



## Supply Chain Contracting Coordination for Fresh Products with Fresh-Keeping Effort

Journal:	<i>Industrial Management &amp; Data Systems</i>
Manuscript ID	IMDS-04-2016-0139.R2
Manuscript Type:	Research Paper
Keywords:	Fresh product, Supply chain, Contract, Coordination, Fresh-keeping effort

SCHOLARONE™  
Manuscripts

## Supply Chain Contracting Coordination for Fresh Products with Fresh-Keeping Effort

### Abstract

**Purpose** – Fresh product loss rates in supply chain operations are particularly high due to the nature of perishable products. This paper aims to maximize profit through the contract between retailer and supplier. The optimized prices for the retailer and the supplier, taking the fresh-keeping effort into consideration, are derived.

**Design/methodology/approach** – To address this issue, we consider a two-echelon supply chain consisting of a retailer and a supplier (i.e., wholesaler) for two scenarios: centralized and decentralized decision-making. We start from investigating the optimal decision in the centralized supply chain and then comparing the results with those of the decentralized decision. Meanwhile, a fresh-keeping cost-sharing contract and a fresh-keeping cost- and revenue-sharing contract are designed. Numerical examples are provided, and managerial insights are discussed at end.

**Findings** – The results show that (a) the centralized decision is more profitable than the decentralized decision; (b) a fresh product supply chain can only be coordinated through a fresh-keeping cost- and revenue-sharing contract; (c) the optimal retail price, wholesale price and fresh-keeping effort can all be achieved; (d) the profit of a fresh product supply chain is positively related to consumers' sensitivity to freshness and negatively correlated with their sensitivity to price.

**Originality/value** – Few studies have considered fresh-keeping effort as a decision

1  
2  
3  
4 variable in the modelling of supply chain. In this paper, a mathematical model for the  
5  
6 fresh-keeping effort and for price decisions in a supply chain is developed. In  
7  
8 particular, fresh-keeping cost sharing contract and revenue-sharing contract are  
9  
10 examined simultaneously in the study of the supply chain coordination problem.  
11  
12

13  
14 **Keywords** Fresh product; Supply chain; Contract; Coordination; Fresh-keeping effort  
15

16  
17 **Paper type** Research paper  
18  
19

## 20 21 **1 Introduction** 22

23  
24 One of biggest challenges in fresh product supply chain (FPSC) is maintaining  
25  
26 product freshness. According to Cai et al. (2010), in developed countries, there is up  
27  
28 to a 15% loss of product due to damage and spoilage. In developing countries, this  
29  
30 loss rate is much higher. Overcoming this problem requires retailers and suppliers to  
31  
32 work closely by coordinating operations across the supply chain. FPSC retailers and  
33  
34 suppliers are severely affected by consumer value and product freshness and price;  
35  
36 these considerations could invalidate such companies' original coordination schemes  
37  
38 in cases lacking a contract. Therefore, research on the issue of coordinating FPSC  
39  
40 management through contract is both meaningful and critical.  
41  
42  
43  
44  
45

46  
47 There have been numerous research on FPSC. The majority of research has focused  
48  
49 on inventory management, pricing and ordering strategies. Dye (2007) developed a  
50  
51 time-varying deterioration rate to formulate an inventory model for perishable  
52  
53 products by assuming a constant loss rate for fresh products. Lodree and Uzochukwu  
54  
55 (2008) investigated the inventory management of fresh products by assuming that  
56  
57  
58  
59  
60

1  
2  
3  
4 consumer demand changes with the product deterioration rate. Ferguson and  
5  
6 Koenigsberg (2007) studied a two-period model in which inventory is left over from  
7  
8 the first period and a firm must decide whether to carry all, some or none of the  
9  
10 leftover inventory to the next period. Such decisions affect reactions to new product  
11  
12 production and pricing strategies. Cachon and Kök (2007) re-examined the  
13  
14 newsvendor problem by assessing the product salvage value and then making optimal  
15  
16 decisions on order quantity. Akcay et al. (2010) investigated the optimal joint  
17  
18 dynamic pricing of various perishable products when considering strategic consumers  
19  
20 using an algorithm of multinomial time. Wang and Li (2012) argued that, although it  
21  
22 is difficult to forecast the quality of perishable products, it is possible to develop a  
23  
24 pricing method to maximize profit based on more exact quality information. Gallego  
25  
26 and Hu (2014) presented a joint pricing approach for competitive products in a special  
27  
28 market environment, with perishable products consisting of substitutable and  
29  
30 complementary products. Nakandala et al. (2016) developed an optimization model  
31  
32 for considering quality and transportation and determined optimal pricing decisions to  
33  
34 minimize total cost for fresh food. Halim et al. (2008) introduced the ordering strategy  
35  
36 of stochastic demand in cases of product shortage using a fuzzy number deterioration  
37  
38 rate. In these studies, inventory management and pricing and ordering strategies were  
39  
40 studied separately.  
41  
42  
43  
44  
45  
46  
47  
48  
49

50  
51 Some researches have considered the three factors in combination. Li et al. (2009)  
52  
53 studied the optimal levels of pricing and inventory simultaneously for perishable  
54  
55 products, developing an optimal inventory replenishment strategy to reduce loss.  
56  
57  
58  
59  
60

1  
2  
3  
4 Kanchanasuntorn and Techanitisawad (2006) developed an inventory model for  
5  
6 perishable products with fixed life cycles, examining how product perishability and  
7  
8 stockout influence supply chain profit, cost, service and inventory. Pasternack (2008)  
9  
10 presented a hierarchical model to determine optimal pricing strategies and return  
11  
12 policies for perishable products with short shelf or demand lives. Dong et al. (2009)  
13  
14 determined optimal decisions for inventory and pricing when considering strategic  
15  
16 consumers using a polynomial model. Herbon et al. (2014) examined a replenishment  
17  
18 policy in regular time for perishable products and developed a dynamic pricing  
19  
20 strategy to attract more consumers and generate greater profit. Chen et al. (2014)  
21  
22 analysed the issue of joint pricing and inventory control for perishable products with  
23  
24 fixed lifetimes over a finite horizon. Li et al. (2015) considered strategies of inventory  
25  
26 control and joint dynamic pricing for perishable products in a stochastic inventory  
27  
28 system. Chew et al. (2014) investigated optimal decision making for perishable  
29  
30 products with multiple-cycle lifetimes, including decisions regarding price and order  
31  
32 quantity. Avinadav et al. (2013) developed an optimization model for considering  
33  
34 time-dependent and price-dependent demand and determined optimal order quantities,  
35  
36 pricing decisions and replenishment periods for perishable products. Sainathan (2013)  
37  
38 considered perishable products with two-period shelf lives in an infinite horizon and  
39  
40 derived optimal pricing decisions and ordering strategies. None of these studies  
41  
42 considered ways to coordinate FPSC with a contract.  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52

53  
54 The literature on FPSC contract coordination is very sparse. Most studies have  
55  
56 focused on non-perishable products. Feng and Lu (2013) studied a two-echelon  
57  
58  
59  
60

1  
2  
3  
4 supply chain consisting of retailers and manufacturers and analysed contracting  
5  
6 behaviours in different competitive scenarios. Xu et al. (2014) investigated how the  
7  
8 risk aversion of dual-channel supply chain partners influences the coordination of  
9  
10 contracts using a mean-variance mathematical model. Sommer and Loch (2009)  
11  
12 suggested that employee effort can be motivated by incentive contracts in cases of  
13  
14 unpredictable events. Xiao et al. (2011) examined how to coordinate the supply chain  
15  
16 which contains a manufacturer and a retailer by revenue-sharing contract, proposed a  
17  
18 product quality assurance policy, and consumer's utility is used in the model.  
19  
20 Krishnan et al. (2004) investigated the effects of retailer promotional effort on  
21  
22 consumer demand and develop a contract for channel coordination through  
23  
24 consideration of this promotional effort. Shang and Yang (2015) investigated the  
25  
26 choice of profit-sharing coefficient and the distribution of increased profit when the  
27  
28 dual-channel supply chain is coordinated by profit-sharing contract, and risk  
29  
30 preference and negotiation ability had an effect on the two factors. Jiang and Chen  
31  
32 (2016) presented a newsvendor model to coordinate the supply chain, and  
33  
34 characterized expectations equilibrium to obtain the optimal solutions when  
35  
36 considering consumer's strategic behaviour. Lee et al., (2014) proposed procurement  
37  
38 strategies and derived optimal procurement quantity so as to maximize firm's profit  
39  
40 by forward contract, and finally realized the coordination of supply chain. Cachon and  
41  
42 Lariviere (2005) developed a newsvendor model for one supplier and one retailer  
43  
44 using a revenue-sharing contract and compared the profits generated by this contract  
45  
46 to profits generated by other contracts in one period. He and Zhao (2012) investigated  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 the coordination of multi-tier supply chains when supply and demand are not definite,  
4  
5 showing that supply chains can be coordinated through wholesale price contracts with  
6  
7 return strategies. Lau et al. (2008) suggested that purchase contracts are designed to  
8  
9 coordinate supply chains when considering price-sensitive demand, thus allowing the  
10  
11 dominant retailer to generate greater profit. Chen and Bell (2011) examined supply  
12  
13 chain coordination with buy-back contracts using fixed percentages of consumer  
14  
15 returns. Sana and Chaudhuri (2008) analysed how to coordinate supply chains to  
16  
17 maximize profit using credit and price-discount contracts when considering  
18  
19 time-dependent demands. Ma et al. (2013) discussed the issue of channel coordination  
20  
21 in a two-tier supply chain, proposing an innovative supply chain contract to induce  
22  
23 effort on the parts of both the retailer and the manufacturer. Xiao et al. (2010)  
24  
25 coordinated a supply chain using a buyback contract and a markdown money contract,  
26  
27 respectively, under a partial refund policy. Furthermore, they analysed how changes  
28  
29 to some model parameters affected supply chain profit. However, their models did not  
30  
31 consider the characteristics of fresh products.  
32  
33  
34  
35  
36  
37  
38  
39

40  
41 A few studies have examined the coordination of FPSC in consideration of product  
42  
43 loss rates. Ketzenberg and Ferguson (2008) investigated the value of information  
44  
45 sharing between retailers and suppliers for perishable products, considering the effects  
46  
47 of information sharing on deterioration and demand for supply chain coordination.  
48  
49 Blackburn and Scudder (2009) presented a combined strategy involving mixed  
50  
51 product speed and efficiency for perishable products to coordinate FPSC. Rong et al.  
52  
53 (2011) modelled the production and distribution of perishable food items and studied  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 their quality and cost in a supply chain with mixed-integer linear programming. Cai et  
4  
5  
6 al. (2013) designed an incentive scheme to coordinate the FPSC, examining whether  
7  
8 the incentive contract could remove the “double marginalization” that exists in supply  
9  
10 chains and encourage partners to act in a coordinated way. Wang and Webster  
11  
12 (2009) showed that percent markdown money contracts and quantity markdown  
13  
14 money contracts can coordinate the supply chains for perishable goods with clearance  
15  
16 pricing. However, the extant literature has not yet simultaneously examined  
17  
18 fresh-keeping cost sharing contracts and revenue-sharing contracts in the study of the  
19  
20 FPSC coordination problem.  
21  
22  
23  
24

25  
26 From the above review, it suggests: first, the food supply chain is a relative less  
27  
28 studied area; second, taking freshness of the food into consideration is rather scarce;  
29  
30 third, simultaneously examining fresh-keeping cost and revenue issues is rare. This  
31  
32 motives our research in developing a model by taking these two tactics, i.e.  
33  
34 fresh-keeping cost sharing and revenue-sharing, into consideration.  
35  
36  
37  
38

39 This paper examines the coordination of a two-echelon supply chain consisting of a  
40  
41 retailer and a supplier by considering fresh-keeping effort as a decision variable in the  
42  
43 modelling of supply chain. In this research, the supplier refers to the wholesaler. We  
44  
45 present a mathematical model for the fresh-keeping effort and for price decisions in  
46  
47 centralized and decentralized FPSC, respectively; provide optimal solutions for both  
48  
49 supplier and retailer, including with respect to retail price, wholesale price and  
50  
51 fresh-keeping effort; and analyse the impacts of consumer sensitivities to price and  
52  
53 freshness on FPSC profit. We investigate how FPSC coordination and a win-win  
54  
55  
56  
57  
58  
59  
60



1  
2  
3 outcome can be achieved through cost-sharing and revenue-sharing contracts between  
4  
5  
6 retailer and supplier. We also derive the optimal cost-sharing and revenue-sharing  
7  
8 coefficients to realize a win-win result. Figure 1 demonstrates the research framework  
9  
10 for a FPSC.  
11

12  
13  
14 *Inset: Figure 1 Research Framework for a FPSC*  
15

16 The rest of the paper is organized as follows. Section 2 describes the model and  
17  
18 assumptions. Section 3 studies a centralized and a decentralized coordination model  
19  
20 for a FPSC coordinated without a contract. Section 4 investigates two types of  
21  
22 contracts for coordinating between the retailer and the supplier: a fresh-keeping cost  
23  
24 sharing contract and a fresh-keeping cost- and revenue-sharing contract. Section 5  
25  
26 uses some numerical examples to illustrate the model. Section 6 concludes.  
27  
28  
29

## 30 31 **2 Model description** 32

33 We consider a FPSC consisting of one supplier and one retailer. It costs  $c$  per unit  
34  
35 for the supplier to procure the product. The supplier then sells the product to the  
36  
37 retailer at a wholesale price  $w$ , and the retailer sells the product to consumers at a  
38  
39 retail price  $p$ . We use a continuous variable  $\tau$  to measure the level of effort (Cai et  
40  
41 al., 2010) used by the retailer to preserve the fresh product. This effort is called the  
42  
43 fresh-keeping effort. The relationships of events in FPSC are presented in Figure 2.  
44  
45  
46  
47

48  
49 *Inset: Figure 2 Relationships of Events under Consideration*  
50

51 Let  $\theta$  denotes a freshness index in the range of  $[0,1]$ , with  $\theta=1$  and  $\theta=0$   
52  
53 representing a “fully fresh” and “completely decayed” product, respectively. We adopt  
54  
55 the freshness index function developed by Avinadav et al. (2013):  
56  
57  
58  
59  
60

$$\theta(t) = \theta_0 - \eta \left(\frac{t}{T}\right)^2, \quad t \in [0, T] \quad (1)$$

where  $T$  is the sale period of the fresh product;  $\theta_0$  is the initial value of freshness; and  $\eta$  is the product's perishability rate. From Eq. (1), we know that if the perishability rate  $\eta$  increases, the product freshness will decrease sharply at the end of the sale period.

Furthermore,  $\eta$  is a function of  $\tau$ , as follows:  $\eta = (1 - k\tau)\eta_0$  (Dan et al., 2012), where  $k$  is the coefficient of  $\tau$ , and  $k \in (0, 1)$ ,  $\tau \in (0, 1)$ .

A fresh-keeping effort implies a certain cost, which is denoted as  $c(\tau)$ . According to Ma et al. (2013), we assume that the fresh-keeping cost function is  $c(\tau) = \frac{1}{2}m\tau^2$ , where  $m$  is the fresh-keeping cost coefficient.

The assumptions in the model are:

- (1) Order quantity of retailer and supplier is equal to the demand (Ma et al., 2013a; Xiao and Xu, 2013; Zhang et al., 2012).
- (2) In a sale period  $T$ , the consumer arrival rate  $\delta$  at any time is constant.
- (3) In any cycle, the lead time is negligible, and shortages are not allowed.
- (4) The retailer and supplier are risk-neutral, therefore they always pursue the maximum profit.

Similar to Xu et al. (2012), we assume that the utility faced by the consumer is a linear function of retail price and freshness of product. The utility function of fresh product is given as:

$$U(t) = U_0 - \alpha p + \beta \theta(t) \quad (2)$$

where  $U_0$  represents the initial value of the fresh product and follows a uniform

distribution of  $[0,1]$ ,  $\alpha$  denotes consumers' sensitivity to the product price and  $\beta$  denotes consumers' sensitivity to the product freshness.

The following notation is used in the model:

$c$ : supplier's procurement cost per unit of fresh product;

$Q_c$ : retailer's ordering quantity in the centralized FPSC;

$p_c$ : retail price of the fresh product in the centralized FPSC;

$\pi_c$ : total profit in the centralized FPSC;

$w_i$ : wholesale price of the supplier in the decentralized FPSC;

$Q_d$ : retailer's ordering quantity in the decentralized FPSC;

$p_d$ : retail price in the decentralized FPSC;

$\pi_{ri}$ : retailer profit in the decentralized FPSC;

$\pi_{si}$ : supplier profit in the decentralized FPSC;

$\pi_i$ : total profit in the decentralized FPSC;

$i$ :  $i=1$  without a contract;  $i=2$  for a fresh-keeping cost-sharing contract;  $i=3$  for a fresh-keeping cost- and revenue-sharing contract.

### 3 A coordination model without contract

In this section, we examine the optimal decisions for retail price and fresh-keeping effort in a centralized and a decentralized FPSC without contract.

#### 3.1 Decisions in centralized FPSC

In the centralized FPSC, the supplier and retailer are treated as one entity. They make optimal decisions to maximize their total profit.

From a consumer point of view, the decision to purchase a fresh product is based

on the expectation of a positive utility function i.e.  $U(t) > 0$ ; otherwise, the consumer will walk away. Therefore, the market demand of a fresh product at any time  $t$  is  $D(t) = \delta P(U_t > 0)$ .  $P(U_t > 0)$  is the probability when consumers' utility function is positive. Substituting Eq. (1) and Eq. (2) into the market demand function, we obtain:

$$\begin{aligned} D(t) &= \delta P(U_0 - \alpha p_c + \beta(\theta_0 - \eta(\frac{t}{T})^{\frac{1}{2}}) > 0) \\ &= \delta P(U_0 > \alpha p_c - \beta(\theta_0 - \eta(\frac{t}{T})^{\frac{1}{2}})) = \delta(1 - \alpha p_c + \beta(\theta_0 - \eta(\frac{t}{T})^{\frac{1}{2}})) \end{aligned} \quad (3)$$

Eq. (3) represents the whole market demand in the FPSC at any time. Therefore, in a sale period  $T$ , the actual ordering quantity of fresh product is:

$$Q_c = \int_0^T D(t) dt = \int_0^T \delta(1 - \alpha p_c + \beta(\theta_0 - \eta(\frac{t}{T})^{\frac{1}{2}})) dt \quad (4)$$

Then, the total profit function  $\pi_c$  in the centralized FPSC is given by:

$$\begin{aligned} \pi_c &= [(p_c - w) + (w - c)]Q_c - c(\tau) \\ &= (p_c - c) \int_0^T \delta(1 - \alpha p_c + \beta(\theta_0 - \eta(\frac{t}{T})^{\frac{1}{2}})) dt - \frac{1}{2} m \tau^2 \end{aligned} \quad (5)$$

In Eq. (5), we notice that wholesale price  $w$  disappears in the centralized FPSC. We seek to determine the optimal decisions for the price  $p_c$  and the fresh-keeping effort  $\tau$  to coordinate the supply chain.

**Theorem 1** In the centralized FPSC, for any given parameters  $(\alpha, \beta, \eta_0, k)$ , the

optimal retail price of a fresh product is  $p_c^* = \frac{3m(3\alpha c + B_1) + 4B_2 c}{2(9\alpha m - 2B_2)}$  and the optimal

fresh-keeping effort of the fresh product is  $\tau_c^* = \frac{\delta \beta T \eta_0 k (B_1 - 3\alpha c)}{9\alpha m - 2B_2}$ , where

$$B_1 = 3(1 + \beta \theta_0) - 2\beta \eta_0, \quad B_2 = \delta T \beta^2 \eta_0^2 k^2.$$

**Proof.**

To find the optimal retail price and fresh-keeping effort to maximize  $\pi_c$ , we differentiate  $\pi_c$  with respect to  $p_c$  and  $\tau_c$ , setting both them equal to 0. Solving

$\frac{\partial \pi_c}{\partial p_c} = 0$  and  $\frac{\partial \pi_c}{\partial \tau_c} = 0$ , we find that the optimal retail price is

$p_c^* = \frac{3m(3\alpha c + B_1) + 4B_2c}{2(9\alpha m - 2B_2)}$  and the optimal fresh-keeping effort is

$$\tau_c^* = \frac{\delta\beta T\eta_0 k(B_1 - 3\alpha c)}{9\alpha m - 2B_2}.$$

However, to ensure that the first order derivation is the optimal result, we need to prove that the function is concave. The Hessian matrix is

$$H = \begin{bmatrix} \frac{\partial^2 \pi_c}{\partial p_c^2} & \frac{\partial^2 \pi_c}{\partial p_c \partial \tau_c} \\ \frac{\partial^2 \pi_c}{\partial \tau_c \partial p_c} & \frac{\partial^2 \pi_c}{\partial \tau_c^2} \end{bmatrix} = \begin{bmatrix} -2\alpha\delta T & \frac{2\eta_0\beta T\delta k}{3} \\ \frac{2\eta_0\beta T\delta k}{3} & -m \end{bmatrix}. \text{ This shows that the Hessian matrix}$$

of  $\pi_c$  is a negative definite for all values of  $p_c$  and  $\tau_c$  if  $2\alpha\delta Tm - (\frac{2\eta_0\beta T\delta k}{3})^2 > 0$ . Therefore, total profit  $\pi_c$  is concave to  $p_c$  and  $\tau_c$ .

Hence, theorem 1 holds.

Substituting  $p_c$  and  $\tau_c$  into Eq. (5), we obtain the optimal total profit in centralized FPSC as follows:

$$\pi_c^* = \frac{\delta Tm(B_1 - 3\alpha c)^2}{4(9\alpha m - 2B_2)} \quad (6)$$

Since  $2\alpha\delta Tm - (\frac{2\eta_0\beta T\delta k}{3})^2 > 0$ , we can obtain  $9\alpha m - 2T\delta(\eta_0\beta k)^2 > 0$ , which is  $9\alpha m - 2B_2 > 0$ . Therefore, the optimal total profit is positive.

Note that  $9\alpha m - 2B_2 > 0$  is considered in the rest paper. In addition, the optimal

fresh-keeping effort  $\tau_c^* \in (0, 1)$ ; thus, we can derive that  $0 < B_1 - 3\alpha c < \frac{9\alpha m - 2B_2}{\delta\beta T\eta_0 k}$ .

### 3.2 Decisions in decentralized FPSC

In this subsection, we consider a decentralized supply chain in which the retailer and supplier make their decisions independently. This section aims to determine the optimal retail price, the optimal fresh-keeping effort and the optimal wholesale price to maximize expected individual profit.

#### 3.2.1 Optimal decisions of the fresh product retailer

In the decentralized FPSC, the retailer makes optimal decisions according to the wholesale price  $w_1$ , which is given by the supplier. The retailer's process of deducing its market demand function and ordering quantity function is similar to that in the centralized supply chain. Thus, the profit function of a fresh product retailer is:

$$\begin{aligned}\pi_{r1} &= (p_d - w_1)Q_d - c(\tau) \\ &= (p_d - w_1) \int_0^T \delta(1 - \alpha p_d + \beta(\theta_0 - (1 - k\tau)\eta_0(\frac{t}{T})^2))dt - \frac{1}{2}m\tau^2\end{aligned}\quad (7)$$

From Eq. (7), we can obtain the optimal retail price and the optimal fresh-keeping effort.

**Lemma 1** In the decentralized FPSC, for any given supplier's wholesale price  $w_1$ , the

optimal retail price is  $p_d^*(w_1) = \frac{3m(3\alpha w_1 + B_1) + 4B_2 w_1}{2(9\alpha m - 2B_2)}$  and the optimal fresh-keeping

effort is  $\tau_d^*(w_1) = \frac{\delta\beta T\eta_0 k(B_1 - 3\alpha w_1)}{9\alpha m - 2B_2}$ .

**Proof.**

As in the proof of Theorem 1, to find the optimal retail price and the optimal fresh-keeping effort to maximize  $\pi_{r1}$ , we differentiate  $\pi_{r1}$  with respect to  $p_d$  and  $\tau_d$ , respectively, setting these equal to 0.

The Hessian matrix is  $H = \begin{bmatrix} -2\alpha\delta T & \frac{2\eta_0\beta T\delta k}{3} \\ \frac{2\eta_0\beta T\delta k}{3} & -m \end{bmatrix}$ . This shows that the Hessian

matrix of  $\pi_{r_1}$  returns a negative definite for all values of  $p_d$  and  $\tau_d$  if

$2\alpha\delta Tm - \left(\frac{2\eta_0\beta T\delta k}{3}\right)^2 > 0$ . Therefore, we find that the optimal retail price is

$p_d^*(\tau_d) = \frac{3(\beta\theta_0 + \alpha w_1 + 1) - 2\beta\eta_0(1 - k\tau_d)}{6\alpha}$  and the optimal fresh-keeping effort is

$\tau_d^*(p_d) = \frac{2(p_d - w_1)\beta\eta_0 T\delta k}{3m}$ . Simultaneously, from the two equations, we can obtain

$p_d^*(w_1) = \frac{3m(3\alpha w_1 + B_1) + 4B_2 w_1}{2(9\alpha m - 2B_2)}$  and  $\tau_d^*(w_1) = \frac{\delta\beta T\eta_0 k(B_1 - 3\alpha w_1)}{9\alpha m - 2B_2}$ .

Lemma 1 shows that the optimal retail price and the optimal fresh-keeping effort are functions of the supplier's wholesale price  $w_1$ . The supplier determines its optimal wholesale price according to the retailer's reaction function.

### 3.2.2 Optimal decisions of the fresh product supplier

For any given wholesale price  $w_1$  of a fresh product supplier, the retailer has a corresponded ordering quantity. The profit function of a fresh product supplier is:

$$\begin{aligned} \pi_{s_1} &= (w_1 - c)Q_d \\ &= (w_1 - c) \int_0^T \delta(1 - \alpha p_d + \beta(\theta_0 - (1 - k\tau_d)\eta_0(\frac{t}{T})^{\frac{1}{2}}))dt \end{aligned} \quad (8)$$

Substituting  $p_d^*(w_1)$  and  $\tau_d^*(w_1)$  into Eq. (8), we obtain the optimal supplier profit in the decentralized FPSC. The profit function has only one decision variable:

$w_1$ .

**Lemma 2** In the decentralized FPSC, the optimal wholesale price of a fresh product

supplier is  $w_1^* = \frac{3m(B_1 + 3\alpha c) + 2B_2 c}{2(9\alpha m - B_2)}$ .

**Proof.**

Taking the first derivative of Eq. (8) with respect to wholesale price  $w_1$ , we set it equal to 0. Taking the second derivative of Eq. (8) with respect to  $w_1$ , we have

$$\frac{\partial^2 \pi_{s1}}{\partial w_1^2} = -\delta\alpha T < 0, \text{ which is the fresh product supplier's profit function } \pi_{s1} \text{ and}$$

which is concave to  $w_1$ . Therefore, we find that the optimal wholesale price is

$$w_1^* = \frac{3m(B_1 + 3\alpha c) + 2B_2 c}{2(9\alpha m - B_2)}.$$

Lemma 2 gives an optimal wholesale price  $w_1^*$ . By substituting  $w_1^*$  into Lemma 1, we can obtain the optimal retail price and the optimal fresh-keeping effort.

**Theorem 2** In the decentralized FPSC, the optimal retail price of the fresh product is

$$p_d^* = \frac{9m(B_1 + 3\alpha c) + 4B_2 c}{4(9\alpha m - B_2)} \text{ and the optimal fresh-keeping effort of fresh product is}$$

$$\tau_d^* = \frac{\delta\beta T \eta_0 k_1 (B_1 - 3\alpha c)}{2(9\alpha m - B_2)}.$$

**Proof.**

Substituting the optimal wholesale price of the fresh product supplier

$$w_1^* = \frac{3m(B_1 + 3\alpha c) + 2B_2 c}{2(9\alpha m - B_2)} \text{ into } p_d^*(w_1) \text{ and } \tau_d^*(w_1), \text{ we obtain}$$

$$p_d^* = \frac{9m(B_1 + 3\alpha c) + 4B_2 c}{4(9\alpha m - B_2)} \text{ and } \tau_d^* = \frac{\delta\beta T \eta_0 k (B_1 - 3\alpha c)}{2(9\alpha m - B_2)}.$$

Substituting  $p_d^*$ ,  $\tau_d^*$  and  $w_1^*$  into (7) and (8), we obtain the retailer's optimal profit and the supplier's optimal profit in the decentralized FPSC:

$$\pi_{r1}^* = \frac{\delta T m (9\alpha m - 2B_2)(B_1 - 3\alpha c)^2}{16(9\alpha m - B_2)^2} \quad (9)$$

$$\pi_{s1}^* = \frac{9\delta\alpha T m^2 (B_1 - 3\alpha c)^2}{8(9\alpha m - B_2)^2} \quad (10)$$



Because  $9\alpha m - 2B_2 > 0$ , as given previously, we know that  $B_2 = \delta T \beta^2 \eta_0^2 k_1^2 > 0$ .

Hence,  $9\alpha m - B_2 > 0$ ; therefore,  $p_d^* > 0$ . Similarly, the optimal fresh-keeping effort

$\tau_c^* \in (0,1)$ ,  $\tau_d^* = \frac{\delta \beta T \eta_0 k_1 (B_1 - 3\alpha c)}{2(9\alpha m - B_2)}$ ; thus, we only consider the situation in which

$$0 < B_1 - 3\alpha c < \frac{9\alpha m - 2B_2}{\delta \beta T \eta_0 k} < \frac{9\alpha m - B_2}{\delta \beta T \eta_0 k}.$$

### 3.2.3 Comparison of centralized and decentralized decisions

In the above discussions, Theorem 1 provides the optimal retail price and the optimal fresh-keeping effort for a centralized FPSC, while Theorem 2 provides the optimal retail price and the optimal fresh-keeping effort for a decentralized FPSC. We can obtain Proposition 1 by contrasting the centralized supply chain and the decentralized supply chain with regard to optimal retail price, optimal fresh-keeping effort and total profit.

**Proposition 1** 1)  $\tau_d^* < \tau_c^*$ ;

2) when  $2B_2 < 9\alpha m < 4B_2$ ,  $p_d^* < p_c^*$ ; when  $9\alpha m > 4B_2$ ,  $p_d^* > p_c^*$ ;

3)  $\pi_{r1}^* + \pi_{s1}^* < \pi_c^*$ .

**Proof.**

$$1) \tau_d^* - \tau_c^* = \frac{\delta \beta T \eta_0 k (B_1 - 3\alpha c)}{2(9\alpha m - B_2)} - \frac{\delta \beta T \eta_0 k (B_1 - 3\alpha c)}{9\alpha m - 2B_2}.$$

Since the numerator is same, the denominator  $2(9\alpha m - B_2) = 18\alpha m - 2B_2 > 9\alpha m - 2B_2$ . Thus, we get  $\tau_d^* - \tau_c^* < 0$ .

Therefore,  $\tau_d^* < \tau_c^*$ .

2)  $9\alpha m - 2B_2 > 0$  has been previously given. The retail price is positive; thus,

$9\alpha m - B_2 > 0$ . Therefore:

$$p_d^* - p_c^* = \frac{9m(3\alpha c + B_1) + 4B_2c}{4(9\alpha m - B_2)} - \frac{3m(3\alpha c + B_1) + 4B_2c}{2(9\alpha m - 2B_2)}$$

$$= \frac{9m(9\alpha m - 4B_2)(B_1 - 3\alpha c)}{2(9\alpha m - B_2)(9\alpha m - 2B_2)}$$

Then, we find that when  $9\alpha m - 4B_2 > 0$ ,  $p_d^* > p_c^*$ , while when  $9\alpha m - 4B_2 < 0$ ,  $2B_2 < 9\alpha m < 4B_2$  and  $p_d^* < p_c^*$ .

3) Using the sum of the retailer's profit (Eq. [9]) and the supplier's profit (Eq. [10]), we can determine the total profit of the decentralized FPSC.

$$\pi_{r1}^*(p_d^*, \tau_d^*) + \pi_{s1}^*(p_d^*, \tau_d^*) = \frac{\delta T m (B_1 - 3\alpha c)^2 (27\alpha m - 2B_2)}{16(9\alpha m - B_2)^2}, \quad \pi_c^*(p_c^*, \tau_c^*)$$

is the total profit of the centralized FPSC. Therefore,

$$\frac{\pi_c^*(p_c^*, \tau_c^*)}{\pi_{r1}^*(p_d^*, \tau_d^*) + \pi_{s1}^*(p_d^*, \tau_d^*)} = \frac{4(9\alpha m - B_2)^2}{(9\alpha m - 2B_2)(27\alpha m - 2B_2)} = \frac{324\alpha^2 m^2 - 72\alpha m B_2 + 4B_2^2}{243\alpha^2 m^2 - 72\alpha m B_2 + 4B_2^2} > 1,$$

giving us:  $\pi_{r1}^*(p_d^*, \tau_d^*) + \pi_{s1}^*(p_d^*, \tau_d^*) < \pi_c^*(p_c^*, \tau_c^*)$ .

Proposition 1 indicates that the total profit of a decentralized FPSC is less than that of a centralized FPSC. The optimal fresh-keeping effort in a decentralized supply chain is lower than that in a centralized supply chain. This suggests that, in a decentralized FPSC, the total profit is not optimal due to the double marginal effect of supply chain. Therefore, it is necessary to design proper contracts to coordinate FPSC.

We highlight that a decision to centralize may achieve maximum profit. In the following sections, we take  $\pi_c$  as a target for a decentralized supply chain, serving as the motivation behind the supplier-retailer contract, that is, both retailer and supplier intend to achieve individual maximised profit whilst also maximised total profit in the supply chain.

#### 4 Contracting to facilitate coordination

In this section, we first examine whether the fresh-keeping cost-sharing contract is effective or not. Then, we investigate the best way to coordinate the FPSC by sharing both costs and revenues in fresh-keeping contracts. It is expected that the FPSC will be more effective if it is bonded by a contract. It is also understandable that parties will accept such a contract only when they do not need to sacrifice their own profit (compared to situations with no contract).

#### 4.1 Fresh-keeping cost-sharing contract

From Proposition 1, we know that  $\tau_d^* < \tau_c^*$ . Therefore, to achieve the optimal fresh-keeping effort  $\tau_c^*$  in the decentralized supply chain, a retailer must pay a higher fresh-keeping cost; however, the supplier may not have enough motivation to do this. Thus, it is necessary to design a cost-sharing contract to coordinate both parties.

A cost-sharing contract typically includes two parameters. The first is the wholesale price  $w_2$ , which the retailer pays. The second is the cost-sharing coefficient of the supplier, represented by  $\varphi_1$  ( $0 < \varphi_1 < 1$ ).

According to the above description, we know that the profit function of retailer is

$$\begin{aligned}\pi_{r_2} &= (p_d - w_2)Q_d - (1 - \varphi_1)c(\tau) \\ &= (p_d - w_2) \int_0^T \delta(1 - \alpha p_d + \beta(\theta_0 - (1 - k\tau_d)\eta_0(\frac{t}{T})^{\frac{1}{2}}))dt - \frac{1}{2}(1 - \varphi_1)m\tau_d^2\end{aligned}\quad (11)$$

The profit function of the supplier is

$$\begin{aligned}\pi_{s_2} &= (w_2 - c)Q_d - \varphi_1 c(\tau) \\ &= (w_2 - c) \int_0^T \delta(1 - \alpha p_d + \beta(\theta_0 - (1 - k\tau_d)\eta_0(\frac{t}{T})^{\frac{1}{2}}))dt - \frac{1}{2}\varphi_1 m\tau_d^2\end{aligned}\quad (12)$$

Based on the above, we can derive Theorem 3.

**Theorem 3** Under the fresh-keeping cost-sharing contract, for any given fresh-keeping cost sharing coefficient  $\varphi_1$ , the optimal retail price is

$p_d^* = \frac{9m(1-\varphi_1)(B_1+3\alpha c)+4B_2c}{4(9(1-\varphi_1)\alpha m-B_2)}$ , and the optimal fresh-keeping effort is

$$\tau_d^* = \frac{\delta\beta T\eta_0 k(B_1-3\alpha c)}{2(9(1-\varphi_1)\alpha m-B_2)}.$$

**Proof.**

Taking the second derivative of Eq. (11) with respect to  $p_d$  and  $\tau_d$ , we get

$$\frac{\partial^2 \pi_{r2}}{\partial p_d^2} = -2\delta\alpha T < 0, \quad \frac{\partial^2 \pi_{r2}}{\partial \tau_d^2} = -m(1-\varphi_1) < 0. \quad \text{The Hessian matrix is}$$

$$H = \begin{bmatrix} -2\alpha\delta T & \frac{2\eta_0\beta T\delta k}{3} \\ \frac{2\eta_0\beta T\delta k}{3} & -m(1-\varphi_1) \end{bmatrix}. \quad \text{This shows that the Hessian matrix of } \pi_{r2} \text{ is a}$$

negative definite for all values of  $p_d$  and  $\tau_d$  if  $2\alpha\delta Tm(1-\varphi_1) - \left(\frac{2\eta_0\beta T\delta k}{3}\right)^2 > 0$ .

Therefore, we find that, if  $\pi_{r2}$  is concave in  $p_d$  and  $\tau_d$ , the optimal solution exists.

Similarly, taking the second derivative of Eq. (12) with respect to  $w_2$ , we get

$$\frac{\partial^2 \pi_{s2}}{\partial w_2^2} = -\delta\alpha T < 0. \quad \text{Here, if } \pi_{s2} \text{ is concave in } w_2, \text{ the optimal solution also exists.}$$

Hence, by solving  $\frac{\partial \pi_{s2}}{\partial w_2} = 0$  first, then substitute  $w_2$  into  $\frac{\partial \pi_{r2}}{\partial p_d} = 0, \frac{\partial \pi_{r2}}{\partial \tau_d} = 0$ , we

can develop the fresh-keeping cost-sharing contract. For any given fresh-keeping

cost-sharing coefficient  $\varphi_1$ , the optimal retail price of the fresh product retailer is

$p_d^* = \frac{9m(1-\varphi_1)(B_1+3\alpha c)+4B_2c}{4(9(1-\varphi_1)\alpha m-B_2)}$  and the optimal fresh-keeping effort is

$$\tau_d^* = \frac{\delta\beta T\eta_0 k(B_1-3\alpha c)}{2(9(1-\varphi_1)\alpha m-B_2)}.$$

Theorem 3 gives the optimal retail price and fresh-keeping effort for FPSC.

Substituting  $p_d^*$  and  $\tau_d^*$  into Eq. (11) and (12), we derive the optimal profit for both retailer and supplier respectively.

$$\pi_{r2}^* = \frac{\delta T m (9(1-\varphi_1)^2 \alpha m - 2B_2)(B_1 - 3\alpha c)^2}{16(9(1-\varphi_1)\alpha m - B_2)^2} \quad (13)$$

$$\pi_{s2}^* = \frac{\delta T m (9(1-\varphi_1)^2 \alpha m - \varphi_1 B_2)(B_1 - 3\alpha c)^2}{8(9(1-\varphi_1)\alpha m - B_2)^2} \quad (14)$$

In the cost sharing contract, the retailer has significant motivation to engage in fresh-keeping effort because part of cost is supposedly shared by the supplier. Let the optimal fresh-keeping effort is the same as in the centralized supply chain i.e.,  $\tau_d^* = \tau_c^*$ . By comparing the optimal decisions under the fresh-keeping cost-sharing contract for the scenario of a centralized decision without a contract, we derive Proposition 2.

### Proposition 2

When  $\tau_d^* = \tau_c^*$ , 1)  $p_d^* > p_c^*$ ; 2)  $\pi_{r2}^* + \pi_{s2}^* < \pi_c^*$ .

### Proof.

1) From  $\tau_d^* = \frac{\delta \beta T \eta_0 k (B_1 - 3\alpha c)}{2(9(1-0.5)\alpha m - B_2)} = \frac{\delta \beta T \eta_0 k (B_1 - 3\alpha c)}{9\alpha m - 2B_2} = \tau_c^*$ , we get  $\varphi_1 = 0.5$ .

Therefore,  $p_d^* = \frac{9m(1-0.5)(B_1 + 3\alpha c) + 4B_2 c}{4(9(1-0.5)\alpha m - B_2)} > \frac{3m(3\alpha c + B_1) + 4B_2 c}{2(9\alpha m - 2B_2)} = p_c^*$ . Hence,

$p_d^* > p_c^*$ .

2) Then, we can derive the total profit:

$$\begin{aligned} \pi_{r2}^* + \pi_{s2}^* &= \frac{\delta T m (9(1-0.5)^2 \alpha m - 2B_2)(B_1 - 3\alpha c)^2}{16(9(1-0.5)\alpha m - B_2)^2} + \frac{\delta T m (9(1-0.5)^2 \alpha m - 0.5B_2)(B_1 - 3\alpha c)^2}{8(9(1-0.5)\alpha m - B_2)^2} \\ &= \frac{\delta T m (B_1 - 3\alpha c)^2 (6.75\alpha m - 3B_2)}{16(4.5\alpha m - B_2)^2} \end{aligned}$$

Therefore,  $\frac{\pi_c^*}{\pi_{r_2}^* + \pi_{s_2}^*} > 1$ . Hence,  $\pi_{r_2}^* + \pi_{s_2}^* < \pi_c^*$ .

Proposition 2 shows that the retail price under the fresh-keeping cost-sharing contract is higher than that in a centralized supply chain, and the total profit is lower than that without a contract. Therefore, it is useful for retailer to improve their fresh-keeping effort through fresh-keeping cost-sharing contracts; however, the FPSC cannot be coordinated under fresh-keeping cost-sharing contract. Thus, we must consider how to maximize profits by adding a revenue-sharing contract.

#### 4.2 Fresh-keeping cost- and revenue-sharing contract

To achieve the optimal retail price and the same fresh-keeping effort as well as total profit as in the centralized supply chain, we consider a case in which a supplier offers a discount to a retailer (apart from sharing the fresh-keeping cost). In such a case, the retailer may be willing to reduce the price due to the lower procurement price, and it may also be willing to share some revenue with the supplier.

Fresh-keeping cost- and revenue-sharing contracts include three parameters. The first is the wholesale price  $w_3$  that the retailer pays. The second is the cost share coefficient of the supplier, represented by  $\varphi_1$  ( $0 < \varphi_1 < 1$ ). The third is the revenue share coefficient of supplier, represented by  $\varphi_2$  ( $0 < \varphi_2 < 1$ ).

According to the above descriptions, we know that the profit function of the retailer is as follows:

$$\begin{aligned} \pi_{r_3} &= (1 - \varphi_2) p_d Q_d - w_3 Q_3 - (1 - \varphi_1) c(\tau) \\ &= ((1 - \varphi_2) p_d - w_3) \int_0^T \delta \left[ 1 - \alpha p_d + \beta \left( \theta_0 - (1 - k\tau_d) \eta_0 \left( \frac{t}{T} \right)^{\frac{1}{2}} \right) \right] dt - \frac{1}{2} (1 - \varphi_1) m \tau_d^2 \end{aligned} \quad (15)$$

Then, the profit function of the supplier is:

$$\begin{aligned}\pi_{s3} &= \varphi_2 p_d Q_d + (w_3 - c)Q_d - \varphi_1 c(\tau) \\ &= (w_3 - c + \varphi_2 p_d) \int_0^T \delta \left( 1 - \alpha p_d + \beta \left( \theta_0 - (1 - k \tau_d) \eta_0 \left( \frac{t}{T} \right)^{\frac{1}{2}} \right) \right) dt - \frac{1}{2} \varphi_1 m \tau_d^2\end{aligned}\quad (16)$$

Based on the above, we can derive Theorem 4.

**Theorem 4** Under the fresh-keeping cost- and revenue-sharing contract, for any given wholesale price  $w_3$ , fresh-keeping cost-sharing coefficient  $\varphi_1$  and revenue-sharing coefficient  $\varphi_2$ , the optimal retail price of a fresh product retailer is

$$p_d^*(\tau_d^*) = \frac{3(1-\varphi_2)(\beta\theta_0+1)-2(1-\varphi_2)\beta\eta_0(1-k\tau_d)+3w_3\alpha}{6(1-\varphi_2)\alpha} \quad \text{and the optimal}$$

$$\text{fresh-keeping effort is } \tau_d^*(p_d^*) = \frac{2((1-\varphi_2)p_d^* - w_3)\beta\eta_0 T \delta k}{3(1-\varphi_1)m}.$$

**Proof.**

Taking the second derivative of Eq. (15) with respect to  $p_d$  and  $\tau_d$ , we have

$$\frac{\partial^2 \pi_{r3}}{\partial \tau_d^2} = -(1-\varphi_1)m < 0, \quad \frac{\partial^2 \pi_{r3}}{\partial p_d^2} = -2(1-\varphi_2)\delta\alpha T < 0. \quad \text{The Hessian matrix is}$$

$$H = \begin{bmatrix} -2(1-\varphi_2)\alpha\delta T & \frac{2(1-\varphi_2)\eta_0\beta T \delta k}{3} \\ \frac{2(1-\varphi_2)\eta_0\beta T \delta k}{3} & -m(1-\varphi_1) \end{bmatrix}. \quad \text{This shows that the Hessian matrix of}$$

$\pi_{r3}$  returns a negative definite for all values of  $p_d$  and  $\tau_d$  if  $2\alpha\delta T m(1-\varphi_1) - \left(\frac{2\eta_0\beta T \delta k}{3}\right)^2 > 0$ . Therefore, we find that  $\pi_{r2}$  is concave in  $p_d$  and  $\tau_d$ , suggesting that the optimal solution exists.

Hence, solving  $\frac{\partial \pi_{r3}}{\partial \tau_d} = 0$  and  $\frac{\partial \pi_{r3}}{\partial p_d} = 0$ , we can derive the optimal retail price

$$p_d^*(\tau_d^*) = \frac{3(1-\varphi_2)(\beta\theta_0+1)-2(1-\varphi_2)\beta\eta_0(1-k\tau_d)+3w_3\alpha}{6(1-\varphi_2)\alpha} \quad \text{and the optimal}$$

$$\text{fresh-keeping effort } \tau_d^*(p_d^*) = \frac{2((1-\varphi_2)p_d^* - w_3)\beta\eta_0 T \delta k}{3(1-\varphi_1)m}.$$

Let  $p_d^* = p_c^*$  and  $\tau_d^* = \tau_c^*$ . It is then necessary to adjust the wholesale price  $w_3$  to facilitate coordination, leading us to theorem 5.

**Theorem 5** If the fresh-keeping cost- and revenue-sharing contract  $(\varphi_1, \varphi_2, w_3)$  is

$$\text{satisfied by } \varphi_1 = \varphi_2, \quad w_3 = (1-\varphi_2)c \quad \text{and} \quad \frac{9\alpha m(9\alpha m - 2B_2)}{2(9\alpha m - B_2)^2} \leq \varphi_2 \leq 1 - \frac{(9\alpha m - 2B_2)^2}{4(9\alpha m - B_2)^2},$$

then  $\pi_{r_3}^* + \pi_{s_3}^* = \pi_c^*$  is achieved, and the FPSC can be coordinated.

**Proof.**

$$\text{Let } p_d^* = p_c^*; \text{ that is } \frac{w_3}{2(1-\varphi_2)} = \frac{c}{2}. \text{ Thus, we obtain } w_3 = c(1-\varphi_2).$$

$$\text{Similarly, let } \tau_d^* = \tau_c^*; \text{ thus, we obtain } \frac{(1-\varphi_2)p_d^* - w_3}{1-\varphi_1} = p_c^* - c. \text{ That is,}$$

$$(1-\varphi_2)(p_d^* - c) = (1-\varphi_1)(p_c^* - c); \text{ therefore, } \varphi_1 = \varphi_2.$$

Substituting  $\varphi_1 = \varphi_2$ ,  $w_3 = c(1-\varphi_2)$  and  $p_c^*$  and  $\tau_c^*$  into Eq. (15) and Eq. (16), we derive the optimal total profit of the retailer as follows:

$$\pi_{r_3}^* = \frac{(1-\varphi_2)\delta T m (B_1 - 3\alpha c)^2}{4(9\alpha m - 2B_2)} \quad (17)$$

The optimal total profit of supplier is:

$$\pi_{s_3}^* = \frac{\varphi_2 \delta T m (B_1 - 3\alpha c)^2}{4(9\alpha m - 2B_2)} \quad (18)$$

Comparing Eq. (17) and Eq. (18) with Eq. (9) and Eq. (10), we get

$$\frac{9\alpha m(9\alpha m - 2B_2)}{2(9\alpha m - B_2)^2} \leq \varphi_2 \leq 1 - \frac{(9\alpha m - 2B_2)^2}{4(9\alpha m - B_2)^2}.$$

Then, the total profit under the fresh-keeping cost- and revenue-sharing contract is:



$$\pi_3^* = \pi_{r_3}^* + \pi_{s_3}^* = \frac{(1-\varphi_2)\delta Tm(B_1-3\alpha c)^2}{4(9\alpha m-2B_2)} + \frac{\varphi_2\delta Tm(B_1-3\alpha c)^2}{4(9\alpha m-2B_2)} = \frac{\delta Tm(B_1-3\alpha c)^2}{4(9\alpha m-2B_2)} \quad (19)$$

It is equal to the total profit  $\pi_c^*$  in the centralized FPSC. Thus,  $\pi_{r_3}^* + \pi_{s_3}^* = \pi_c^*$ , and the fresh-keeping cost- and revenue-sharing contract makes sense.

Comparing the retailer's profit under cost- and revenue- sharing contract with the case in decentralized FPSC, we get

$$\begin{aligned} \pi_{r_3}^* - \pi_{r_1}^* &= \frac{(1-\varphi_1)\delta Tm(B_1-3\alpha c)^2}{4(9\alpha m-2B_2)} - \frac{\delta Tm(9\alpha m-2B_2)(B_1-3\alpha c)^2}{16(9\alpha m-B_2)^2} \\ &= \delta Tm(B_1-3\alpha c)^2 \left[ \frac{(1-\varphi_1)}{4(9\alpha m-2B_2)} - \frac{(9\alpha m-2B_2)}{16(9\alpha m-B_2)^2} \right] \end{aligned}$$

$$\text{Because of } \varphi_1 \in \left[ \frac{9\alpha m(9\alpha m-2B_2)}{2(9\alpha m-B_2)^2}, 1 - \frac{(9\alpha m-2B_2)^2}{4(9\alpha m-B_2)^2} \right], \quad 1-\varphi_1 \geq \frac{(9\alpha m-2B_2)^2}{4(9\alpha m-B_2)^2}.$$

Therefore,  $\pi_{r_3}^* - \pi_{r_1}^* \geq 0$ . That is the retailer under cost- and revenue- sharing contract can earn more profit than the case in decentralized FPSC.

$$\begin{aligned} \text{Similarly, } \pi_{s_3}^* - \pi_{s_1}^* &= \frac{\varphi_2\delta Tm(B_1-3\alpha c)^2}{4(9\alpha m-2B_2)} - \frac{9\alpha\delta Tm(B_1-3\alpha c)^2}{8(9\alpha m-B_2)^2} \\ &= \delta Tm(B_1-3\alpha c)^2 \left[ \frac{\varphi_2}{4(9\alpha m-2B_2)} - \frac{9\alpha}{8(9\alpha m-B_2)^2} \right] \end{aligned}$$

$$\text{Because of } \varphi_2 \in \left[ \frac{9\alpha m(9\alpha m-2B_2)}{2(9\alpha m-B_2)^2}, 1 - \frac{(9\alpha m-2B_2)^2}{4(9\alpha m-B_2)^2} \right], \quad \varphi_2 \geq \frac{9\alpha m(9\alpha m-2B_2)}{2(9\alpha m-B_2)^2}.$$

Hence,  $\pi_{s_3}^* - \pi_{s_1}^* \geq 0$ . That is the supplier under cost- and revenue- sharing contract can earn more profit than the case in decentralized FPSC.

Theorem 5 indicates that when the cost-sharing coefficient  $\varphi_1$  is equal to the revenue-sharing coefficient  $\varphi_2$ , and they are all in the range of

$$\left[ \frac{9\alpha m(9\alpha m-2B_2)}{2(9\alpha m-B_2)^2}, 1 - \frac{(9\alpha m-2B_2)^2}{4(9\alpha m-B_2)^2} \right], \text{ the FPSC can be coordinated by the}$$

fresh-keeping cost- and revenue-sharing contract and that a win-win situation between

the fresh product retailer and supplier can be achieved. A comparison of the FPSC profits shows that all parties incur higher profits in the cost- and revenue-sharing contract in comparison to the decentralized case. Consequently, the retailer and the supplier have enough motivation to accept cost- and revenue- sharing contract.

We now discuss how the cost- and revenue- sharing contract can be implemented in practice.

The supplier and the retailer first agree on cost- and revenue- sharing contract  $(\varphi_1, \varphi_2, w_3)$ , the supplier can observe the optimal retail price and the optimal fresh-keeping effort which determined by retailer. As for  $Q$ , the supplier can conduct a check of the ordering quantity when the contract is reached. The wholesale price can then be determined by  $w_3 = (1 - \varphi_2)c$ . According to the contract, the fresh-keeping cost sharing proportion of supplier is  $\varphi_1$ , the retailer's proportion is  $(1 - \varphi_1)$ ; the revenue sharing proportion of supplier is  $\varphi_2$ , the retailer's proportion is  $(1 - \varphi_2)$ ;

where  $\varphi_1 = \varphi_2$ , they are in the range of  $\left[ \frac{9\alpha m(9\alpha m - 2B_2)}{2(9\alpha m - B_2)^2}, 1 - \frac{(9\alpha m - 2B_2)^2}{4(9\alpha m - B_2)^2} \right]$ .

**Corollary 1** Under the fresh-keeping cost- and revenue-sharing contract  $(\varphi_1, \varphi_2, w_3)$ , if consumers' sensitivity to the price of product  $\alpha$  is greater, the FPSC will be difficult to coordinate. However if consumers' sensitivity to the freshness of product  $\beta$  is greater, the FPSC will be easy to coordinate.

**Proof.**

According to Theorem 5  $\varphi_2 \in \left[ \frac{9\alpha m(9\alpha m - 2B_2)}{2(9\alpha m - B_2)^2}, 1 - \frac{(9\alpha m - 2B_2)^2}{4(9\alpha m - B_2)^2} \right]$ , denoting as

$\varphi_2 \in [\varphi_{2min}, \varphi_{2max}]$ . Taking the first derivative of  $\varphi_{2min}$  with respect to  $\alpha$ , we get

$\frac{\partial \varphi_{2min}}{\partial \alpha} = \frac{9mB_2^2}{(9\alpha m - B_2)^3} > 0$ ; that is,  $\varphi_{2min}$  is positively related to  $\alpha$ . Taking the first

derivative of  $\varphi_{2max}$  with respect to  $\alpha$ , we get  $\frac{\partial \varphi_{2max}}{\partial \alpha} = -\frac{9(9\alpha m - 2B_2)mB_2}{2(9\alpha m - B_2)^3} < 0$ ;

that is  $\varphi_{2max}$  is negatively correlated to  $\alpha$ . Therefore, the range of  $\varphi_2$  is decreasing with an increasing  $\alpha$  when  $\varphi_2 \in [\varphi_{2min}, \varphi_{2max}]$ . In other words, the revenue-sharing coefficient of the fresh product supplier is negatively correlated with consumers' sensitivity to price, making the supplier unwilling to accept the contract and the FPSC difficult to coordinate.

Similarly,  $\frac{\partial \varphi_{2min}}{\partial \beta} = -\frac{18\alpha m B_2^2}{\beta(9\alpha m - B_2)^3} < 0$ ,  $\frac{\partial \varphi_{2max}}{\partial \beta} = \frac{9\alpha m(9\alpha m - 2B_2)B_2}{\beta(9\alpha m - B_2)^3} > 0$ .

Therefore, the range of  $\varphi_2$  is increasing with the increasing  $\beta$  when  $\varphi_2 \in [\varphi_{2min}, \varphi_{2max}]$ . In other words, the revenue-sharing coefficient of the fresh product supplier is positively related to consumers' sensitivity to freshness, making the supplier willing to accept the contract and the FPSC easy to coordinate.

From Theorem 5 and Corollary 1, we know that it is necessary to choose the proper conditions when negotiating a contract. The total FPSC profit is positively related with consumers' sensitivity to product price and negatively correlated with consumers' sensitivity to product freshness.

## 5 Numerical analysis

In the above sections, we theoretically discuss how to coordinate the FPSC under a contract situation and a non-contract contract situation and then explore the differences between the centralized FPSC and the decentralized FPSC. To illustrate the theoretical results, we present some numerical examples in this section. The

parameters are summarized in Table 1.

*Insert Table 1 Parameters*

Using the parameters in Table 1, we apply them into previously analysed scenarios.

*Insert Figure 3 Optimal decisions under different preferences without a contract*

The results in Figure 3 verify Theorems 1 and 2 and Proposition 1. They show the optimal retail price and the optimal fresh-keeping effort between the centralized FPSC and the decentralized FPSC. Figure 3.1 & 3.4 indicate that the optimal fresh-keeping effort in a centralized supply chain is higher than that in a decentralized supply chain. Figure 3.2 & 3.5 illustrate that the optimal retail price in a centralized supply chain is lower than that in a decentralized supply chain. Figure 3.3 & 3.6 demonstrate that the optimal total profit in a centralized supply chain is greater than that in a decentralized supply chain. In sum, the optimal decisions in the centralized FPSC are better than those in the decentralized FPSC.

*Insert Figure 4 Optimal decisions and profits under the fresh-keeping cost-sharing contract*

From Figure 4, we can see that the optimal fresh-keeping effort under the fresh-keeping cost-sharing contract is the same as that found in the centralized FPSC (Figure 4.1 & 4.4). However, the retailer price is higher than that in the centralized FPSC (Figure 4.2 & 4.5); and the total profit is lower (Figure 4.3 & 4.6). Therefore, the FPSC cannot be coordinated via a fresh-keeping cost-sharing contract.

*Insert Figure 5 Optimal decisions and profits under the fresh-keeping cost- and revenue-sharing contract*

Figure 5 reveals the optimal decisions and profits under the fresh-keeping cost- and revenue-sharing contract. These findings confirm Theorems 4 and 5. By comparing

1  
2  
3  
4 the results in Figure 3.1 & 3.4 with Figure 5.1 & 5.4, and Figure 3.2 & 3.5 with  
5  
6 Figure 5.2 & 5.5, it becomes clear that the optimal fresh-keeping effort and retail  
7  
8 price under the fresh-keeping cost- and revenue-sharing contract achieve the level of  
9  
10 the centralized FPSC; the individual profit is higher than those in other two scenarios.  
11  
12 Moreover, from Figure 5.3 & 5.6, it can be seen that the total profit is the same as that  
13  
14 in the centralized supply chain.  
15  
16

17  
18 *Insert Figure 6. The effects of consumers' sensitivity to price and freshness on profit*  
19

20  
21 Based on Corollary 1, we can illustrate the effects of consumers' sensitivity to price  
22  
23 and freshness on profit, which is depicted in Figure 6. We know that the optimal profit  
24  
25 that under the fresh-keeping cost- and revenue-sharing contract achieve the level of  
26  
27 the centralized FPSC. From Figure 6, it is clear that the FPSC profit increases with the  
28  
29 increasing of consumers' sensitivity to product freshness, and it decreases with the  
30  
31 increasing of consumers' sensitivity to product price.  
32  
33

34  
35 Our analysis thus reveals that from the product's fresh-keeping perspective, cost- and  
36  
37 revenue- sharing contract offered by the retailer or obtained through negotiation leads  
38  
39 to a higher fresh-keeping effort in FPSC, brings more profit to both supplier and  
40  
41 retailer. The results explain the reason why supplier and retailer would prefer cost-  
42  
43 and revenue- sharing contract under fresh-keeping effort, and would cooperate with  
44  
45 supply chain partners in order to benefit from the fresh-keeping initiatives.  
46  
47  
48  
49

## 50 **6 Conclusion and future research**

51  
52 One of the specific challenges in food supply chain is that freshness of food is one  
53  
54 of the keys for customers purchasing decision. This leads to two important questions:  
55  
56 first, how much effort and resources are needed among FPSC members in order to  
57  
58  
59  
60

1  
2  
3 keep the product refresh. Second, how to motivate and coordinate PFSC members  
4  
5  
6 through contract mechanism. This paper strives to answer these questions.  
7  
8

9 In this paper, we have examined the coordination of FPSC with a fresh-keeping  
10 effort. We focus on the coordination of the FPSC through different contracts when the  
11 fresh-keeping effort is considered in the model. Two cases are considered: a  
12 fresh-keeping cost-sharing contract and a fresh-keeping cost- and revenue-sharing  
13 contract. In each case, we determine the optimal retail price, the optimal wholesale  
14 price and the optimal fresh-keeping effort. The result suggests that the fresh-keeping  
15 cost- and revenue-sharing contract is more effective for coordinating the FPSC.  
16  
17  
18  
19  
20  
21  
22  
23  
24

25 We find that, in negotiating the contract, it is necessary to carefully consider the  
26 conditions to maximize total profit without sacrificing individual profit. It is worth  
27 noting that the profit of the FPSC is negatively correlated with consumers' sensitivity  
28 to product price, while it is positively related to consumers' sensitivity to product  
29 freshness.  
30  
31  
32  
33  
34  
35  
36  
37  
38

39 There are several topics that merit further research. In this paper, we assume that  
40 the fresh-keeping cost is paid by the fresh product retailer in a centralized supply  
41 chain. A natural extension is to examine a setting in which the fresh-keeping cost is  
42 paid by the fresh product supplier. Since, in this research, the consumer arrival rate at  
43 any time is assumed to be constant, another interesting possibility is to examine a  
44 situation in which the rate is stochastic. Finally, we will extend our model to consider  
45 how to coordinate the FPSC through cost- and revenue-sharing contracts when two  
46 retailers compete by studying the coordination mechanisms of the FPSC when one  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

retailer has the priority to make its decision first.

## Reference

- Akcay, Y., Natarajan, H.P. and Xu, S.H. (2010), "Joint dynamic pricing of multiple perishable products under consumer choice", *Management Science*, Vol. 56 No. 8, pp. 1345–1361.
- Avinadav, T., Herbon, A. and Spiegel, U. (2013), "Optimal inventory policy for a perishable item with demand function sensitive to price and time", *International Journal of Production Economics*, Vol. 144 No. 2, pp. 497–506.
- Blackburn, J. and Scudder, G. (2009), "Supply Chain Strategies for Perishable Products : The Case of Fresh Produce", *Production and Operations Management*, Vol. 18 No. 2, pp. 129–137.
- Cachon, G.P. and Kök, A.G. (2007), "Implementation of the newsvendor model with clearance pricing: How to (and how not to) estimate a salvage value", *Manufacturing & Service Operations Management*, Vol. 9 No. 3, pp. 276–290.
- Cachon, G.P. and Lariviere, M.A. (2005), "Supply chain coordination with revenue-sharing contracts: strengths and limitations", *Management science*, Vol. 51 No. 1, pp. 30–44.
- Cai, X., Chen, J., Xiao, Y. and Xu, X. (2010), "Optimization and Coordination of Fresh Product Supply Chains with Freshness-Keeping Effort", *Production and Operations Management*, Vol. 19 No. 3, pp. 261–278.
- Cai, X., Chen, J., Xiao, Y., Xu, X. and Yu, G. (2013), "Fresh-product supply chain management with logistics outsourcing", *Omega*, Vol. 41 No. 4, pp. 752–765.
- Chen, J. and Bell, P.C. (2011), "Coordinating a decentralized supply chain with customer returns and price-dependent stochastic demand using a buyback policy", *European Journal of Operational Research*, Vol. 212 No. 2, pp. 293–300.
- Chew, E.P., Lee, C., Liu, R., Hong, K. and Zhang, A. (2014), "Optimal dynamic pricing and ordering decisions for perishable products", *International Journal of Production Economics*, Vol. 157, pp. 39–48.
- Dan, B., Xu, G. and Liu, C. (2012), "Pricing policies in a dual-channel supply chain with retail services", *International Journal of Production Economics*, Vol. 139 No. 1, pp. 312–320.
- Dong, L., Kouvelis, P. and Tian, Z. (2009), "Dynamic pricing and inventory control of substitute products", *Manufacturing & Service Operations Management*, Vol. 11 No. 2, pp. 317–339.
- Dye, C.-Y. (2007), "Joint pricing and ordering policy for a deteriorating inventory with partial backlogging", *Omega*, Vol. 35 No. 2, pp. 184–189.
- Feng, Q. and Lu, L.X. (2013), "Supply chain contracting under competition: bilateral bargaining vs. Stackelberg", *Production and Operations Management*, Vol. 22 No. 3, pp. 661–675.
- Ferguson, M.E. and Koenigsberg, O. (2007), "How should a firm manage deteriorating inventory?", *Production and Operations Management*, Vol. 16 No. 3, pp. 306–321.
- Gallego, G. and Hu, M. (2014), "Dynamic pricing of perishable assets under competition",

1  
2  
3                   *Management Science*, Vol. 60 No. 5, pp. 1241–1259.

4 Halim, K.A., Giri, B.C. and Chaudhuri, K.S. (2008), “Fuzzy economic order quantity model for  
5 perishable items with stochastic demand, partial backlogging and fuzzy deterioration rate”,  
6 *International Journal of Operational Research*, Vol. 3 No. 1-2, pp. 77–96.

7  
8  
9 He, Y. and Zhao, X. (2012), “Coordination in multi-echelon supply chain under supply and demand  
10 uncertainty”, *International Journal of Production Economics*, Vol. 139 No. 1, pp. 106–115.

11  
12 Herbon, A., Levner, E. and Cheng, T.C.E. (2014), “Perishable inventory management with dynamic  
13 pricing using time-temperature indicators linked to automatic detecting devices”, *International*  
14 *Journal of Production Economics*, Vol. 147, pp. 605–613.

15  
16  
17 Jiang, W. and Chen, X. (2016), “Optimal strategies for manufacturer with strategic customer behavior  
18 under carbon emissions-sensitive random demand”, *Industrial Management & Data Systems*, Vol.  
19 116 No. 4, pp. 759–776.

20  
21 Kanchanasuntorn, K. and Techanitisawad, A. (2006), “An approximate periodic model for fixed-life  
22 perishable products in a two-echelon inventory–distribution system”, *International Journal of*  
23 *Production Economics*, Vol. 100 No. 1, pp. 101–115.

24  
25 Ketzenberg, M. and Ferguson, M.E. (2008), “Managing Slow-Moving Perishables in the Grocery  
26 Industry”, *Production and Operations Management*, Vol. 17 No. 5, pp. 513–521.

27  
28 Krishnan, H., Kapuscinski, R. and Butz, D.A. (2004), “Coordinating contracts for decentralized supply  
29 chains with retailer promotional effort”, *Management science*, Vol. 50 No. 1, pp. 48–63.

30  
31 Lau, A.H.L., Lau, H.-S. and Wang, J.-C. (2008), “How a dominant retailer might design a purchase  
32 contract for a newsvendor-type product with price-sensitive demand”, *European Journal of*  
33 *Operational Research*, Vol. 190 No. 2, pp. 443–458.

34  
35  
36 Lee, C.K.M., Lin, D. and Pasari, R. (2014), “Strategic procurement from forward contract and spot  
37 market”, *Industrial Management & Data Systems*, Vol. 114 No. 5, pp. 778–796.

38  
39 Li, S., Zhang, J. and Tang, W. (2015), “Joint dynamic pricing and inventory control policy for a  
40 stochastic inventory system with perishable products”, *International Journal of Production*  
41 *Research*, Vol. 53 No. 10, pp. 2937–2950.

42  
43 Li, Y., Lim, A. and Rodrigues, B. (2009), “Note-pricing and inventory control for a perishable product”,  
44 *Manufacturing & Service Operations Management*, Vol. 11 No. 3, pp. 538–542.

45  
46 Lodree, E.J. and Uzochukwu, B.M. (2008), “Production planning for a deteriorating item with  
47 stochastic demand and consumer choice”, *International Journal of Production Economics*, Vol.  
48 116 No. 2, pp. 219–232.

49  
50 Ma, P., Wang, H. and Shang, J. (2013a), “Contract design for two-stage supply chain coordination:  
51 Integrating manufacturer-quality and retailer-marketing efforts”, *International Journal of*  
52 *Production Economics*, Vol. 146 No. 2, pp. 745–755.

53  
54  
55 Ma, P., Wang, H. and Shang, J. (2013b), “Supply chain channel strategies with quality and marketing  
56 effort-dependent demand”, *International Journal of Production Economics*, Vol. 144 No. 2, pp.  
57 572–581.  
58  
59  
60



- 1  
2  
3 Nakandala, D., Lau, H. and Zhang, J. (2016), "Cost-optimization modelling for fresh food quality and  
4 transportation", *Industrial Management & Data Systems*, Vol. 116 No. 3, pp. 564–583.
- 5  
6 Pasternack, B.A. (2008), "Optimal pricing and return policies for perishable commodities", *Marketing  
7 science*, Vol. 27 No. 1, pp. 133–140.
- 8  
9 Rong, A., Akkerman, R. and Grunow, M. (2011), "An optimization approach for managing fresh food  
10 quality throughout the supply chain", *International Journal of Production Economics*, Vol. 131  
11 No. 1, pp. 421–429.
- 12  
13 Sainathan, A. (2013), "Pricing and replenishment of competing perishable product variants under  
14 dynamic demand substitution", *Production and Operations Management*, Vol. 22 No. 5, pp.  
15 1157–1181.
- 16  
17 Sana, S.S. and Chaudhuri, K.S. (2008), "A deterministic EOQ model with delays in payments and  
18 price-discount offers", *European Journal of Operational Research*, Vol. 184 No. 2, pp. 509–533.
- 19  
20 Shang, W. and Yang, L. (2015), "Contract negotiation and risk preferences in dual-channel supply  
21 chain coordination", *International Journal of Production Research*, No. ahead-of-print, pp. 1–20.
- 22  
23 Sommer, S.C. and Loch, C.H. (2009), "Incentive contracts in projects with unforeseeable uncertainty",  
24 *Production and Operations Management*, Vol. 18 No. 2, pp. 185–196.
- 25  
26 Wang, C.X. and Webster, S. (2009), "Markdown money contracts for perishable goods with clearance  
27 pricing", *European Journal of Operational Research*, Vol. 196 No. 3, pp. 1113–1122.
- 28  
29 Wang, X. and Li, D. (2012), "A dynamic product quality evaluation based pricing model for perishable  
30 food supply chains", *Omega*, Vol. 40 No. 6, pp. 906–917.
- 31  
32 Xiao, T., Shi, K. and Yang, D. (2010), "Coordination of a supply chain with consumer return under  
33 demand uncertainty", *International Journal of Production Economics*, Vol. 124 No. 1, pp. 171–  
34 180.
- 35  
36 Xiao, T. and Xu, T. (2013), "Coordinating price and service level decisions for a supply chain with  
37 deteriorating item under vendor managed inventory", *International Journal of Production  
38 Economics*, Vol. 145 No. 2, pp. 743–752.
- 39  
40 Xiao, T., Yang, D. and Shen, H. (2011), "Coordinating a supply chain with a quality assurance policy  
41 via a revenue-sharing contract", *International Journal of Production Research*, Vol. 49 No. 1, pp.  
42 99–120.
- 43  
44 Xin, C., Pang, Z. and Limeng, P. (2014), "Coordinating Inventory Control and Pricing Strategies for  
45 Perishable Products", *Operations Research*, Vol. 62 No. May, pp. 284–300.
- 46  
47 Xu, G., Dan, B., Zhang, X. and Liu, C. (2014), "Coordinating a dual-channel supply chain with  
48 risk-averse under a two-way revenue sharing contract", *International Journal of Production  
49 Economics*, Vol. 147, pp. 171–179.
- 50  
51 Xu, H., Liu, Z.Z. and Zhang, S.H. (2012), "A strategic analysis of dual-channel supply chain design  
52 with price and delivery lead time considerations", *International Journal of Production  
53 Economics*, Vol. 139 No. 2, pp. 654–663.
- 54  
55 Zhang, W.G., Fu, J., Li, H. and Xu, W. (2012), "Coordination of supply chain with a revenue-sharing  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

contract under demand disruptions when retailers compete”, *International Journal of Production Economics*, Vol. 138 No. 1, pp. 68–75.



Table 1 Parameters

$k$	$m$	$c$	$\delta$	$T$	$\theta_0$	$\eta_0$
0.20	100	0.50	100	10	0.90	0.80

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Industrial Management &amp; Data Systems

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

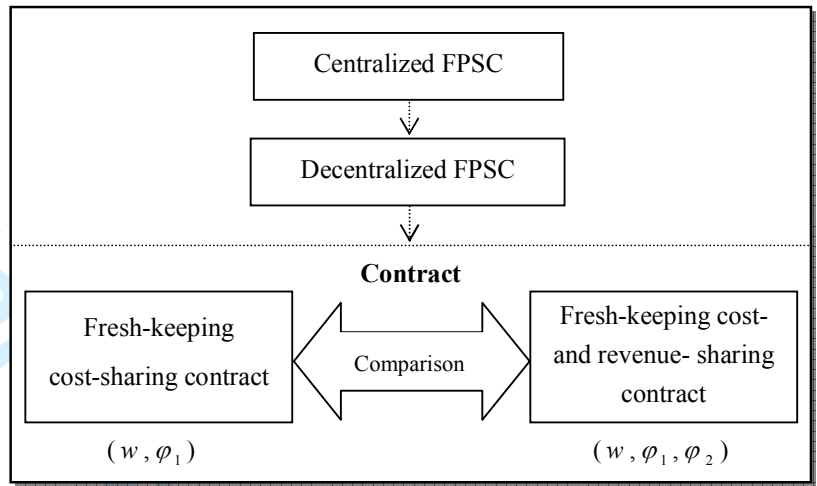


Figure 1 Research Framework for a FPSC

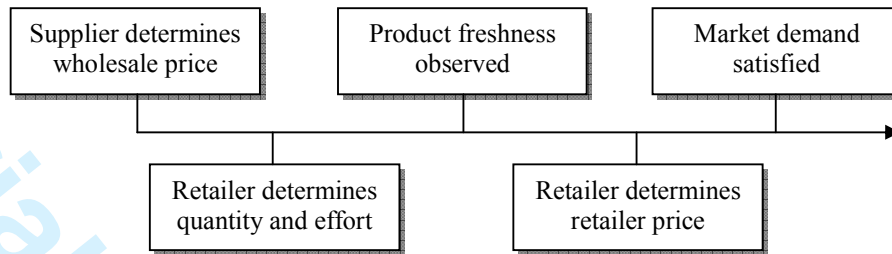


Figure 2 Relationships of Events under Consideration

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

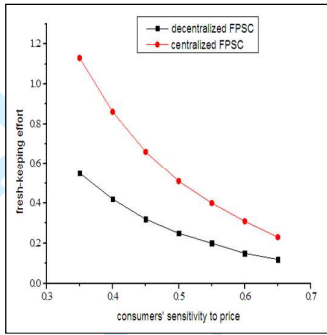


Figure 3.1 The effect of consumers' sensitivity to price on fresh-keeping effort

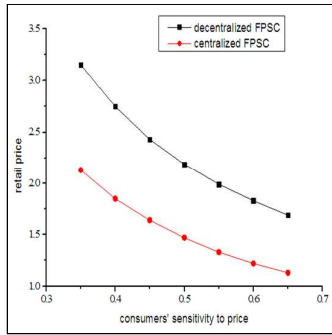


Figure 3.2 The effect of consumers' sensitivity to price on retail price

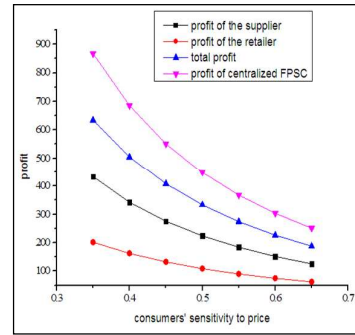


Figure 3.3 The effect of consumers' sensitivity to price on profit

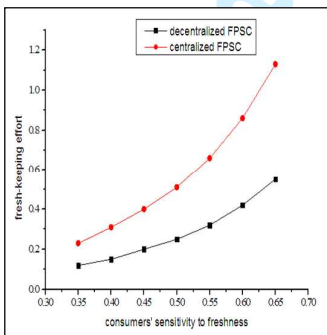


Figure 3.4 The effect of consumers' sensitivity to freshness on fresh-keeping effort

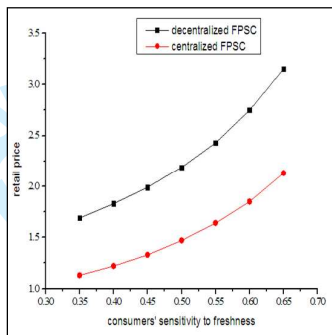


Figure 3.5 The effect of consumers' sensitivity to freshness on retail price

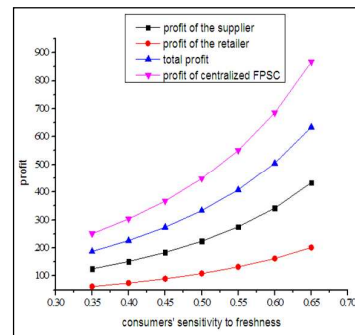


Figure 3.6 The effect of consumers' sensitivity to freshness on profit

Figure 3 Optimal decisions under different preferences without a contract

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

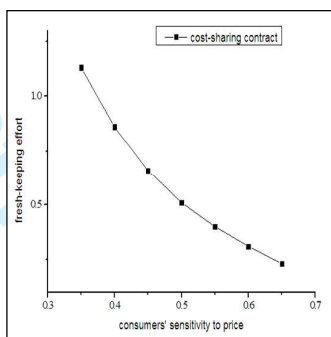


Figure 4.1 The effect of consumers' sensitivity to price on fresh-keeping effort

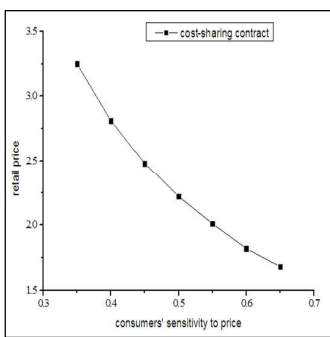


Figure 4.2 The effect of consumers' sensitivity to price on retail price

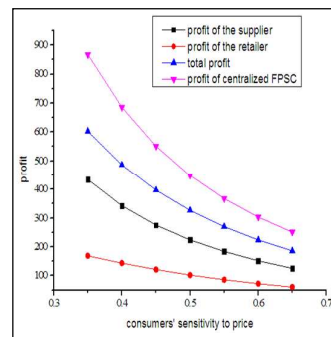


Figure 4.3 The effect of consumers' sensitivity to price on profit

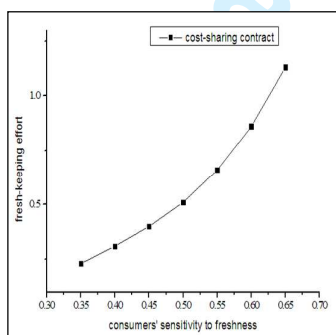


Figure 4.4 The effect of consumers' sensitivity to freshness on fresh-keeping effort

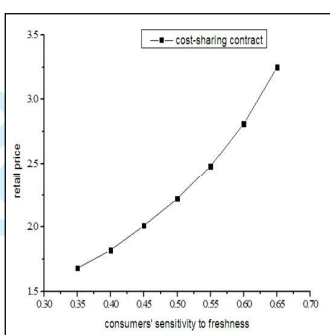


Figure 4.5 The effect of consumers' sensitivity to freshness on retail price

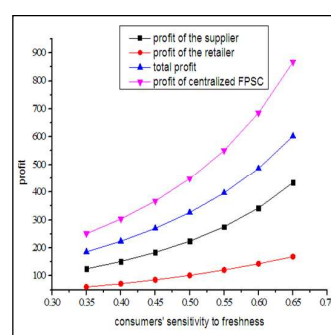


Figure 4.6 The effect of consumers' sensitivity to freshness on profit

**Figure 4 Optimal decisions and profits under the fresh-keeping cost-sharing contract**

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

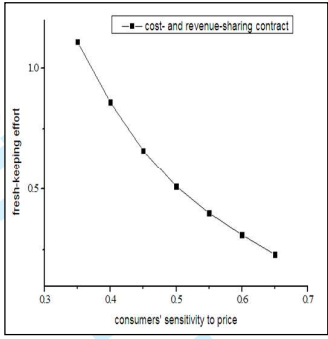


Figure 5.1 The effect of consumers' sensitivity to price on fresh-keeping effort

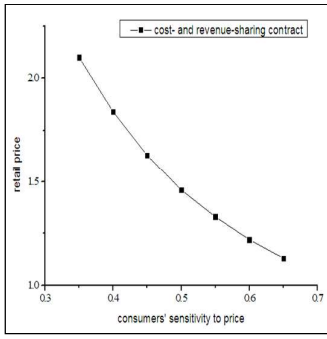


Figure 5.2 The effect of consumers' sensitivity to price on retail price

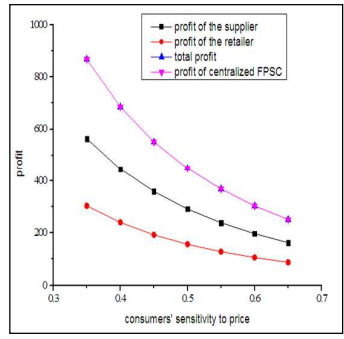


Figure 5.3 The effect of consumers' sensitivity to price on profit

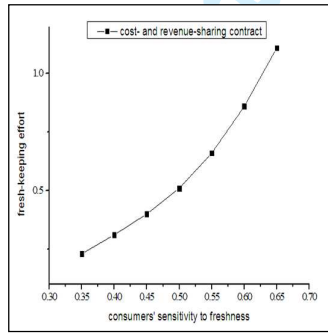


Figure 5.4 The effect of consumers' sensitivity to freshness on fresh-keeping effort

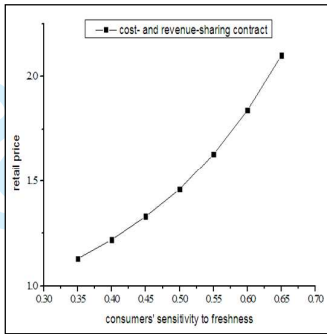


Figure 5.5 The effect of consumers' sensitivity to freshness on retail price

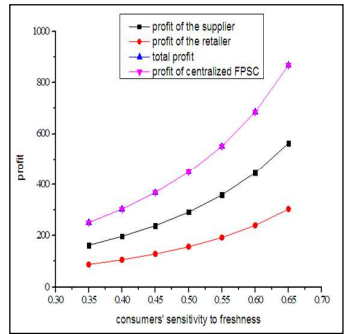


Figure 5.6 The effect of consumers' sensitivity to freshness on profit

**Figure 5 Optimal decisions and profits under the fresh-keeping cost- and revenue-sharing contract**



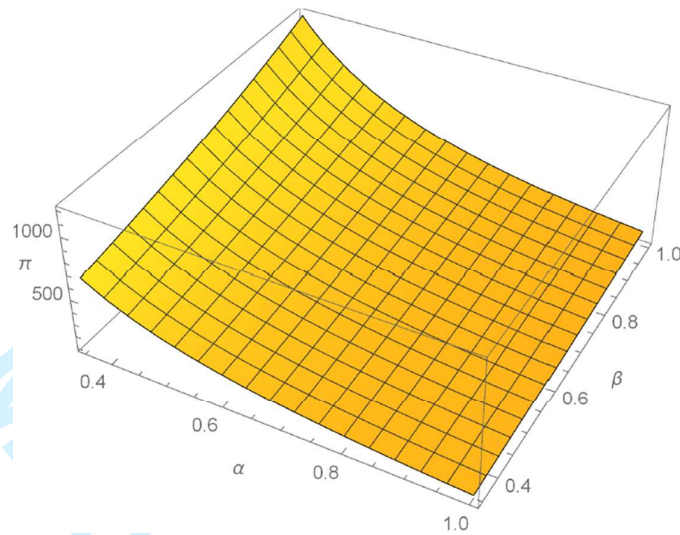


Figure 6 The effects of consumers' sensitivity to price and freshness on profit

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60