag et al. (2010) established that the exponential demand function requires less stringent conditions than the linear demand function to achieve coordination when only the retailer is concerned about fairness. Katok et al. (2012) showed that supply chain efficiency is lower when members have incomplete information than when fairness preferences are known by all members. Chang et al. (2016) developed a simulation model for agricultural-product pricing strategies by considering customer preferences. Chen et al. (2017) found that the retailer's fairness concern can change contract coordination under specific conditions. We refer the reader to the recent literature review by Dania et al. (2018) for a more detail discussion on behavioral factors affecting agricultural-food supply chains. In summary, studies on investment decisions that account for the fairness to supply chain members are important undertakings.

2.3 Supply chain contracts

Researchers have been afforded considerable attention to mitigates double marginalization and achieve supply chain coordination (Cachon 2003). Regarding supply chain coordination by revenue-sharing contract, Cachon and Lariviere (2005) provided a comprehensive survey. Revenue-sharing contracts have attracted attention among academics because they offer a relatively straightforward way to ensure aligned objectives that enhance performance (see, e.g., Pan et al. 2010; Cai et al. 2012; Avinadav et al. 2015; Moon et al. 2015; Giri and Sarker 2016; Hou et al. 2017; Muzaffar et al. 2017; He et al. 2018). From the perspective of an agricultural supply chain, Ye et al. (2017) proposed a hybrid contract mechanism that was based on revenue sharing, production cost sharing, and guaranteed money to coordinate an agricultural supply chain under an uncertainty environment. Yang et al. (2017) explored a bidirectional option contract mechanism to coordinate a supplier–retailer agricultural supply chain under the sales-effort-dependent demand. In this paper, revenue sharing coupled with a retailer investment cost-sharing contract is proposed to coordinate a supply chain affected by fairness concerns. We call this stratagem a *revenue and investment cost sharing* (RSIS) contract. However, if the order-processing cost of the retailer is high, then the manufacturer must charge negative wholesale prices, which is unacceptable. Therefore, as an alternative, an *incremental quantity discount* (IQD) contract was suggested for the supply chain. The abundant academic literature on quantity discount contracts includes work by Shin and Benton (2004), Cachon and Kok (2010), Huang et al. (2015), and Karray and Surti (2016). In addition to linear wholesale price discounts, under IQD, the manufacturer offers an aggressive quantity discount plan to coordinate the supply chain and improve the utility of each member while maintaining fairness for all. This type of discount model is continuous, differentiable, and concave (Cachon and Kok 2010). Under an IQD contract, the manufacturer can charge wholesale prices that exceed marginal costs.

3 Mathematical model and analysis

The following notations are used to develop the models:

a	Overall size of the potential market demand
b	Price sensitivity parameter of demand
c	Cost of the manufacturer per unit
t_c	Processing cost of the retailer per unit
λ_r	Retailer fairness-concern index
λ_m	Manufacturer fairness-concern index
γ	Investment cost coefficient of the retailer
α	Coefficient of freshness-keeping cost to the retailer
π_{ij}	i = m & r; and j = mr, r, & m; manufacturer's and retailer's profit in Scenarios MR, R, and M, respectively
π_{ij}^k	k = d & c; profit under the decentralized and centralized supply chain
U_{it}	t = mr, r & m; manufacturer's and retailer's utility in Scenarios MR, R, and M, respectively
p_j^k	Retail price per unit
w_j	Wholesale price per unit
h_j^k	j = mr & r; level of investment effort of the retailer
e_j^k	j = mr & m; level of freshness keeping investment effort of the manufacturer

We considered a distribution channel with one manufacturer and one retailer. The manufacturer produces an agricultural-product and sells it to consumers through the retailer. In making pricing and investment decisions, the manufacturer acts as the Stackelberg leader and the retailer is the follower. We made the following assumptions to formulate models:

(1) Manufacturer and retailer are both rational and risk neutral.

(2) There is complete information within the channel for the manufacturer and retailer.
(3) Market demand is influenced by retail price, and the level of the freshness-keeping efforts by the manufacturer and retailer. After receiving the product, the retailer cannot enhance the freshness level but can invest to stimulate market demand for and reduce the degradation rate of the product. Because the investment effort of the retailer cannot directly influence the freshness of the product, we considered the demand in multiplicative form. The functional form of market demand is expressed as follows:

$$D(p, e, h) = \left(1 - \frac{\theta e_0}{e}\right)(a - bp + \gamma h)$$

where $\theta (0 < \theta < 1)$ represents the sensitivity of the freshness of the agricultural products, which is realized by the freshness-keeping efforts of the manufacturer. The retailer's investment does not directly affect the freshness level of the product. Moreover, if $e \to \infty$, then the manufacturer's investment effort leads to a product with a maximum freshness level. The manufacturer needs to invest at least $e_{min} = e_0 (> 0)$ to ensure that the product is acceptable to consumers in the market, where freshness level reaches the lowest level $1 - \theta$. Agricultural products, such as meats, raw fish, apples, tomatoes, potatoes, and dairy products, can be stored for specific periods through proper preservation technology. Therefore, we assumed that, through investment efforts, the retailer keeps products fresh and deterioration is not significant during the replenishment period.
(4) The function for the freshness-keeping cost of the manufacturer is considered to be linear (Desiraju and Moorthy 1997; Chaab and Rasti-Barzoki 2016). This assumption cannot violate the concavity condition of the profit function $\frac{\partial D}{\partial e} > 0$ and $\frac{\partial^2 D}{\partial e^2} < 0$. If $e \to \infty$, then the product reach its maximum freshness level. We assumed the following two conditions to ensure concavity: (1) $a - b(c + t_c) > 0$ and (2) $2b\alpha > \gamma^2$. Without a retailer's investment effort, the demand is positive if $a - bp > 0$. Therefore, the retail price of the product must satisfy $p > c + t_c$. The retail price must exceed the sum of the manufacturing cost and processing cost; otherwise, the total profits are negative. The second condition describes the relations among system parameters.
(5) The function of the freshness-keeping cost of the retailer is $\frac{\alpha h^2}{2}$, which is an extensively accepted assumption (Chintagunta and Jain 1992; Saha 2013) because the increased freshness-keeping efforts carry increased costs.
(6) A unit processing cost to the retailer, which is relevant for every agricultural product, was assumed. The impact of processing costs for product categories, such as vegetables, beef, pork, margarine, and bread, is particularly difficult to ignore. Those costs make a significant impact on the profitability of the retailer.

In the next subsection, derivations of the expressions for all the decision variables of three different decentralized scenarios are presented. The corresponding centralized supply chain profits were obtained by adding the individual profits of the two members.

3.1 The decentralized scenarios

The decision sequences for the three scenarios are as follows: (1) In Scenario MR, the manufacturer determines the wholesale price and investment level, and the retailer subsequently determines the retail price and investment level. (2) In Scenario R, the manufacturer determines the wholesale price, and the retailer subsequently determines both the retail price and investment level. (3) In Scenario M, the manufacturer determines the wholesale price and investment level, and the retailer determines the retail price. We determine the unique equilibrium of all three games by employing backward induction. With the demand function, the individual profit functions of the retailer and manufacturer in Scenario MR are obtained as follows:

We first considered the case of decentralized decisions; that is, each supply chain player maximizes utility. We adopted a manufacturer Stackelberg game (Taleizadeh and Noori-daryan 2016; Saha 2016; Moon et al. 2018) to model strategic interactions within the supply chain in all three scenarios. The decision sequences for the three scenarios are as follows: (1) In Scenario MR, the manufacturer determines the wholesale price and investment level, and the retailer subsequently determines the retail price and investment level. (2) In Scenario R, the manufacturer determines the wholesale price, and the retailer subsequently determines both the retail price and investment level. (3) In Scenario M, the manufacturer determines the wholesale price and investment level, and the retailer determines the retail price. We determine the unique equilibrium of all three games by employing backward induction. With the demand function, the individual profit functions of the retailer and manufacturer in Scenario MR are obtained as follows:

$$\pi^{d}_{rmr} = (p - w - t_c)\left(1 - \frac{\theta e_0}{e}\right)(a - bp + \gamma h) - \frac{\alpha h^2}{2} \tag{1}$$

$$\pi^{d}_{mmr} = (w - c)\left(1 - \frac{\theta e_0}{e}\right)(a - bp + \gamma h) - e \tag{2}$$

To incorporate social fairness concerns into the study, we modified the classical models described herein. We follow the analytical framework described in Loch and Wu (2008) and Qin et al. (2017), and considered the case in which both the manufacturer and retailer utility functions include concerns for the other members's payoffs as follows:

$$U_{rmr} = \pi^{d}_{rmr} + \lambda_r \pi^{d}_{mmr} \tag{3}$$

$$U_{mmr} = \pi^{d}_{mmr} + \lambda_m \pi^{d}_{rmr} \tag{4}$$

The optimal response for retailer is obtained by solving $\frac{\partial U_{rmr}}{\partial p} = 0$, and $\frac{\partial U_{rmr}}{\partial h} = 0$. On simplification one can obtain the following responses:

$$p = \frac{ae\alpha + (be\alpha - \gamma^2(e - e_0\theta))(t_c + w + c\lambda_r - w\lambda_r)}{2be\alpha - \gamma^2(e - e_0\theta)} \text{ and}$$
$$h = \frac{\gamma(e - e_0\theta)(a - b(t_c + w + c\lambda_r - w\lambda_r))}{2be\alpha - \gamma^2(e - e_0\theta)}$$

Now $\frac{\partial^2 U_{rmr}}{\partial p^2} = -2b\left(1 - \frac{e_0\theta}{e}\right) < 0,$ $\frac{\partial U^2_{rmr}}{\partial h^2} = -\alpha < 0$ and $\frac{\partial U^2_{rmr}}{\partial p^2} \times \frac{\partial U^2_{rmr}}{\partial h^2} - \left(\frac{\partial U^2_{rmr}}{\partial h \partial p}\right)^2 = \frac{(e-e_0\theta)\Psi_1}{e^2}$, i.e., the utility function of the retailer is concave if $\Psi_1 = 2be\alpha - \gamma^2(e - e_0\theta) > 0$. Substituting p and h in Eq. (4), one can obtain the utility function of the manufacturer as follows:

$$U_{mmr} = \frac{1}{2\Psi_1}\big[(e - e_0\theta)(2e\gamma^2 + \alpha(a - b(t_c + w + c\lambda_r - w\lambda_r))(a\lambda_m + b((w - c)(2 - \lambda_m\lambda_r) - (t_c + w)\lambda_m)) - 4be^2\alpha\big] \tag{5}$$

Finally, the optimal decision for the manufacturer is obtained by solving $\frac{\partial U_{mmr}}{\partial e} = 0$ and $\frac{\partial U_{mmr}}{\partial w} = 0$. On simplification, one can obtain the following responses:

$$e = \frac{M\alpha(1 - \lambda_m\lambda_r)R}{2b\alpha - \gamma^2} - \frac{e_0\gamma^2\theta}{2b\alpha - \gamma^2} \text{ and } w = \frac{M(1 - \lambda_m)}{b(1 - \lambda_r)(2 - \lambda_m - \lambda_m\lambda_r)} + c$$

where $M = a - b(c + t_c)$, $N = \sqrt{(1 - \lambda_r)(2 - \lambda_m - \lambda_m\lambda_r)}$, and $R = \sqrt{\frac{be_0\theta}{N}}$. Because, $e \geq e_0$ must be satisfied, that is $M\alpha(1 - \lambda_m\lambda_r)R \geq (2b\alpha - (1 - \theta)\gamma^2)e_0$.

Similar to the retailer utility, $\frac{\partial^2 U_{mmr}}{\partial w^2} = -\frac{b^2\alpha(e-e_0\theta)(1-\lambda_r)(2-\lambda_m+\lambda_m\lambda_r)}{\Psi_1} < 0$ and $\frac{\partial^2 U_{mmr}}{\partial w^2} \times \frac{\partial^2 U_{mmr}}{\partial e^2} - \left(\frac{\partial^2 U_{mmr}}{\partial e \partial w}\right)^2 = \frac{2bN^2\sqrt{be_0\theta}\left(M\alpha(1-\lambda_m\lambda_r)N-2\sqrt{be_0\theta}N^2\right)}{e_0M^2\alpha\theta(1-\lambda_m\lambda_r)^2} > 0$ i.e., the utility function of the manufacturer is also concave if $M\alpha(1 - \lambda_m\lambda_r) > 2\sqrt{be_0\theta}N$. Substituting optimal decisions, profits of the retailer and manufacturer, and the sales volume are obtained as follows:

$$\pi^d_{rmr} = \frac{M\alpha(1 - \lambda_r(3 - \lambda_m - \lambda_m\lambda_r))(R(1 - \lambda_m\lambda_r)R - 2be_0\theta)}{2P(2b\alpha - \gamma^2)(1 - \lambda_r)(2 - \lambda_m - \lambda_m\lambda_r)^2} \tag{6}$$

$$\pi^d_{mmr} = \frac{1}{R(2b\alpha - \gamma^2)(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)^2}[M\alpha(1-\lambda_m)(R(1-\lambda_m\lambda_r)M - 2be_0\theta) - R(1-\lambda_r)(RM\alpha(1-\lambda_m\lambda_r) - e_0\gamma^2\theta)(2-\lambda_m-\lambda_m\lambda_r)^2] \tag{7}$$

$$Q^d_{mr} = \frac{b\alpha(R(1-\lambda_m\lambda_r)M - 2be_0\theta)}{R(2b\alpha-\gamma^2)(2-\lambda_m-\lambda_m\lambda_r)} \tag{8}$$

If one substitutes $e = e_0$ into Eqs. (1) and (2) (i.e., the manufacturer invests the minimum), then the profit functions of the retailer and manufacturer in Scenario R are obtained as

$$\pi^d_{rr} = (p - w - t_c)(1-\theta)(a - bp + \gamma h) - \frac{\alpha h^2}{2} \tag{9}$$

$$\pi^d_{mr} = (w - c)(1-\theta)(a - bp + \gamma h) - e_0 \tag{10}$$

The corresponding utility functions of the retailer and manufacturer in Scenario R are given below:

$$U_{rr} = \pi^d_{rr} + \lambda_r \pi^d_{mr} \tag{11}$$

$$U_{mr} = \pi^d_{mr} + \lambda_m \pi^d_{rr} \tag{12}$$

Similarly, by substituting $\alpha = 0$ and $\gamma = 0$ into Eqs. (1) and (2), the profit functions of the retailer and manufacturer in Scenario M are obtained as

$$\pi^d_{rm} = (p - w - t_c)\left(1 - \frac{\theta e_0}{e}\right)(a - bp) \tag{13}$$

$$\pi^d_{mm} = (w - c)\left(1 - \frac{\theta e_0}{e}\right)(a - bp) - e \tag{14}$$

The utility functions of the retailer and manufacturer in Scenario M are given below:

$$U_{rm} = \pi^d_{rm} + \lambda_r \pi^d_{mm} \tag{15}$$

$$U_{mm} = \pi^d_{mm} + \lambda_m \pi^d_{rm} \tag{16}$$

We used a similar approach to find an optimal decision under the decentralized environments of Scenarios R and M and present the results in Table 1.

Table 1 Equilibrium outcomes in Scenarios R and M

	Scenario R	Scenario M
e_j^d	–	$\frac{M(1-\lambda_m\lambda_r)\sqrt{R}}{2b}$
h_j^d	$\frac{M\gamma(1-\theta)(1-\lambda_m\lambda_r)}{(2b\alpha-\gamma^2(1-\theta))(2-\lambda_m-\lambda_m\lambda_r)}$	–
w^j	$\frac{(a-bt_c)(1-\lambda_m)+bc(1-\lambda_r(2-\lambda_m\lambda_r))}{b(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)}$	$\frac{a(1-\lambda_m)-b(t_c(1-\lambda_m)-c(1-\lambda_r(2-\lambda_m\lambda_r)))}{b(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)}$
p_j^d	$\frac{a\Psi_1(2-\lambda_m-\lambda_m\lambda_r)-M(b\alpha-\gamma^2(1-\theta))(1-\lambda_m\lambda_r)}{b(2b\alpha-\gamma^2(1-\theta))(2-\lambda_m-\lambda_m\lambda_r)}$	$\frac{a(3-\lambda_m(2+\lambda_r))-b(c+t_c)(1-\lambda_m\lambda_r)}{2b(2-\lambda_m-\lambda_m\lambda_r)}$
U_{rj}	$\frac{M^2\alpha(1-\theta)(1-\lambda_m\lambda_r)^2}{2(2b\alpha+\gamma^2(1-\theta))(2-\lambda_m-\lambda_m\lambda_r)^2} - e_0\lambda_r$	$\frac{M(1-\lambda_m\lambda_r)^2(M-2(1+\lambda_r)\sqrt{R}(2-\lambda_m-\lambda_m\lambda_r))}{4b(2-\lambda_m-\lambda_m\lambda_r)^2}$
U_{mj}	$\frac{M^2\alpha(1-\theta)(1-\lambda_m\lambda_r)^2}{2(2b\alpha+\gamma^2(1-\theta))(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)} - e_0$	$\frac{M(1-\lambda_m\lambda_r)(M(1-\lambda_m\lambda_r)-\frac{4be_0\theta}{R})}{4b(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)}$
Q_j^d	$\frac{bM\alpha(1-\theta)(1-\lambda_m\lambda_r)}{(2b\alpha-\gamma^2(1-\theta))(2-\lambda_m-\lambda_m\lambda_r)}$	$\frac{M(1-\lambda_m\lambda_r)-\frac{2be_0\theta}{\sqrt{R}}}{2(2-\lambda_m-\lambda_m\lambda_r)}$

3.2 The centralized scenarios

In centralized scenarios, both the manufacturer and retailer collaborate in maximizing the profit of the entire supply chain. The wholesale price of the product does not make any impact on the optimal decision. Therefore, the profit function of the centralized supply chain in Scenario MR was obtained by adding an individual profits function as presented in Eqs. (1) and (2). The fairness indices did not affect the profitability of the benchmark centralized scenario.

$$\pi_{mr}^c = (p-c-t_c)\left(1-\frac{\theta e_0}{e}\right)(a-bp+\gamma h) - e - \frac{\alpha h^2}{2} \tag{17}$$

Similarly, the profit function of the centralized supply chain in Scenario M was obtained from Eqs. (9) and (10) and in Scenario R they were obtained from Eqs. (13) and (14). The simplified expressions are given as follows:

$$\pi_r^c = (p-c-t_c)(1-\theta)(a-bp+\gamma h) - \frac{\alpha h^2}{2} - e_0 \tag{18}$$

$$\pi_m^c = (p-c-t_c)\left(1-\frac{\theta e_0}{e}\right)(a-bp) \tag{19}$$

The equilibrium decisions in three centralized scenarios are shown in Table 2.

Where $\Delta_1 = 2b\alpha_1 - \gamma^2$. The following propositions summarize the comparison results.

Table 2 Optimal solutions of the centralized scenarios

	Scenario MR	Scenario R	Scenario M
e_j^c	$\frac{\alpha_1 M\sqrt{be_0\theta}-e_0\gamma^2\theta}{\Delta_1}$	–	$\frac{M}{2}\sqrt{\frac{e_0\theta}{b}}$
h_j^c	$\frac{\gamma(M-2\sqrt{be_0\theta})}{\Delta_1}$	$\frac{M\gamma(1-\theta)}{\Delta_1}$	–
p_j^c	$\frac{M(b\alpha-\gamma^2)\sqrt{be_0\theta}-e_0\gamma^2\theta}{2\Delta_1}$	$\frac{a\alpha+(c+tc)(b\alpha+\gamma^2(1-\theta))}{\Delta_1}$	$\frac{a+b(c+t_c)}{2b}$
π_j^c	$\frac{2e_0\gamma^2\theta+\alpha(M-4\sqrt{be_0\theta})}{2\Delta_1}$	$\frac{\alpha_1 M^2(1-\theta)}{2\Delta_1}-e_0$	$\frac{M^2-4M\sqrt{e_0\theta b}}{4b}$
Q_j^c	$\frac{b\alpha(M-2\sqrt{be_0\theta})}{\Delta_1}$	$\frac{\alpha b(1-\theta)M}{\Delta_1}$	$\frac{M-2\sqrt{e_0\theta b}}{2}$

Proposition 1 *In a centralized supply chain,*

(i) *The supply chain system gains the highest profit in Scenario MR.*
(ii) *The consumer receives products at the highest freshness level in Scenario MR, but needs to pay a higher price in Scenario MR than in other scenarios.*
(iii) *The sales volume of the supply chain system is the highest in Scenario MR.*

Proof From Table 2, one can observe that the difference among centralized supply chain profits in Scenarios MR, R, and M as $\pi_{mr}^c - \pi_r^c = \frac{2\alpha^2 b\theta M^2}{2(2b\alpha-(1-\theta)\gamma^2)(2b\alpha-\gamma^2)} + e_0 + \frac{e_0\gamma^2\theta}{2b\alpha-\gamma^2}$ and $\pi_{mr}^c - \pi_m^c = \frac{M\gamma^2(M-4\sqrt{be_0\theta})+2\gamma^2 e_0\theta}{2b(2b\alpha-\gamma^2)}$. The differences are nonnegative because of $M > 2\sqrt{be_0\theta}$.

Differences among the prices of the products in centralized supply chain are $p_{mr}^c - p_r^c = \frac{\gamma^2\theta(\alpha\sqrt{be_0\theta}(M-2\sqrt{be_0\theta})+e_0\gamma^2(1-\theta))}{\sqrt{be_0\theta}(2b\alpha-(1-\theta)\gamma^2)(2b\alpha-\gamma^2)} > 0$ and $p_{mr}^c - p_m^c = \frac{\gamma^2(M-2\sqrt{be_0\theta})}{2b(2b\alpha-\gamma^2)} > 0$.

Differences between fresh-keeping effort in centralized supply chain are $e_{mr}^c - e_m^c = \frac{\gamma^2\sqrt{be_0\theta}(M-2\sqrt{be_0\theta})}{2b(2b\alpha-\gamma^2)} > 0$ and $h_{mr}^c - h_m^c = \frac{2b\alpha\gamma(M-2\sqrt{be_0\theta})+2\gamma^3\sqrt{be_0\theta}(1-\theta)}{(2b\alpha-(1-\theta)\gamma^2)(2b\alpha-\gamma^2)} > 0$.

Differences among the sales volume of in the centralized supply chains are $Q_{mr}^c - Q_m^c = \frac{2b^2\alpha^2(M-2\sqrt{be_0\theta})+2b\alpha\gamma^2\sqrt{be_0\theta}(1-\theta)}{(2b\alpha-(1-\theta)\gamma^2)(2b\alpha-\gamma^2)} > 0$ and $Q_{mr}^c - Q_r^c = \frac{\gamma^2(M-2\sqrt{be_0\theta})}{2(2b\alpha-\gamma^2)} > 0$.

Therefore, this proposition is proved. □

Proposition 2 *In a decentralized supply chain, the manufacturer places higher emphasis on fresh-keeping measures in Scenario MR than in Scenario M. The retailer also places higher emphasis on fresh-keeping measures in Scenario MR than in Scenario R.*

Proof From Table 1, one can observe that the difference between fresh-keeping effort of the manufacturer in Scenarios MR and M is

$$e^d_{mr} - e^d_m = \frac{\gamma^2 \sqrt{be_0\theta}N(M(1-\lambda_m\lambda_r) - 2\sqrt{be_0\theta}N)}{2bN^2(2b\alpha - \gamma^2)} > 0$$

Similarly, one can observe that the difference between fresh-keeping effort of the retailer in Scenarios MR and R is

$$h^d_{mr} - h^d_m = \frac{2b\alpha\gamma(M(1-\lambda_m\lambda_r) - 2\sqrt{be_0\theta}N) + 2\gamma^3(1-\theta)\sqrt{be_0\theta}N}{\Psi(2-\lambda_m-\lambda_m\lambda_r)(2b\alpha-\gamma^2)} > 0$$

This completes the proof of Proposition 2. □

Proposition 3 *In Scenario MR, the fresh-keeping efforts of the channel member increases as the fairness index of the other increases.*

Proof Differentiating the fresh-keeping efforts of the manufacturer with respect to λ_r, one can obtain the following

$$\frac{\partial e^d_{mr}}{\partial \lambda_r} = \frac{\alpha\theta^2 b^2 e_0^2 M(1-\lambda_m)}{(2b\alpha-\gamma^2)(be_0\theta)^{3/2}N^{3/2}}$$

Similarly, differentiating the fresh-keeping efforts of the retailer with respect to λ_m, one can obtain the following

$$\frac{\partial e^d_{mr}}{\partial \lambda_r} = \frac{\gamma(1-\lambda_r)(M-\sqrt{be_0\theta}N)}{(2b\alpha-\gamma^2)(2-\lambda_m-\lambda_m\lambda_r)^2}$$

Hence, Proposition 3 holds. □

If both supply chain members make investments, then the demand for the product also increases such that each can be compensated for investment costs. Moreover, in Scenario MR, the supply chain member can provide products at the highest freshness level, but in Scenarios R and M, they may offer products at the lowest freshness level. Therefore, one can infer that in a decentralized supply chain, regardless of other parameters, both the manufacturer and the retailer acquire the greatest benefit from a joint investment effort and consumers receive the freshest possible products.

4 Supply chain coordination

In this study, the characteristics of the decentralized and centralized supply chain have been presented through three different scenarios. In both decentralized and centralized scenarios, the supply chain profit and member utility are highest in Scenario MR; that is, the joint investment effort is the most beneficial to supply chain members. Therefore, we introduce contract mechanisms to remove supply chain inefficiency and provide a means to coordinate the members in Scenario MR.

4.1 Coordinating supply chain by using an RSIS contract

The RSIS contract is described by three parameters: wholesale price, w; retailer fresh-keeping investment cost-sharing fraction, $\eta(0 < \eta < 1)$; and revenue-sharing fraction, $\rho(0 < \rho < 1)$. To entice the retailer to order products, set retail price, and make investments that benefit the supply chain, the manufacturer charges unit wholesale prices lower than the production costs and shares a percentage of the retailer investment cost. In exchange, the retailer gives a fraction of revenue, ρ, to the manufacturer. Under this contract mechanism, the profit functions of the retailer (π_{rrsis}) and the manufacturer (π_{mrsis}) are as follows:

$$\pi_{rrsis} = ((1-\rho)p - w - t_c)\left(1 - \frac{\theta e_0}{e}\right)(a - bp + \gamma h) - \frac{(1-\eta)\alpha h^2}{2} \tag{20}$$

$$\pi_{mrsis} = (\rho p + w - c)\left(1 - \frac{\theta e_0}{e}\right)(a - bp + \gamma h) - \frac{\eta \alpha h^2}{2} - e \tag{21}$$

Therefore, the corresponding utility functions of the retailer (U_{rrsis}) and manufacturer (U_{mrsis}) with fairness concern are as follows:

$$U_{rrsis} = \pi_{rrsis} + \lambda_r \pi_{mrsis} \tag{22}$$

$$U_{mrsis} = \pi^d_{mrsis} + \lambda_m \pi_{rrsis} \tag{23}$$

To verify whether the contract can coordinate the supply chain, it is necessary to determine the response of the retailer by solving $\frac{\partial U_{rrsis}}{\partial p} = 0$ and $\frac{\partial U_{rrsis}}{\partial h} = 0$. After simplification, we obtain

$$h = \frac{\gamma(e - e_0\theta)(a(1-\rho+\rho\lambda_r) - b(t_c + w + c\lambda_r - w\lambda_r))}{2be\alpha(1-\eta+\eta\lambda_r) - \gamma^2(e-e_0\theta)(1-\rho+\rho\lambda_r)} \tag{24}$$

$$p = \frac{e\alpha(1-\eta+\eta\lambda_r)(a(1-\rho+\rho\lambda_r) - b(t_c + w + c\lambda_r - w\lambda_r))}{(1-\rho-\rho\lambda_r)(2be\alpha(1-\eta+\eta\lambda_r) - \gamma^2(e-e_0\theta)(1-\rho+\rho\lambda_r))} + \frac{t_c + w - \lambda_r(w-c)}{1-\rho+\rho\lambda_r} \tag{25}$$

Therefore, the manufacturer has two alternatives: (1) the manufacturer can maximize its own utility by maximizing U_{mrsis} with respect to w and e, or (2) the manufacturer can coordinate with the retailer to enhance the supply chain utility. If the manufacturer coordinates the retailer's decision, then by equating the value of the retailer investment obtained in Eq. (24) and the retail price obtained in Eq. (25) with respective to the centralized values of each, as presented in Table 2, the manufacturer wholesale price is obtained as follows:

$$\begin{aligned} w =& \frac{1}{b(2b\alpha-\gamma^2)(e-e_0\theta)(1-\lambda_r)}\Big[(2\gamma^2\sqrt{be_0\theta}(e-e_0\theta)(1-\rho+\rho\lambda_r))-2b^2\alpha \\ & (t_c(e_0\theta-e\rho(1+\lambda_r))+c(e(1-\rho)(1-\lambda_r)+e_0\theta\lambda_r)) \\ & +b(2ae_0\alpha\theta-e_0\rho(2a\alpha-t_c\gamma^2) \\ & +\theta(1-\lambda_r)c(1-\rho)\gamma^2(e-e_0\theta)(1-\lambda_r)+e(t_c\rho\gamma^2(1-\lambda_r) \\ & +4\alpha\sqrt{be_0\theta}(1-\rho+\rho\lambda_r)))\Big] \end{aligned} \tag{26}$$

$$w = \frac{\Psi_2(1-\rho+\rho\lambda_r)(\gamma^2(e-e_0\theta)(1-\rho+\rho\lambda_r))-2be\alpha(1-\eta+\eta\lambda_r)}{2(1-\lambda_r)(be\alpha(1-\eta+\eta\lambda_r))+\gamma^2(e-e_0\theta)(1-\rho+\rho\lambda_r)} \tag{27}$$

where $\Psi_2 = \frac{2a\alpha-(c+t_c)\gamma^2)-4\alpha\sqrt{be_0\theta}}{2b\alpha-\gamma^2} + \frac{2e_0\theta}{\sqrt{be_0\theta}} + \frac{t_c\rho-c(1-\rho)(1-\lambda_r)}{1-\rho+\rho\lambda_r}$ $+\frac{\gamma^2(e-e_0\theta)(t_c+c\lambda_r)-2ae\alpha(1-\eta+v\lambda_r)}{2be\alpha(1-\eta+\eta\lambda_r)-\gamma^2(e-e_0\theta)(1-\rho+\rho\lambda_r)}$.

However, the wholesale prices obtained in Eqs. (26) and (27) must be identical. On simplification

$$e = \frac{\Psi_3}{\Psi_4} \tag{28}$$

where $\Psi_3 = \alpha e_0\theta(2b\alpha-\gamma^2)(1-\eta+\eta\lambda_r)(1-\rho+\rho\lambda_r)\sqrt{be_0\theta}-e_0\theta(1-y+y\lambda_r)$ $(2b^2(c+t_c)\alpha^2\sqrt{be_0\theta}(1-\eta+\eta\lambda_r)+\gamma^2(a\alpha\sqrt{be_0\theta}(1+\eta-2\rho(1-\lambda_r)-x\lambda_r)-2e_0\gamma^2\theta(1$ $-\rho+\rho\lambda_r))-b\alpha(-4e_0\gamma^2\theta(1-\eta+\eta\lambda_r)+\sqrt{be_0\theta}(2a\alpha(1-\eta+\eta\lambda_r)+(c+t_c)\gamma^2(1+$ $\eta-2\rho(1-\lambda_r)-\eta\lambda_r))))$ and $\Psi_4 = 2(2b\alpha(1-\eta+\eta\lambda_r)-\gamma^2(1-\rho+\rho\lambda_r)(b\alpha(2e_0\theta(1-$ $\eta+\eta\lambda_r)+(c+t_c)(\eta-\rho)\sqrt{be_0\theta}(1-\lambda_r))-a(\eta-\rho)\alpha\sqrt{be_0\theta}(1-\lambda_r)+e_0\gamma^2\theta(1-\rho$ $+\rho\lambda_r))$.

The supply chain profit is optimal if the level of fresh-keeping investment obtained in Eq. (28) of the manufacturer is identical with the corresponding centralized value presented in Table 2. One can verify that the equality is satisfied if $\rho = \eta$. By substituting $\rho = \eta$, one can obtain the wholesale price of the retailer as

$$w = c - (c + t_c)\rho \tag{29}$$

Using Eqs. (24)–(29), the profits of the retailer and manufacturer under RSIS contract are obtained as follows:

$$\pi_{rrsis} = \frac{M(1-\rho)\alpha(M - 2\sqrt{be_0\theta})}{4b\alpha - 2\gamma^2} \tag{30}$$

$$\pi_{mrsis} = \frac{2e_0\gamma^2\theta + M\alpha(My - 2(1+\rho)\sqrt{be_0\theta}}{4b\alpha - 2\gamma^2} \tag{31}$$

From Eqs. (30) and (31), one can easily verify that $\pi_{rrsis} + \pi_{mrsis} = \pi^c_{mr}$, that is, the supply chain becomes coordinated. The corresponding utilities of the retailer and manufacturer are obtained as follows:

$$U_{rrsis} = \frac{M(1-\rho)\alpha(M - 2\sqrt{be_0\theta}) + (2e_0\gamma^2\theta - M\alpha(a\rho - b(c+t_c)\rho + 2(1+\rho)\sqrt{be_0\theta}))\lambda_r}{4b\alpha - 2\gamma^2} \tag{32}$$

$$U_{mrsis} = \frac{2e_0\gamma^2\theta - M\alpha(2\sqrt{be_0\theta} - (M - 2\sqrt{be_0\theta})(\rho(1-\lambda_m) + \lambda_m))}{4b\alpha - 2\gamma^2} \tag{33}$$

For a win–win outcome for all channel members, we must have $U_{rrsis} \geq U_{rmr}$ and $U_{mrsis} \geq U_{mmr}$. Simplifying the inequalities, we have obtained the following range $\rho = \eta \in [\rho_L, \rho_U]$, where

$$\rho_L = \frac{1}{\Delta(1-\lambda_m)}\Big[MR(1-\lambda_m)^2 - 2be_0\theta(1-\lambda_m\lambda_r) + 2R(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r) (\sqrt{be_0\theta}(1+\lambda_m) - R(1-\lambda_m\lambda_r))\Big] \tag{34}$$

$$\rho_U = \frac{1}{\Delta(2-\lambda_m-\lambda_m\lambda_r)}\Big[MR(1-\lambda_m)(3-\lambda_m-2\lambda_m\lambda_r) + 2R(2-\lambda_m-\lambda_m\lambda_r)^2 (\sqrt{be_0\theta}(1+\lambda_r) - R(1-\lambda_m\lambda_r)) + 2be_0\theta(1-\lambda_m\lambda_r)\Big] \tag{35}$$

$\Delta = R(M - 2\sqrt{be_0\theta})(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)$.

Hence, one can infer that the RSIS contract can coordinate the supply chain. The utility of the manufacturer will be maximum or the utility of the retailer will be minimum at the upper bound of the interval. However, from Eq. (29), one can see that the wholesale price of the product may be negative for the product associated with a high processing cost. Agricultural products such as fruits and vegetables are produced seasonally, but the market requires products throughout the year. Therefore, the unit processing cost of the retailer sometime becomes substantial. We found that the performance of the contract mechanism is highly sensitive to the unit processing cost parameter. According to the analysis, we made the following proposition:

Proposition 4 *Any arbitrary values of the revenue or retailer investment cost-sharing fraction may coordinate the system perfectly and lead to acceptable outcomes for all the supply chain members.*

The graphical representations of the wholesale price under the RSIS contract are shown in Fig. 1a, b. The following parameters are used for illustration: $a = 200$, $b = 1$, $c = 20$, $t_c = 5$, $\alpha_1 = 1$, $\theta = 0.3$, $\gamma = 0.8$, $e_0 = 1000$, $\lambda_r = 0.2$, and $\lambda_m = 0.2$.

Figure 1b justifies the phenomenon. The corresponding range of revenue-sharing or cost-sharing fractions is $\rho \in [0.5794, 0.8879]$. However, the wholesale price of the manufacturer becomes negative as the revenue-sharing fraction reaches close to the upper bound. In this circumference, the manufacturer never receives the highest possible benefit. Although, Fig. 1a demonstrates that, within the range, it can distribute profits arbitrarily, the RSIS contract is not always acceptable for the manufacturer in a supply chain of fresh agricultural products. This finding motivated us to search for more robust contract mechanism.

4.2 Coordinating supply chain by using an IQD contract

The IQD contract can be described by two parameters: wholesale prices, w, and quantity discount factor, ϵ. To entice the retailer to order more products, set retail price, and make investments that benefit the supply chain, the manufacturer provides incremental discounts according to order quantity. The wholesale-price contract is a subset of the IQD contract, which is equivalent to the wholesale-price contract if $\epsilon = 0$. The IQD contract is applied to verify whether the manufacturer can charge a wholesale price greater than its marginal cost to the retailer. Under this contract, the

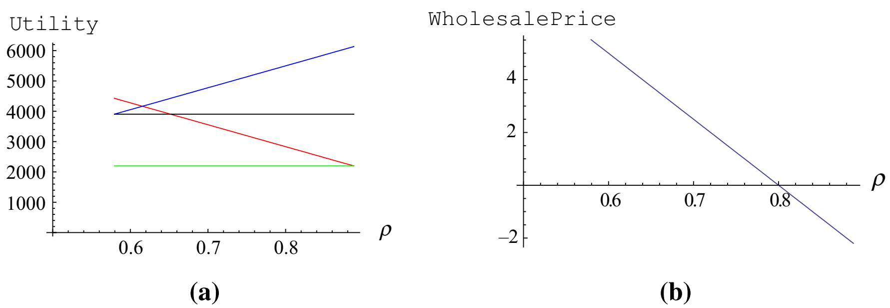

Fig. 1 **a** U^{d}_{rmr} (green), U_{rrsis} (red), U^{d}_{mmr} (black), and U_{mrsis} (blue). **b** Wholesale price under the RSIS contract (color figure online)

profit functions of the retailer (π_{riqd}) and the manufacturer (π_{miqd}) for Scenario MR are obtained as follows:

$$\pi_{riqd} = (p - w - t_c)\left(1 - \frac{\theta e_0}{e}\right)(a - bp + \gamma h) - \frac{\alpha h^2}{2} + \epsilon\left(1 - \frac{\theta e_0}{e}\right)^2 (a - bp + \gamma h)^2 \tag{36}$$

$$\pi_{miqd} = (w - c)\left(1 - \frac{\theta e_0}{e}\right)(a - bp + \gamma h) - \epsilon\left(1 - \frac{\theta e_0}{e}\right)^2 (a - bp + \gamma h)^2 - e \tag{37}$$

Therefore, the corresponding utility functions of the retailer (U_{rrsis}) and the manufacturer (U_{mrsis}) with fairness concerns are as follows:

$$U_{riqd} = \pi_{riqd} + \lambda_r \pi_{miqd} \tag{38}$$

$$U_{miqd} = \pi^d_{miqd} + \lambda_m \pi_{riqd} \tag{39}$$

To verify whether the IQD contract can coordinate the supply chain, it is necessary to determine the response of the retailer by solving $\frac{\partial U_{riqd}}{\partial p} = 0$ and $\frac{\partial U_{riqd}}{\partial h} = 0$. After simplification, the retail price and the fresh-keeping efforts of the retailer are obtained as follows:

$$p = \frac{a\alpha(e(1 - 2b\epsilon(1 - \lambda_r)) + 2be_0\epsilon\theta(1 - \lambda_r)) + (be\alpha - \gamma^2(e - e_0\theta))(t_c + w + c\lambda_r - w\lambda_r)}{2be\alpha - \gamma^2(e - e_0\theta) - 2b^2\epsilon\alpha(e - e_0\theta)(1 - \lambda_r)} \tag{40}$$

$$h = \frac{\gamma(e - e_0\theta)(a - b(t_c + w + c\lambda_r - w\lambda_r))}{2be\alpha - \gamma^2(e - e_0\theta) - 2b^2\epsilon\alpha(e - e_0\theta)(1 - \lambda_r)} \tag{41}$$

Similar to the RSIS contract, under the IQD contract, if the manufacturer coordinates the retailer's decision, then by equating the value of the retailer's fresh-keeping efforts obtained in Eq. (41) and the price of the product obtained in Eq. (40) with their respective centralized values presented in Table 2, the manufacturer fresh-keeping efforts and wholesale price are obtained as follows:

$$e = \frac{M\alpha\sqrt{be_0\theta_1} - e_0\gamma^2\theta}{2b\alpha_1 - \gamma^2} \tag{42}$$

$$w = \frac{2b\alpha(c + \epsilon(a - 2\sqrt{be_0\theta}) - 2b^2(c + t_c)\epsilon\alpha - c\gamma^2}{2b\alpha_1 - \gamma^2} \tag{43}$$

From Eq. (43), one can observe that $\frac{\partial w}{\partial \epsilon} = \frac{2b\alpha(M-2\sqrt{be_0\theta})}{2b\alpha_1-\gamma^2} > 0$; therefore, the wholesale price increases as ϵ increases. Using Eqs. (40)–(43), the profits of the retailer and the manufacturer under the IQD contract are obtained as follows:

$$\pi_{riqd} = \frac{2M\alpha(2b(2b\epsilon-1)\alpha+\gamma^2)\sqrt{be_0\theta}+\alpha(2b(b\epsilon-1)\alpha M^2+\gamma^2)-8b^3e_0\epsilon\alpha\theta)}{2(2b\alpha-\gamma^2)^2} \tag{44}$$

$$\pi_{miqd} = \frac{(b^2M^2\epsilon\alpha^2+e_0(4b^3\epsilon\alpha^2+2b\alpha\gamma^2-\gamma^4)\theta)-\sqrt{be_0\theta}M\alpha(2b(1+2b\epsilon)\alpha-\gamma^2)}{(2b\alpha-\gamma^2)^2} \tag{45}$$

From Eqs. (44) and (45), it is clear that $\pi_{riqd} + \pi_{miqd} = \pi^c_{mr}$; that is, the supply chain becomes coordinated. Moreover, the profits of the retailer and manufacturer decrease and increase, respectively, as ϵ increases. This finding is consistent with the behavior of the wholesale price. The corresponding utilities of the retailer and manufacturer are as follows:

$$\begin{aligned} U_{riqd} =& aM\alpha(2b\alpha(1-b\epsilon(1-\lambda_r))-\gamma^2)-2b^3\alpha^2((c+t_c)^2-4e_0\epsilon\theta(1-\lambda_r))+4be_0\alpha\gamma^2\theta\lambda_r \\ &- 2e_0\gamma^4\theta\lambda_r-\alpha b^2(c+t_c)^2(2b^2\epsilon\alpha(1-\lambda_r)+\gamma^2) \\ &- 2M\alpha\sqrt{be_0\theta}((2b\alpha-\gamma^2)(1+\lambda_r)-4b^2\epsilon\alpha(1-\lambda_r)) \end{aligned} \tag{46}$$

$$\begin{aligned} U_{miqd} =& 2e_0(4b^3\epsilon\alpha^2+2b\alpha\gamma^2-\gamma^4)\theta-\alpha((a-b(c+t_c))^2(2b(b\epsilon-1)\alpha+\gamma^2)+8b^3e_0\epsilon\alpha\theta)\lambda_m \\ & 2b^2M^2\epsilon\alpha^2+2M\alpha\sqrt{be_0\theta}(4b^2\epsilon\alpha(\lambda_m-1)-2b\alpha(1+\lambda_m)+\gamma^2(1+\lambda_m)) \end{aligned} \tag{47}$$

Now, the win–win outcomes of the system will be achieved only when all the members of the supply chain achieve higher utility than they might achieve in a decentralized scenario. For a win–win outcome for all the channel members, we must have $U_{riqd} \geq U_{rmr}$ and $U_{miqd} \geq U_{mmr}$. Simplifying the inequalities, we obtain the following range $\epsilon \in [\epsilon_L, \epsilon_U]$, where

$$\epsilon_U = \frac{M(2b\alpha-\gamma^2)\sqrt{be_0\theta}\Upsilon_3}{2b^2R\alpha(\sqrt{be_0\theta}M^2-4be_0\theta(M-\sqrt{be_0\theta}))(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)^2} \tag{48}$$

$$\epsilon_L = \frac{M(2b\alpha-\gamma^2)\Upsilon_4}{2b^2R\alpha(\sqrt{be_0\theta}M^2-4be_0\theta(M-\sqrt{be_0\theta}))(1-\lambda_m)(1-\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)} \tag{49}$$

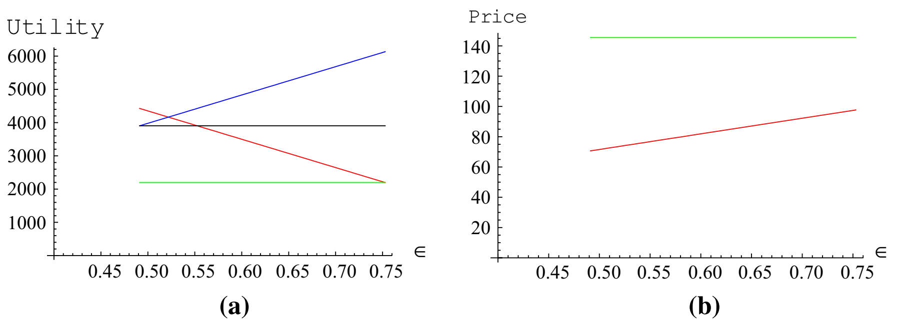

Fig. 2 **a** U^{d}_{rmr} (green), U_{riqd} (red), U^{d}_{mmr} (black), and U_{miqd} (blue). **b** Wholesale price (red) and retail price (green) under the IQD contract (color figure online)

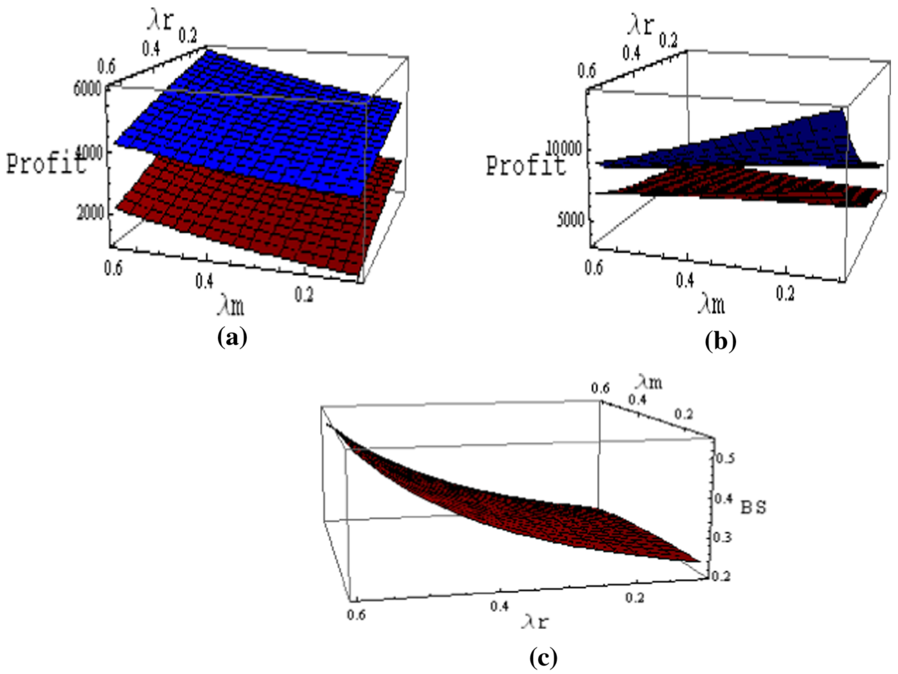

Fig. 3 **a** U^{d}_{rmr} (red) and U^{max}_{riqd} (blue). **b** U^{d}_{mmr} (red) and U^{max}_{miqd} (blue). **c** BS $= \epsilon_U - \epsilon_L$ (color figure online)

where $\Upsilon_3 = RM(1-\lambda_m)(3-\lambda_m-2\lambda_m\lambda_r) + 2be_0\theta(1-\lambda_m\lambda_r) + 2R(2-\lambda_m-\lambda_m\lambda_r)^2 (\sqrt{be_0\theta}(1+\lambda_r) - R\lambda_r(1-\lambda_m\lambda_r))$ and $\Upsilon_4 = R\sqrt{be_0\theta}(a(1-\lambda_m)^2 - 2R(1-\lambda_r)(1-\lambda_m\lambda_r)(2-\lambda_m-\lambda_m\lambda_r)) + b(2e_0\theta(\sqrt{be_0\theta}(1-\lambda_m\lambda_r) - R(c+t_c)\sqrt{be_0\theta}(1-\lambda_m)^2 + R(1+\lambda_m)(1-\lambda_r)(2-\lambda_m+\lambda_m\lambda_r)))$.

Hence, one can infer that the IQD contract always coordinates the system. The utility of the manufacturer will be maximum or the utility of the retailer will be minimum at the lower bound of the interval (i.e., at $\epsilon = \epsilon_L$). From the discussion herein, we propose the following proposition:

Proposition 5 *Any arbitrary values of discount factor $\epsilon \in [\epsilon_L, \epsilon_U]$ coordinate the system perfectly and lead to acceptable outcomes for all the supply chain members.*

The graphical representation of wholesale price under the IQD contract and the corresponding profits of the manufacturer and retailer are shown in Fig. 2a, b, respectively. The parameter values are the same as those used in the RSIS contract.

The discount factor for the data set is $\epsilon \in [0.4912, 0.7528]$. Figure 2b shows that the manufacturer is able to charge a wholesale price greater than its marginal cost. Figure 2a indicates that the utility of the manufacturer increases while the utility of the retailer decreases, which is also consistent with the utility structures of the retailer and manufacturer obtained in Eqs. (46) and (47). Figure 3a–c show the impacts of λ_r and λ_m on the maximum utility of the manufacturer (substituting $\epsilon = \epsilon_U$ into Eq. 47) and the retailer (substituting $\epsilon = \epsilon_U$ into Eq. 46) under coordination, the corresponding decentralized utilities, and the bargaining space ($BS = \epsilon_U - \epsilon_L$), respectively.

Figure 3a, b are consistent with the nature of utilities obtained under a decentralized supply chain and the maximum utilities obtained under an IQD contract. The manufacturer or retailer utility is positively correlated with its own fairness concern and negatively correlated with the other's fairness concern. Figure 3c shows that the bargaining range of the contract parameter ϵ sharply increases with an increase in the fairness index of the retailer and moderately decreases with an increase in the fairness index of the manufacturer. Therefore, one can conclude that the fairness index of the retailer is an important strategic parameter for the successful implementation of a coordination mechanism in a supply chain of fresh agricultural products. Although we have explored the characteristics of two contract mechanisms in Scenario MR, the supremacy of the two mechanisms can be verified in the other two scenarios as well; however, in the others, the utility values will be less than in Scenario MR because the supply chain profit is the highest in Scenario MR. Therefore, a retailer with greater bargaining power than the manufacturer will always choose to participate in Scenario MR to take advantage of greater flexibility in profit-sharing opportunities.

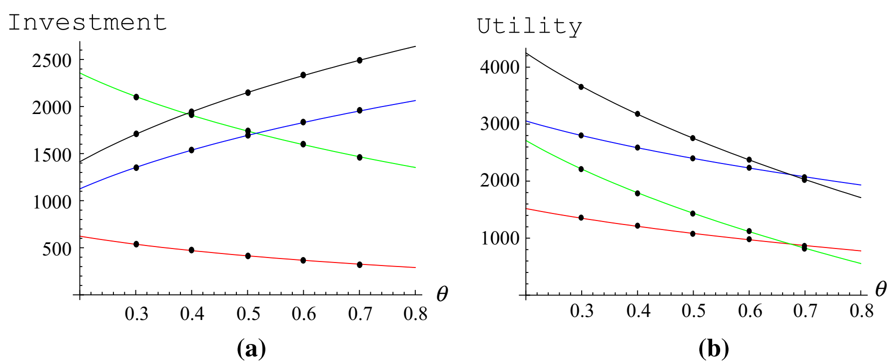

Fig. 4 **a** $\frac{\alpha h_{mr}^{d2}}{2}$ (red), $\frac{\alpha h_{mr}^{c2}}{2}$ (green), e_{mr}^{d} (blue), and e_{mr}^{c} (black). **b** U_{rmr}^{d} (red), U_{mmr}^{d} (green), U_{rmr}^{cmax} (blue), and U_{mmr}^{cmax} (black) (color figure online)

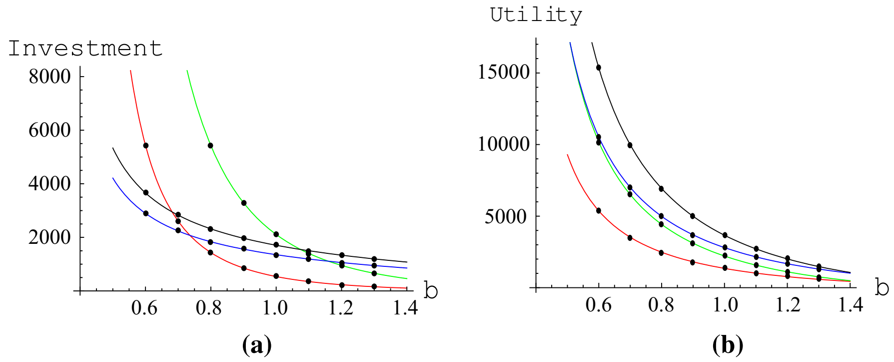

Fig. 5 **a** $\frac{\alpha h_{mr}^{d2}}{2}$ (red), $\frac{\alpha h_{mr}^{c2}}{2}$ (green), e_{mr}^{d} (blue), and e_{mr}^{c} (black). **b** U_{rmr}^{d} (red), U_{mmr}^{d} (green), U_{rmr}^{cmax} (blue), and U_{mmr}^{cmax} (black) (color figure online)

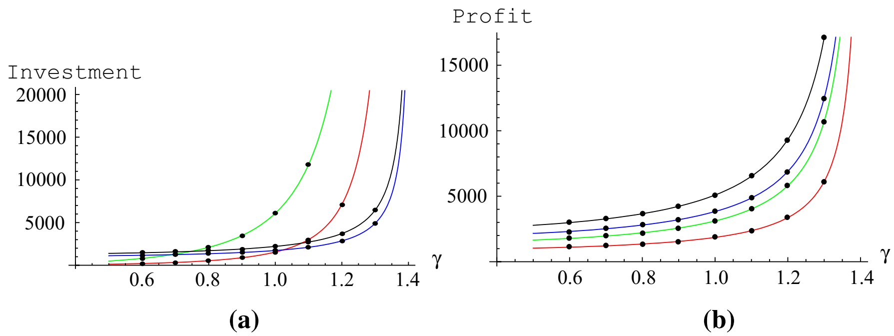

Fig. 6 **a** $\frac{\alpha h_{mr}^{d2}}{2}$ (red), $\frac{\alpha h_{mr}^{c2}}{2}$ (green), e_{mr}^{d} (blue), and e_{mr}^{c} (black). **b** U_{rmr}^{d} (red), U_{mmr}^{d} (green), U_{rmr}^{cmax} (blue), and U_{mmr}^{cmax} (black) (color figure online)

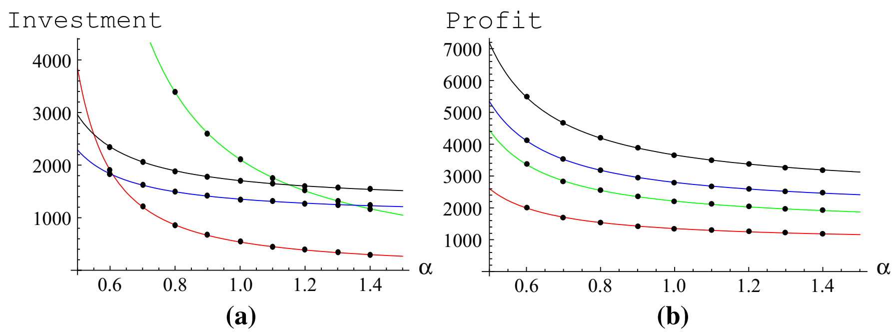

Fig. 7 **a** $\frac{\alpha h_{mr}^{d2}}{2}$ (red), $\frac{\alpha h_{mr}^{c2}}{2}$ (green), e_{mr}^{d} (blue), and e_{mr}^{c} (black). **b** U_{rmr}^{d} (red), U_{mmr}^{d} (green), U_{rmr}^{cmax} (blue), and U_{mmr}^{cmax} (black) (color figure online)

We conducted a sensitivity analysis with respect to some key parameters to identify their impact on the investment decisions of the retailer and manufacturer, the utilities of the supply chain members in a decentralized supply chain, and the maximum achievable utilities under an IQD contract. When the value of one parameter varies, all others remained unchanged. On the basis of the computational results, we obtained the following managerial insights (Figs. 4, 5, 6 and 7):

1. When the values of parameters θ, b, and α increased, the investment effort of the retailer decreased, and the reverse trend was seen for changes in parameter γ. It makes sense that the price sensitivity and the efficiency of the investment effort have a strong and negative effect upon the retailer investment decision. As γ increases, the demand for the product increases, and therefore, the retailer can charge a higher price and make a greater investment. Results also show that the investment decision of the retailer was significantly influenced by θ; that is, the retailer needs to invest less for products of inferior freshness.
2. When the values of parameters θ and γ increased, the fresh-keeping investment effort of the manufacturer increased, and the reverse trend was seen for changes in parameters α and b. If θ increases, then the manufacture needs to invest more to maintain the freshness of the product and maintain market demand for the product. Similar to the retailer investment decision, the price sensitivity suggests that the manufacturer should not invest more for a product that is not as fresh as possible. Moreover, the efficiency of the retailer investment effort moderately influences the investment decision of the manufacturer.
3. The utilities of the retailer in the decentralized and centralized decision model were positively correlated with γ, and negatively correlated with α, θ, and b. Overall, a large γ implies greater demand, which increases utility. As a consequence, taking measures to enhance γ, such as adopting more effective displays, improving the shopping environment, and so forth, benefits the retailer. A high value of θ discouraged the retailer from investing and produced lower utility. This result is quite realistic. If a product is not particularly fresh, then the demand for it is less than it is for a fresher product; therefore, the utility of the retailer is also relatively low. The retailer utility is always less than the utility of the manufacturer, but the scenario changes for the parameter θ. For a higher value of θ, the manufacturer needs a relatively large fresh-keeping investment; therefore, the retailer can earn higher utility compared to the manufacturer. Surprisingly, the utility of the retailer and the investment effort both decrease with respect to θ. Therefore, the freshness of the product is crucial for the investment decision. Similar to the nature of the retailer utility, the manufacturer utility is highly sensitive to changes in the value of parameters b and γ, and it is moderately sensitive to the change of value in α.

5 Summary and concluding remarks

This study was developed in light of three major areas featured in the supply chain literature, namely investment decisions to maintain freshness of agricultural products, fairness concerns of supply chain members, and contract-based mechanisms for supply chain coordination. To explore the optimal investment strategies of a supply chain member that work in an agricultural-product supply chain, the fairness for each member must be considered. We considered a supply chain structure consisting of a single manufacturer and single retailer, and analyzed characteristics of three scenarios on the basis of investment efforts in decentralized and centralized environments. To study collaboration between the channel members, effectiveness of two coordination mechanisms were also discussed.

The research results indicate that efforts to keep products fresh decrease progressively when the fairness index decreases for either member. Correspondingly, increases in the fairness index of either party reduce the freshness and market demand of fresh agricultural products. By comparing the supply chain profits in the three centralized scenarios, we found that the joint investment is always advisable for supply chain members. Therefore, we introduced the RSIS contract for supply chain coordination. Our analysis reveals that the manufacturer needs to charge a negative wholesale price under the RSIS, which leads to a suboptimal and infeasible solution. A higher processing cost for the retailer is an obstacle to implementing the RSIS contract between the supply chain members. Subsequently, we applied an IQD coordination mechanism that not only effectively coordinated the channel but also encouraged the retailer to cooperate with the manufacturer. With an IQD, the manufacturer can also charge wholesale prices greater than the marginal cost of the product. The analytical results under coordination revealed that the fairness indices were critical parameters for the determination of the bargaining range of the contract parameter and the corresponding profits of the supply chain member. The retailer with the greater bargaining power always preferred to a joint investment strategy to take an advantage of the greater higher flexibility in profit sharing and the sale of fresh products.

Research on this problem can be extended in several ways. For instance, the freshness level depends on the natural properties of products, so surveys to estimate the parameter values of freshness and explore their dependency on fairness indices would be a worthwhile study. The concepts addressed in the paper could also be advanced in several ways. One could extend the proposed model by incorporating trade credit financing as seen in Zhang et al. (2014). Also, one may take advertising into consideration as shown in Taleizadeh et al. (2015). In addition, one could expand a single sales channel to dual sales channels as done by Saha et al. (2016).

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