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Three-level supply chain coordination of fresh produces under demand disruption with buy back contracts

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ABSTRACT

This paper studies a three-level fresh and live produce supply chain consisting of producer, distributor, and retailer, and an optimal response to disruptions under buy back contract is tried to be presented. Firstly, the coordination model under normal conditions is given. Then, the influence of disruptions to the supply chain is discussed when demand perturbation factor distribution is fluctuated by disruptions. The result shows that supply chain coordination is broken off when demand perturbation factor distribution is fluctuated by disruption. So, an adjusted buy back contract is proposed, and it is proved that the new contract can coordinate the supply chain and achieve optimal reaction. Finally, an application example is given.

KEYWORDS

Fresh produces; Disruptions management; Demand disruption; Buy back contract.

INTRODUCTIONS

Fresh produce, as a kind of special easy-deteriorating products, refer to five kinds of produces including fresh fruit, fresh aquatic product, live livestock and new meat, milk and egg[1]. Fresh produces are perishable and vulnerable and tend to deteriorate in the links of procurement, transportation and marketing. Hence, quantity loss and reduction of freshness will be caused. In recent years, research on coordination of supply chain of fresh produces has increased. Xiao Yongbo and other people researched supply chain of fresh produces transported for a long distance under FOB[2] and CIF[3] business model and achieved coordination through cost sharing mechanism; Zhao Xia, et al.[4] analyzed two-level supply chain coordination with random output and demand under revenue sharing contract; Lin Lue, et al.[5] researched three-level supply chain coordination of fresh produces under sharing contract. The research shows that the revenue sharing contract can effectively coordinate the supply chain of three-level fresh produces and contract parameters can achieve tripartite win-win within certain scope.

Current society is a society where disruptions occur frequently. In recent years, terrorist attack, war, tsunami, food safety event, major public health event and other disruptions have seriously influence normal operation of global supply chain and directly cause supply chain uncoordinated or original plan unfeasible. Hence, it is extremely important how coordination supply chain system copes with research of disruptions and research on coordinating supply chain system to cope with disruptions has become the focus of management science research in recent years.

At present, research for coordination of supply chain under disruptions is at a stage of starting. Qi, et al.[6] designed quantity discount contract pertinent to perturbation of supply chain demand to coordinate disruptions; Yu Hui, et al.[7] assumed that the demand is a linear function. Considering sensitivity coefficient of demand, quantity discount contract resisting disruptions is given; Xiao, et al.[8] researched coordination response of two-level supply chain composed of one supplier and two competitive retailers to disruptions with varying demand; Cao Erbao, et al.[9] researched the coordination mechanism of supply chain system composed of one manufacturer and n Cournot competitive retailers in the face of perturbation of production cost and market demand and proposed coordination strategy of revenue sharing contract; Sheng Fang, et al.[10] considered application of linear transfer payment contract in the supply chain with disruptions to coordinate supply chain in the supply chain composed of one supplier and n retailers and provided conditions to be met by transfer payment contract which can coordinate supply chain. As for research on spread effect of supply chain management, Yang Zhihui, et al.[11] researched the supply chain of goods with short life cycle composed of one supplier and one retailer. When disruptions cause market demand of retailers to change and production cost of supplier fluctuates with regard to coordination countermeasures of supply chain, it’s found in research that coordination response to spread effect of supply chain can be achieved through quantity discount contract. As for supply chain of perishable goods composed of one supplier and one retailer, Gao Bo, et al.[12] researched how to cope with disruptions with coordination supply chain of revenue sharing contract while response time is sensitive and provided optimal coping strategy of supply chain.

In reality, multi-stage supply chain is more common. Hu Jinsong, et al.[13] researched the three-level supply chain composed of supplier, manufacturer and retailer. On the basis of considering random demand, the price discount contract coping with disruptions is proposed; Pang Qinghua, et al.[14] also researched the emergency coordination of three-level supply chain and considered using revenue sharing contract to coordinate three-level supply chain when distribution of market demand changes.

Buy back contract is a kind of coordination mechanism where order quantity is different from actual demand quantity owing to uncertain demand. It can both encourage retailers to increase order quantity to reduce loss caused by stock-out and share all risks brought by increase of order quantity to a certain degree. As for emergency coordination of supply chain as per the buy back contract, Yu Hui, et al.[15] researched optimal decision of two-level supply chain coordination coping with disruptions under buy back contract; Wang Yuyan, et al.[16] researched the impact on marketing activity and waste recycling activity of supply chain when disruptions cause market distribution confronted by retailers under two-level closed-loop supply chain and provided optimal coping strategy of closed-loop supply chain for disruptions.

In recent years, disruptions caused by quality safety of fresh produces occur frequently, such as SARS, bird flu, H1N1 flu, melamine powdered milk event, Hainan poisonous green bean event, “lean-meat pig” event, et al. These events have serious impact on production, marketing, demand of fresh produces, confidence of consumers in food safety. At present, most researches on disruptions emergency management are pertinent to supply chain of industrial products and there is rare research in emergency coordination of supply chain disruptions of fresh produces. Wei Lai, et al.[17] researched asymmetrical transfer of price wave and effect of industry chain of produces. As fresh produces are uncertain owing to product characteristics, production, transportation, demand and other factors and they are directly related to human life and health, the supply chain confronts many complicated disruptions with extensive impact scope. Hence, research on emergency coordination of supply chain of fresh produces is more urgent and important.

The paper uses literature[5] for reference and the literature researches coordination of three-level supply chain of fresh produces with revenue sharing contract. With loss of product quantity and reduction of freshness of fresh produces in the process of transportation, the paper applies buy back contract to research in emergency coordination of three-level supply chain characterized with deterioration and freshness impact and researched coordination response of supply chain when disruptions cause change of distribution function of demand perturbation factor. Supply cost is considered in the model, which is not taken into consideration in the literature[5]. At the same time, to make the model more practical, loss cost and backhaul cost are in the process of buy back of fresh produces are considered.

BASIC ENTERPRISE COORDINATION MODEL FOR THREE-LEVEL SUPPLY CHAIN BUY BACK

By considering a three-level supply chain system composed of one manufacturer (M), one distributor (D) and one retailer (R) and researching a single cycle model, retailer has an opportunity to order goods before selling season.

Assumed conditions

(1) The distributor bears transportation cost and loss in the process of transportation. β is effective factor related to transportation which is used to measure loss of fresh produces in the process of transportation, $\beta \in [0,1]$. The distributor orders fresh produces with order quantity of q/β from the manufacturer with maximization profit goal. q is the quantity of fresh produces ordered by the retailer from the distributor and θ is freshness factor ($0 \le \theta \le 1$).

(2) Market demand function is $q = d(p,t) = ap^{-k}\theta \cdot \varepsilon$, $k > 1$. The form indicates that the price elasticity of market demand is a constant[3]. Where q is market demand and ε is random factor of continuous distribution and the probability density function is $f(x)$, with distribution function of $F(x)$ and $F(x)$ to increase slightly and strictly, $F(0) = 0$. Suppose the expectation of ε $\mu_\varepsilon = E\varepsilon = 1$, $\bar{F}(x) = 1 - F(x)$, a -market size, k -price demand elasticity, p -retail price.

(3) Unit penalty costs of retailer, distributor and manufacturer owing to stock-out are respectively g_r, g_d, g_m, $g = g_r + g_d + g_m$; the expectation of market demand is μ. At the same time, cost, market demand and all other information are assumed to be common and members of supply chain are all risk-neutral and entirely rational.

Definition of other related symbols: q -order quantity of retailer, w_A -wholesale price of unit product of distributor, w_B -wholesale price of unit product of manufacturer, b_A -buy back price of unit product of distributor, b_B -buy back price of unit product of manufacturer, c_r -marginal ordering cost of retailer, c_d -marginal ordering cost of distributor, c_m -marginal production cost of manufacturer, c_t -unit transportation cost of distributor.

To make optimization analysis of the model, with experience of literature[18] for reference, inventory factor $z = \dfrac{q}{\dfrac{ap^{-k}}{\ln 2}\ln(2 - \dfrac{t^2}{T^2})}$ is introduced.

Lemma 1 Optimal decision of supply chain is that optimal inventory factor is (z_0) is determined by the following equation and optimal inventory factor is well-determined.

$$\int_0^z (k-1)xf(x)dx = z(1 - F(z)) \quad \mathbf{(1)}$$

From formula (1), then:

$$1 - \int_0^{z_0} (1 - \frac{x}{z_0}) f(x)dx = \frac{k(1 - F(z_0))}{k-1}$$

Then: expected sales volume

$S(q) = \min\{d,q\} = q\dfrac{k(1 - F(z_0))}{k-1}$, expected period-end inventory $I(q) = q - S(q)$, expected period-end inventory $L(q) = \mu - S(q)$, loss of buy back product in the process of backhaul $b_A(1-\beta)I(q)$, backhaul cost- $c_t I(q)$, buy back contract provided by the distributor $T_A = w_A q - b_A I(q)$ and buy back contract provided by the manufacturer $T_B = \dfrac{w_B q}{\beta} - b_B I(q)$.

Expected profit function of the retailer is:

$$\begin{aligned}\Pi_r &= pE\{\min(d,q)\} - c_r q - T_A - g_r L(q) \quad = (p - b_A + g_r)S(q) - (w_A - b_A + c_r)q - g_r\mu \\ &= ((z_0 a\theta))^{\frac{1}{k}} - \frac{b_A - g_r}{q^{-\frac{1}{k}}})q^{1-\frac{1}{k}}\frac{k(1 - F(z_0))}{k-1} - (w_A - b_A + c_r)q - g_r\mu \end{aligned} \quad \mathbf{(2)}$$

Expected profit function of the distributor is:

$$\begin{aligned}\Pi_d &= T_A - T_B - b_A(1-\beta)I(q) - c_t I(q) - g_d L(q) - \frac{(c_d + c_t)q}{\beta} \\ &= (b_A(2-\beta) - b_B + c_t + g_d)S(q) \\ &- (b_A(2-\beta) - b_B - w_A + \frac{w_B + c_d}{\beta} + c_t(1 + \frac{1}{\beta}))q - g_d\mu \ = (b_A(2-\beta) - b_B + c_t + g_d)q\frac{k(1 - F(z_0))}{k-1}\end{aligned}$$

$$-(b_A(2-\beta)-b_B-w_A+\frac{w_B+c_d}{\beta}+c_t(1+\frac{1}{\beta}))q-g_d\mu \quad (3)$$

Expected profit function of the manufacturer is:

$$\prod_m = T_B - \frac{c_m q}{\beta} - b_B I(q)(1-\beta) - g_m L(q) = (b_B(2-\beta)+g_m)S(q) + (\frac{w_B-c_m}{\beta} - b_B(2-\beta))q - g_m\mu$$

$$= (b_B(2-\beta)+g_m)q\frac{k(1-F(z_0))}{k-1} + (\frac{w_B-c_m}{\beta}w_A \ -b_B(2-\beta))q - g_m\mu \quad (4)$$

Expected profit function of the supply chain is:

$$\prod = pE\{\min(d,q)\} - (c_t+(b_A+b_B)(1-\beta))I(q) \ -gL(q) - (c_r+\frac{c_d+c_t+c_m}{\beta})q$$

$$= (p+c_t+(b_A+b_B)(1-\beta)+g)S(q) - (c_r+\frac{c_d+c_m}{\beta} \ +c_t(1+\frac{1}{\beta}) + (b_A+b_B)(1-\beta))q - g\mu$$

$$= ((z_0 a\theta))^{\frac{1}{k}} + \frac{c_t+(b_A+b_B)(1-\beta)+g}{q^{-\frac{1}{k}}})q^{1-\frac{1}{k}}\frac{k(1-F(z_0))}{k-1} \ -(c_r+\frac{c_d+c_m}{\beta}+c_t(1+\frac{1}{\beta})+(b_A+b_B)(1-\beta))q - g\mu \quad (5)$$

Through derivation of second order for expected profit function of supply chain, we can get:

$$\frac{\partial^2 \prod}{\partial q^2} = -\frac{1}{k}(1-F(z_0))(z_0 a\theta)^{\frac{1}{k}} q^{-\frac{k+1}{k}}$$

As $k>1$, $1-F(z_0)>0$, so $\frac{\partial^2 \prod}{\partial q^2}<0$. Namely, $\prod$ is strictly concave function of q. Hence, the optimal order quantity of supply chain system is:

$$q^* = (z_0 a\theta)(\frac{1-F(z_0)}{(1-\frac{k(1-F(z_0))}{k-1})(c_t+(b_A+b_B)(1-\beta)) - \frac{k(1-F(z_0))}{k-1}g + c_r + \frac{c_d+c_t+c_m}{\beta}})^k \quad (6)$$

Optimal retail price is:

$$p^* = \frac{(1-\frac{k(1-F(z_0))}{k-1})(c_t+(b_A+b_B)(1-\beta)) - \frac{k(1-F(z_0))}{k-1}g + c_r + \frac{c_d+c_t+c_m}{\beta}}{1-F(z_0)} \quad (7)$$

Definition 1[19] If a contract makes the optimal solution of the supply chain Nash break-even point of all members' decisions in the system, the supply chain is deemed to be coordinate under the contract mechanism. Namely, members of supply chain maximize system profit while pursuing respective profit maximization and both parties cannot erode the other party's interest to obtain more interests.

Lemma 2[20] If profit function of members of supply chain is affinity function of profit function of supply chain system, the supply chain is deemed to be coordinated under option contract.

For φ_1, $\varphi_2 \ge 0$, $\varphi_1+\varphi_2 \le 1$, when w_A, b_A, w_B and b_B satisfy the following conditions:

$$\begin{cases} p-b_A+g_r = \varphi_1(p+c_t+(b_A+b_B)(1-\beta)+g) \\ w_A-b_A+g_r = \varphi_1(c_r+\frac{c_d+c_m}{\beta}+c_t(1+\frac{1}{\beta})+(b_A+b_B)(1-\beta)) \end{cases} \quad (8)$$

$$\begin{cases} b_A(2-\beta)-b_B+c_t+g_d = \varphi_2(p+c_t+(b_A+b_B)(1-\beta)+g) \\ b_A(2-\beta)-w_A-b_B+\frac{w_B+c_d}{\beta}+(1+\frac{1}{\beta})c_t = \varphi_2(c_r+\frac{c_d+c_m}{\beta}+c_t(1+\frac{1}{\beta})+(b_A+b_B)(1-\beta)) \end{cases} \quad (9)$$

We can get:

$$
\begin{aligned}
\prod_r &= (p - b_A + g_r)S(q) - (w_A - b_A + c_r)q - g_r\mu \\
&= \varphi_1(p + c_t + (b_A + b_B)(1-\beta) + g)S(q) - \varphi_1(c_r + \frac{c_d + c_m}{\beta} + c_t(1+\frac{1}{\beta}) + (b_A + b_B)(1-\beta))q - g_r\mu \\
&= \varphi_1 \prod + \mu(\varphi_1 g - g_r)
\end{aligned}
$$

$$
\begin{aligned}
\prod_d &= (b_A(2-\beta) - b_B + c_t + g_d)S(q) - (b_A(2-\beta) - b_B - w_A - \frac{w_B + c_d}{\beta} - c_t(1+\frac{1}{\beta}))q - g_d\mu \\
&= \varphi_2(p + c_t + (b_A + b_B)(1-\beta) + g)S(q) - \varphi_2(c_r + \frac{c_d + c_m}{\beta} + c_t(1+\frac{1}{\beta}) + (b_A + b_B)(1-\beta))q - g_d\mu \\
&= \varphi_2 \prod + \mu(\varphi_2 g - g_d)
\end{aligned}
$$

$\prod_m = (1-(\varphi_1+\varphi_2))\prod + \mu((1-(\varphi_1+\varphi_2))g - g_m)$ It shows that expected profit function of members of supply chain is based on affinity function of profit function of the supply chain system. Hence, the buy back contract can achieve coordination of supply chain.

IMPACT OF DISRUPTIONS ON SUPPLY CHAIN

For coordinated supply chain system, prior to selling season, members of supply chain will formulate optimal order quantity q^* according to the buyback contract and formulate corresponding production plan accordingly. However, certain factors will cause change to market conditions. Prior to selling season, disruptions occur, causing change to distribution function of perturbation factor ε and $F(x)$ turns to $G(x)$ ($G(x)$ can be also increased slightly and strictly, $G(0)=0$). At the same time, suppose the density function of ε after disruptions is $g(x)$ and variation quantity of μ_ε is $\Delta\mu_\varepsilon$. Variation of $G(x)$ may cause change to order quantity of the retailer. Therefore, it deviates from original production plan of the manufacturer and production plan shall be adjusted effectively. Thus, extra expense is required.

Under new distribution function, optimal inventory factor z_0 is introduced like lemma 1, then expected sales volume is $S_G(q) = q\frac{k(1-G(z_0))}{k-1}$, expected period-end inventory $I_G(q) = q - S_G(q)$ and expected period-end stock-out quantity $L_G(q) = \mu - S_G(q)$, loss of buy back product in the process of backhaul $b_A(1-\beta)I_G(q)$, backhaul cost $c_t I_G(q)$, buy back contract provided by the distributor for the retailer $T_A = w_A q - b_A I_G(q)$, buy back contract provided by the manufacturer for the distributor $T_B = \frac{w_B q}{\beta} - b_B I_G(q)$.

Expected profit function of the retailer is:

$$
\begin{aligned}
\tilde{\prod}_r &= pE_G\{\min(d,q)\} - c_r q - T_A - g_r L_G(q) = (p - b_A + g_r)S_G(q) - (w_A - b_A + c_r)q - g_r\mu_G \\
&= ((\frac{z_0 a}{\ln 2}\ln(2-\frac{t}{T}))^{\frac{1}{k}} - \frac{b_A - g_r}{q^{-\frac{1}{k}}})q^{1-\frac{1}{k}}\frac{k(1-G(z_0))}{k-1} - (w_A - b_A + c_r)q - g_r\mu_G \qquad \textbf{(10)}
\end{aligned}
$$

Expected profit function of the distributor is:

$$
\begin{aligned}
\tilde{\prod}_d &= T_A - T_B - b_A(1-\beta)I_G(q) - c_t I_G(q) - g_d L_G(q) - \frac{(c_d + c_t)q}{\beta} \\
&= (b_A(2-\beta) - b_B + c_t + g_d)S_G(q) - (b_A(2-\beta) - b_B - w_A + \frac{w_B + c_d}{\beta} + c_t(1+\frac{1}{\beta}))q - g_d\mu_G \\
&= (b_A(2-\beta) - b_B + c_t + g_d)q\frac{k(1-G(z_0))}{k-1} - (b_A(2-\beta) - b_B - w_A + \frac{w_B + c_d}{\beta} + c_t(1+\frac{1}{\beta}))q - g_d\mu_G \qquad \textbf{(11)}
\end{aligned}
$$

Expected profit function of the manufacturer is:

$$
\begin{aligned}
\tilde{\prod}_m &= T_B - \frac{c_m q}{\beta} - b_B I_G(q)(1-\beta) - g_m L_G(q) - \lambda_1(q-q^*)^+ - \lambda_2(q^*-q)^+ \\
&= (b_B(2-\beta) + g_m)S_G(q) + (\frac{w_B - c_m}{\beta} - b_B(2-\beta))q - g_m\mu_G - \lambda_1(q-q^*)^+ - \lambda_2(q^*-q)^+ \\
&= (b_B(2-\beta) + g_m)q\frac{k(1-G(z_0))}{k-1} + (\frac{w_B - c_m}{\beta}w_A - b_B(2-\beta))q - g_m\mu_G - \lambda_1(q-q^*)^+ - \lambda_2(q^*-q)^+ \qquad \textbf{(12)}
\end{aligned}
$$

Expected profit of the supply chain is:

$$\tilde{\Pi} = pE_G\{\min(d,q)\} - (c_t + (b_A + b_B)(1-\beta))I_G(q) \ -gL_G(q) - (c_r + \frac{c_d + c_t + c_m}{\beta})q - \lambda_1(q-q^*)^+ - \lambda_2(q^*-q)^+$$
$$= (p + c_t + (b_A + b_B)(1-\beta) + g)S_G(q) - (c_r + \frac{c_d + c_m}{\beta} + c_t(1+\frac{1}{\beta}) + (b_A + b_B)(1-\beta))q - g\mu_G$$
$$-\lambda_1(q-q^*)^+ - \lambda_2(q^*-q)^+$$
$$= ((z_0 a\theta)^{\frac{1}{k}} + \frac{c_t + (b_A + b_B)(1-\beta) + g}{q^{-\frac{1}{k}}})q^{1-\frac{1}{k}} \times \frac{k(1-G(z_0))}{k-1} - (c_r + \frac{c_d + c_m}{\beta} + c_t(1+\frac{1}{\beta}) + (b_A + b_B)(1-\beta))q$$
$$-g\mu_G - \lambda_1(q-q^*)^+ - \lambda_2(q^*-q)^+ \quad \textbf{(13)}$$

Where, $(x)^+ = \max(0,x)$, $\lambda_1, \lambda_2 > 0$. The two latter items are extra costs brought by destroy of original plan. When λ_1 is $q > q^*$, unit product brought to manufacturer by production shall be increased. When λ_2 is $q < q^*$, it is unit cost brought by disposal of residual product by the manufacturer.

Disruptions may cause market size to increase (or decrease). Namely, for any $q \geq 0$, $\bar{G}(z) \geq \bar{F}(z)$ (or $\bar{G}(z) \leq \bar{F}(z)$). Then, we consider the impact of variation of market size on optimal order quantity of supply chain. Suppose optimal order quantity under disruptions is $\bar{q}$, namely, $\bar{q} = \arg\max_{q\geq 0} \tilde{\Pi}$.

Lemma 3 If disruptions cause market size to increase, namely: $\bar{G}(z) \geq \bar{F}(z)$, for randomly determined transport time t, $\bar{q} \geq q^*$ ($q \geq 0$);If disruptions cause market size to decrease, namely: $\bar{G}(z) \leq \bar{F}(z)$, for randomly determined transport time t $\bar{q} \leq q^*$ ($q \geq 0$).

Prove: proof by contradiction is used. Suppose disruptions cause market size to increase and t is determined, assume $\bar{q} \leq q^*$ contrarily, then the necessary and sufficient condition that $\bar{q}$ is the solution to formula (12) is that $\bar{q}$ is the solution to $\arg\max_{q\geq 0} \tilde{\Pi}$, namely, $\bar{q} = \arg\max_{q\geq 0} \tilde{\Pi}$, where

$$\tilde{\Pi} = ((z_o a\theta)^{\frac{1}{k}} + \frac{c_t + (b_A + b_B)(1-\beta) + g}{q^{-\frac{1}{k}}})q^{1-\frac{1}{k}} \frac{k(1-G(z_o))}{k-1} - (c_r + \frac{c_d + c_m}{\beta} + c_t(1+\frac{1}{\beta})$$
$$+(b_A + b_B)(1-\beta))q - g\mu_G - \lambda_2(q^* - q) \quad \textbf{(14)}$$
$$\frac{\partial^2 \tilde{\Pi}}{\partial q^2} = -\frac{1}{k}(1-G(z_0))(z_0 a\theta)^{\frac{1}{k}} q^{-\frac{k+1}{k}}$$

As $k > 1$, $1 - G(z_0) > 0$, so $\frac{\partial^2 \tilde{\Pi}}{\partial q^2} < 0$,namely, Π is strictly concave function of q. So there exists optimal q to make $\tilde{\Pi}$ maximum and the following conditions are satisfied:

$$\bar{q} = (z_0 a\theta)(\frac{1-G(z_0)}{(1-\frac{k(1-G(z_0))}{k-1})(c_t + (b_A + b_B)(1-\beta)) - \frac{k(1-G(z_0))}{k-1}g + c_r + \frac{c_d + c_t + c_m}{\beta} - \lambda_2})^k$$
$$> (z_0 a\theta)(\frac{1-G(z_0)}{(1-\frac{k(1-G(z_0))}{k-1})(c_t + (b_A + b_B)(1-\beta)) - \frac{k(1-G(z_0))}{k-1}g + c_r + \frac{c_d + c_t + c_m}{\beta}})^k$$
$$> (z_0 a\theta)(\frac{1-F(z_0)}{(1-\frac{k(1-G(z_0))}{k-1})(c_t + (b_A + b_B)(1-\beta)) - \frac{k(1-G(z_0))}{k-1}g + c_r + \frac{c_d + c_t + c_m}{\beta}})^k$$
$$> (z_0 a\theta)(\frac{1-F(z_0)}{(1-\frac{k(1-F(z_0))}{k-1})(c_t + (b_A + b_B)(1-\beta)) - \frac{k(1-F(z_0))}{k-1}g + c_r + \frac{c_d + c_t + c_m}{\beta}})^k$$
$$= q^*$$

It contradicts $\bar{q} < q^*$. So $\bar{q} > q^*$. Similarly, another conclusion can be proved.

COORDINATED RESPONSE TO DISRUPTIONS

Disruptions cause change to distribution function of perturbation factor ε , thus causing market demand to change and the supply chain needs to increase new cost to cope with change of market demand and optimal order strategy of the supply chain also changes. Response of supply chain to disruptions is discussed below.

Theorem 1 When disruptions cause size of market demand to change, optimal order quantity of the supply chain system is

$$\bar{q}=\begin{cases}(z_0a\theta)\left(\dfrac{1-G(z_0)}{(1-\frac{k(1-G(z_0))}{k-1})(c_t+(b_A+b_B)(1-\beta))-\frac{k(1-G(z_0))}{k-1}g+c_r+\frac{c_d+c_t+c_m}{\beta}+\lambda_1}\right)^k & if \quad q>q^* \\ q^* & other \\ (z_0a\theta)\left(\dfrac{1-G(z_0)}{(1-\frac{k(1-G(z_0))}{k-1})(c_t+(b_A+b_B)(1-\beta))-\frac{k(1-G(z_0))}{k-1}g+c_r+\frac{c_d+c_t+c_m}{\beta}-\lambda_2}\right)^k & if \quad q<q^*\end{cases} \tag{15}$$

Optimal retail price of the supply chain system is:

$$\bar{p}=\begin{cases}\dfrac{(1-\frac{k(1-G(z_0))}{k-1})(c_t+(b_A+b_B)(1-\beta))-\frac{k(1-G(z_0))}{k-1}g+c_r+\frac{c_d+c_t+c_m}{\beta}+\lambda_1}{1-G(z_0)} & if \quad q>q^* \\ p^* & other \\ \dfrac{(1-\frac{k(1-G(z_0))}{k-1})(c_t+(b_A+b_B)(1-\beta))-\frac{k(1-G(z_0))}{k-1}g+c_r+\frac{c_d+c_t+c_m}{\beta}-\lambda_2}{1-G(z_0)} & if \quad q<q^*\end{cases} \tag{16}$$

Prove: if $q>q^*$, profit function of the supply

$$\begin{aligned}\tilde{\Pi}_1=&((z_0a\theta)^{\frac{1}{k}}+\frac{c_t+(b_A+b_B)(1-\beta)+g}{q^{-\frac{1}{k}}})q^{1-\frac{1}{k}}\frac{k(1-G(z_0))}{k-1}-(c_r+\frac{c_d+c_m}{\beta}+c_t(1+\frac{1}{\beta})\\&+(b_A+b_B)(1-\beta))q-g\mu_G-\lambda_1(q-q^*)\end{aligned} \tag{17}$$

As the second derivative of $\tilde{\Pi}_1$

$$\frac{\partial^2\tilde{\Pi}_1}{\partial q^2}=-\frac{1}{k}(1-G(z_0))(z_0a\theta)^{\frac{1}{k}}q^{-\frac{k+1}{k}}<0\,,$$

So $\tilde{\Pi}_1$ is strictly concave function concerning q . With optimality condition of the first order, then

$$\bar{q}=(z_0a\theta)\left(\frac{1-G(z_0)}{(1-\frac{k(1-G(z_0))}{k-1})(c_t+(b_A+b_B)(1-\beta))-\frac{k(1-G(z_0))}{k-1}g+c_r+\frac{c_d+c_t+c_m}{\beta}+\lambda_1}\right)^k$$

Hence, corresponding optimal retail price can be obtained.

The other two conclusions can be proved similarly.

Theorem 2 Disruptions cause market size to change. If original buy back contract $T_A=w_Aq-b_AI(q)$ is adopted, $T_B=\frac{w_Bq}{\beta}-b_BI(q)$, then the supply chain will not be coordinated any more.

Prove: after disruptions, if buy back contract is still adopted, then

$$\tilde{\Pi}_r=pE_G\{\min(d,q)\}-c_rq-T_A-g_rL_G(q)=(p-b_A+g_r)S_G(q)-(w_A-b_A+c_r)q-g_r\mu_G$$

$$= \varphi_1 \tilde{\Pi} + \varphi_1(\lambda_1(q-q^*)^+ + \lambda_2(q^*-q)^+) + \mu_G(\varphi_1 g - g_r)$$

$$\tilde{\Pi}_d = T_A - T_B - b_A(1-\beta)I_G(q) - c_t I_G(q) - g_d L_G(q) - (c_d + c_t)q/\beta$$
$$= (b_A(2-\beta) - b_B + c_t + g_d)S_G(q) - (b_A(2-\beta) - b_B - w_A + \frac{w_B + c_d}{\beta} + c_t(1+\frac{1}{\beta}))q - g_d\mu_G$$
$$= \varphi_2 \tilde{\Pi} + \varphi_2(\lambda_1(q-q^*)^+ + \lambda_2(q^*-q)^+) + \mu_G(\varphi_2 g - g_d)$$

$$\tilde{\Pi}_m = \tilde{\Pi} - \tilde{\Pi}_r - \tilde{\Pi}_d$$
$$= (1-(\varphi_1+\varphi_2))\tilde{\Pi} - (\varphi_2+\varphi_2)(\lambda_1(q-q^*)^+ + \lambda_2(q^*-q)^+) + \mu_G((1-(\varphi_1+\varphi_2))g - g_m)$$

Obviously, after disruptions, expected profit function of members of supply chain is not the affinity function of expected profit function of the supply chain system. From lemma 2, at this time, the supply chain is not coordinated any more.

Theorem 3 Disruptions cause market size to change, adjusted buy back contract $\tilde{T}_A = \tilde{w}_A q - b_A I(q)$, $\tilde{T}_B = \frac{\tilde{w}_B q}{\beta} - b_B I(q)$ are adopted. Where, if $\tilde{w}_A$ and $\tilde{w}_B$ satisfy formula (17), adjusted buy back contract can achieve coordination of supply chain after disruptions.

$$\begin{cases} \tilde{w}_A = w_A + \dfrac{\varphi_1(\lambda_1(q-q^*)^+ + \lambda_2(q^*-q)^+)}{q} \\ \tilde{w}_B = w_B - \dfrac{(\varphi_2-\varphi_1)\beta(\lambda_1(q-q^*)^+ + \lambda_2(q^*-q)^+)}{q} \end{cases} \quad \textbf{(18)}$$

Prove: after disruptions and adjusted buy back contract is adopted, then,

$$\tilde{\Pi}_r = pE_G\{\min(d,q)\} - c_r q - \tilde{T}_A - g_r L_G(q) = (p - b_A + g_r)S_G(q) - (\tilde{w}_A - b_A + c_r)q - g_r\mu_G$$
$$= \varphi_1 \tilde{\Pi} + \mu_G(\varphi_1 g - g_r)$$

$$\tilde{\Pi}_d = \tilde{T}_A - \tilde{T}_B - b_A(1-\beta)I_G(q) - c_t I_G(q) - g_d L_G(q) - \frac{(c_d + c_t)q}{\beta}$$
$$= (b_A(2-\beta) - b_B + c_t + g_d)S_G(q) - (b_A(2-\beta) - b_B - \tilde{w}_A + \frac{\tilde{w}_B + c_d}{\beta} + c_t(1+\frac{1}{\beta}))q - g_d\mu_G = \varphi_2 \tilde{\Pi} + \mu_G(\varphi_2 g - g_d)$$

$$\tilde{\Pi}_m = \tilde{\Pi} - \tilde{\Pi}_r - \tilde{\Pi}_d$$
$$= (1-(\varphi_1+\varphi_2))\tilde{\Pi} + \mu_G((1-(\varphi_1+\varphi_2))g - g_m)$$

We can know that expected profit function of members of supply chain is the affinity function of expected profit function of the supply chain system. Hence, adjusted buy back contract can achieve coordination of supply chain.

NUMERICAL ANALYSIS

This part verifies validity of three-level supply chain coordination of fresh produces with buy back contract response to disruptions.

$d = ap^{-k}\theta \cdot \varepsilon$, $k > 1$, suppose $\varepsilon \in U[1,2]$, $k = 2.5$, $a = 30000$, $c_r = 0.60$, $c_m = 1.25$ and $c_d = 0.36$. At the time of stock-out, $g_r = 0.15$, $g_d = 0.2$, $g_m = 0.3$, then $g = g_r + g_d + g_m = 0.65$. $w_A = 3.2$, $b_A = 0.5$, $w_B = 1.8$, $b_B = 0.25$, $\theta = 0.95$, $\beta = 0.92$, $z_0 = \frac{4}{k+1}$, $\varphi_1 = 0.3$, $\varphi_2 = 0.35$. Then the density distribution of ε is $f(x) = 1/2$ and distribution function $F(x) = \frac{2}{k+1} = \frac{2}{3.5}$. Therefore, density function and distribution function of market demand can be obtained. With optimal retail price and optimal order quantity under expectation definition and stable condition, market expectation demand under stable condition $\mu = 137.336$.

Suppose disruptions make distribution function of perturbation factor ε turn to $G(x) = \frac{2}{k+1} + 0.1 = \frac{47}{70}$ and $G(x) =$

$\frac{2}{k+1}-0.1=\frac{11}{14}$. Where, variations of expectation μ_ε of factor ε are respectively $\Delta\mu_\varepsilon = 0.1$ and $\Delta\mu_\varepsilon = -0.1$. Other factors don't change. Suppose extra expense after perturbation $\lambda_1 = \lambda_2 = 0.2$. Similar to solving method under stable condition, market expectation demand under disruptions $\mu_{G1} = 155.291$, $\mu_{G2} = 114.451$. Related calculation results are shown in TABLE 1.

Seen from TABLE 1, when disruptions cause market demand to increase, the manufacturer will respond to disruptions through increasing production. When disruptions cause market demand to decrease, the manufacturer will respond to disruptions through decreasing production. When market demand perturbs within certain scope, optimal production of the supply chain remains constant. It shows that buy back contract of supply chain under disruptions has certain robustness.

Seen from the TABLE, under two circumstances of disruptions, at the time of response of three-level supply chain of fresh produces to disruptions, after adjusting coordination strategy, total profit of the supply chain is higher than not. It fully indicates that it is effective to respond to disruptions with buy back contract; at the same time, adoption of original contract is likely to make the retailer's profit negative and cause the retailer to quit from the supply chain and destroy the supply chain. It manifests the necessity of adjusting contract to respond to disruptions.

TABLE 1 : Comparison of different contracts adopted before and after disruptions

	Under stable conditions ($\Delta\mu_\varepsilon = 0$)	after disruptions ($\Delta\mu_\varepsilon = 0.1$)		($\Delta\mu_\varepsilon = -0.1$)	
	Original contract	**new contract**	**original contract**	**new contract**	
q	480.565	480.565	543.520	480.565	400.617
p	5.401	5.401	5.141	5.401	5.808
w_A	3..2	3.2	3.207	3.2	3.214
w_B	1.8	1.8	1.794	1.8	1.798
$\prod_r$	124.174	326.741	256.296	-143.543	34.864
$\prod_d$	212.995	241.040	284.035	145.330	157.673
$\prod_m$	308.239	329.440	375.156	279.408	240.206
$\prod$	645.408	897.221	915.487	281.285	432.743

CONCLUSIONS

The paper researched optimal coping strategy to disruptions with three-level supply chain of fresh produces interfered by random factors and the following conclusions can be drawn after summarizing related discussion in the paper:

Buy back contract can effectively coordinate the supply chain of three-level fresh produces and has strong robustness. Coordination of supply chain can be achieved by adjusting the contract parameters.

As calculation of inventory factor is established on the basis of accurate prediction of distribution functions F and G of random factor ε, the supply chain needs to increase operation cost to make members of supply chain to accurately predict distribution of perturbation factors and achieve coordination response to disruptions.

The paper only considers the impact on supply chain when freshness and loss ratio of fresh produces within transport time is a constant value. Next, response to disruptions by the supply chain at the time of sudden change of freshness and loss ratio of produces within order cycle time can be researched. At the same time, the paper only considers information symmetry among manufacturer, distributor and retailer and neutral risk among all parties. However, in reality, information asymmetry in the process of production, supply and marketing of fresh produces can be found everywhere, bringing enormous loss to fresh produces and huge difficulty to supply chain management. Hence, under circumstance of information asymmetry, emergency coordination for supply chain of risk preference of supply chain subject will be the research direction in the future.

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