Research on Dynamic Pricing and Ordering Policy of Fresh Agriculture Product Considering Consumers' Perceived Quality

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***Abstract*--In this article, we first formulated the demand function of price and quality. Then we analyzed the order quantity and the pricing decision under the single price markdown condition and the multiple price markdown condition respectively. We find that under the single price markdown condition and the multiple price markdown condition, the fresh agricultural products with different consumers' perceived quality elasticity should make the different optimal ordering quantity and optimal pricing decision.**

Keywords-fresh agriculture product; consumers' perceived quality; price discount; ordering quantity

I INTRODUCTION

Many scholars researched on fresh product pricing and ordering policy. Karen etc. [1] pointed out that the price is an important strategy for the supermarket. Van Ryzin[2] established a fresh product pricing model based on the demand of the production as random variables. When approaching the shelf life of products, businesses often take discounts to promote the products [3-5]. Cai[6] introduced the ideas and the techniques of the supply chain management to the field of the fresh agricultural produces management. Wang and Li [7] established a consumer utility model which taking into account the price and the freshness of fresh produces with time-varying. This paper focused on the impact of the consumers perceives quality to the fresh agriculture product's optimal ordering quantity and optimal pricing decision.

II MODEL DESCRIPTION

Model assumes:① the products' demand was affected by the price named as p and the consumer perceived quality; ② the fresh degree is related to its shelf time named t ,that is $p = p(t)$;③assuming the q is function of p and t, that is $q = q(p,t)$.

Demand function: $D_t = \varepsilon[y_0 - \alpha p(t) + \beta q_0 \phi(p(t)) e^{-\lambda t}]$

y_0 represents potential market demand; ε represents the degree of demand to realize; $f(x)$ and $F(x)$ is the probability density function and distribution function, and $E(\varepsilon) = 1$; q_0 represents the initial quality of the product, $\phi(p(t)) \in (0,1)$,and assume that $\phi(p(t)) = P(t)/P$; λ :the attenuation degree; β :the perceived quality of products; α :the price elasticity of the products; T :the sales period of fresh products; c_p :the unit changing cost; w :unit wholesale price; r:save rate; c_t :transportation cost per unit h :product inventory cost per unit; Q :the quality of the products' ; $I(t)$:the products' inventory levels at time t ; T_i : the adjustment time of the price ; θ : Price discount.

IIIMODEL ANALYSIS

A. One-Time Price Adjustment Analysis

In order to promote the sales of the goods, sellers often adopt the discounts to attract more customers.

Then $p(t) = p, 0 < t < t_1$; $p(t) = \theta p, t_1 < t < T$

The Inventory model: $\frac{dI_0(t)}{dt} = -D_0$, $D_0 = \varepsilon[y_0 - \alpha p + \beta q_0 e^{-\lambda t}]$, From the initial inventory $I(0) = \gamma Q$,we know that

$$I_0(t) = \gamma Q - \varepsilon(y_0 - \alpha p)t - \varepsilon\beta q_0(1 - e^{-\lambda t})/\lambda \tag{1}$$

$$\frac{dI_1(t)}{dt} = -D_1$$

$$D_1 = \varepsilon(y_0 - \alpha\theta p + \beta q_0 \theta e^{-\lambda t})$$

From $I(t) = 0$, we know that

$$I_1(t) = \varepsilon[(y_0 - \alpha\theta p)(T - t) - \beta q_0 \theta(e^{-\lambda T} - e^{-\lambda t})/\lambda], t_1 < t < T \tag{2}$$

The optimal order quantity

$$Q^* = \beta q_0 \varepsilon[(1 - e^{-\lambda t_1}) + \theta(e^{-\lambda t_1} - e^{-\lambda T})]/\lambda\gamma + \varepsilon\frac{y_0 T - \alpha\theta p(T - t_1)}{\gamma} - \varepsilon\frac{\alpha p t_1}{\gamma} \tag{3}$$

During the sales period T,

$$ED = \int_0^{t_1} D_1 dt + \int_{t_1}^{T} D_2 dt = \varepsilon[(y_0 - \alpha p)t_1 + (y_0 - \alpha\theta p)(T - t_1) + \beta q_0 [(1 - e^{-\lambda t_1}) - \theta(e^{-\lambda T} - e^{-\lambda t_1})]/\lambda] < \gamma Q \tag{4}$$

The retailer's profit:

$$\pi_{r1} = p(t)\int_0^T D(t)dt - (w + c_t)Q - c_p(\gamma Q - \int_0^{t_1} D_0 dt) - h\int_0^{t_1} I_0(t)dt - h\int_{t_1}^{T} I_1(t)dt \tag{5}$$

$$\partial\pi_{r1}\big/\partial\theta = p\varepsilon y_0(T-t_1)+\varepsilon h[\frac{\alpha p(T-t_1)^2}{2}+\frac{1}{\lambda}\beta q_0 e^{-\lambda T}(T-t_1)-\frac{\beta q_0(e^{-\lambda t_1}-e^{-\lambda T})}{\lambda^2}]$$
$$-\varepsilon(h\gamma t_1+c_p\gamma+w+c_t)[\frac{\beta q_0(e^{-\lambda t_1}-e^{-\lambda T})}{\lambda\gamma}-\frac{\alpha p}{\gamma}(T-t_1)]-2\alpha\varepsilon\theta p^2(T-t_1)+2\varepsilon p\beta q_0\theta(e^{-\lambda t_1}-e^{-\lambda T})\big/\lambda \quad (6)$$

$$\partial\pi_{r1}^2\big/\partial\theta^2 = -2\alpha\varepsilon p^2(T-t_1)+2p\beta q_0\frac{(e^{-\lambda t_1}-e^{-\lambda T})}{\lambda}<0 \quad (7)$$

The optimal price discount

$$\theta^* = \frac{2\lambda^2 py_0(T-t_1)+h[\lambda^2\alpha p(T-t_1)^2+2\lambda\beta q_0 e^{-\lambda T}(T-t_1)-2\beta q_0(e^{-\lambda t_1}-e^{-\lambda T})]}{4\lambda^2\alpha p^2(T-t_1)-4\lambda p\beta q_0(e^{-\lambda t_1}-e^{-\lambda T})}$$
$$-\frac{(h\gamma t_1+c_p\gamma+w+c_t)[\beta q_0(e^{-\lambda t_1}-e^{-\lambda T})-\lambda\alpha p(T-t_1)]}{2\alpha\lambda\gamma p^2(T-t_1)-2p\beta q_0\gamma(e^{-\lambda t_1}-e^{-\lambda T})} \quad (8)$$

B. *Several-Times Price Adjustment Analysis*

Assuming the products had a greater damage during the transportation. Retailers' re-pricing remaining products.

The inventory model

$$\frac{dI(t)}{dt} = -D(t) = -\varepsilon(y_0-\alpha p_1+\beta q_1 e^{-\lambda t}) \quad (9)$$

From $I(0)=\gamma Q_1$, we get that

$$I(t)=\gamma Q_1-\varepsilon(y_0-\alpha p_1)t-\varepsilon\beta q_1(1-e^{-\lambda t})\big/\lambda \quad (10)$$

$$Q_1^* = \frac{\varepsilon}{\gamma}[(y_0\varepsilon-\alpha p_1)T+\beta q_1(1-e^{-\lambda T})\big/\lambda] \quad (11)$$

The demand of the fresh products during T is:

$$ED=\int_0^T\varepsilon(y_0-\alpha p_1+\beta q_1 e^{-\lambda t})dt=\varepsilon(y_0\varepsilon-\alpha p_1)T+\varepsilon\beta q_1(1-e^{-\lambda T})\big/\lambda \quad (12)$$

The retailer's profit is:

$$\pi_{r2}=p_1ED-(w+c_t)Q_1-c_p\gamma Q_1-h\int_0^T I(t)dt$$
$$=\varepsilon(p_1-c_p-hT-\frac{w+c_t}{\gamma})[(y_0-\alpha p_1)T+\beta q_1 1-e^{-\lambda T}\big/\lambda]+h\varepsilon[\frac{1}{2}(y_0-\alpha p_1)T^2+\frac{\beta q_1 T}{\lambda}-\frac{\beta q_1(1-e^{-\lambda T})}{\lambda^2}] \quad (13)$$

$$\frac{\partial\pi_{r2}}{\partial p_1}=y_0\varepsilon T+\frac{\varepsilon\alpha T(\gamma c_p+w+c_t)}{\gamma}+\frac{\varepsilon\alpha hT^2}{2}+\varepsilon\beta q_1\frac{1-e^{-\lambda T}}{\lambda}-2\varepsilon\alpha Tp_1\quad \frac{\partial\pi_{r2}^2}{\partial p_1^2}=-2\alpha\varepsilon T<0$$

$$p_1^*=\frac{2\gamma y_0+2\alpha(\gamma c_p+w+c_t)+\alpha\gamma hT}{4\alpha\gamma}+\frac{\beta q_1(1-e^{-\lambda T})}{2\alpha\lambda T} \quad (14)$$

If it has several price adjustment, the demand function is:

$$D_i=\varepsilon(y_0-\alpha p_i+\beta q_0\frac{p_i}{p_0}e^{-\lambda_i t})\quad (t_i<t<t_{i+1}) \quad (15)$$

In order to simplify the calculations, we assume that the time factor of the quality λ_i is the same with λ, and assume $t_0=0$,before the n-th price adjustment we know that $\frac{dI_{n-1}(t)}{dt}=-D_{n-1}$, at the same time $I_0(0)=\gamma Q_1$, $I_0(t_1)=I_1(t_1)$,… $I_{i-1}(t_i)=I_i(t_i)$,so we can obtained that :

$$I_0(t)=\gamma Q_1-\beta q_0\varepsilon/\lambda-\varepsilon[(y_0-\alpha p_0)t-\beta q_0 e^{-\lambda t}/\lambda]\quad 0<t<t_1 \quad (16)$$

$$I_1(t)=\gamma Q_1-\varepsilon(y_0-\alpha p_0)t_1-\varepsilon(y_0-\alpha p_1)(t-t_1)-\frac{\varepsilon\beta q_0}{\lambda}(1-\frac{p_0-p_1}{p_0}e^{-\lambda t_1}-\frac{p_1}{p_0}e^{-\lambda t})\big/\lambda\quad t_1<t<t_2$$

$$I_i(t)=\gamma Q_1-\varepsilon(y_0-\alpha p_i)(t-t_i)-\varepsilon\sum_{k=0}^{i-1}(y_0-\alpha p_k)(t_{k+1}-t_k)-\frac{\varepsilon\beta q_0}{\lambda}(1-\frac{p_i}{p_0}e^{-\lambda t})/\lambda$$
$$+\frac{\varepsilon\beta q_0}{\lambda p_0}\sum_{k=0}^{i-1}(p_k-p_{k+1})e^{-\lambda t_{k+1}}\quad t_i\le t\le t_{i+1} \quad (17)$$

And because $I_n(T)=0$, we can get the optimal order quantity:

$$Q_i^*=\frac{\varepsilon}{\gamma}[\sum_{k=0}^{n-1}(y_0-\alpha p_k)(t_{k+1}-t_k)+(y_0-\alpha p_n)(T-t_n)+\frac{\beta q_0}{\lambda}(1-\frac{p_n}{p_0}e^{-\lambda T})-\frac{\beta q_0}{\lambda p_0}\sum_{k=0}^{n-1}(p_k-p_{k+1})e^{-\lambda t_{k+1}}] \quad (18)$$

The retailer's profit:

$$\pi_{r3}=\sum_{k=0}^{n}p_k ED_k-c_p[n(\gamma Q_1^*-ED_0)-\sum_{k=1}^{n}(n+1-k)ED_k]-h\sum_{k=0}^{n-1}\int_{t_k}^{t_{k+1}}I(t)dt-h\int_{t_n}^{T}I(t)dt-(w+c_t)Q_1^*$$

With respect to p_n are:

$$\partial\pi_{r3}\big/\partial p_n=\varepsilon(y_0-\alpha c_p)(T-t_n)+\frac{\varepsilon\beta q_0 c_p(e^{-\lambda t_n}-e^{-\lambda T})}{\lambda p_0}+\varepsilon h[\frac{\alpha(T-t_n)^2}{2}+\frac{\beta q_0(T-t_n)e^{-\lambda t_n}}{\lambda p_0}-\frac{\beta q_0(e^{-\lambda t_n}-e^{-\lambda T})}{\lambda^2 p_0}]$$
$$+\varepsilon(h\gamma(T-t_n)+nc_p\gamma+w+c_t)[-\frac{\beta q_0(e^{-\lambda t_n}-e^{-\lambda T})}{\lambda\gamma p_0}+\frac{\alpha p_0}{\gamma}(T-t_n)]-2\alpha\varepsilon p_n(T-t_n)+2\varepsilon p_n\beta q_0(e^{-\lambda t_n}-e^{-\lambda T})\big/\lambda p_0 \quad (19)$$

$$\partial\pi_{r3}^2\big/\partial p_n^2=-2\alpha\varepsilon(T-t_n)+2\varepsilon\beta q_0(e^{-\lambda t_1}-e^{-\lambda T})\big/\lambda p_0<0 \quad (20)$$

$$p_n=\frac{2\lambda^2 p_0(y_0-\alpha c_p)(T-t_n)+h\lambda[\alpha\lambda p_0(T-t_n)^2+2\beta q_0(T-t_n)e^{-\lambda t_n}]-2(h-\lambda c_p)\beta q_0(e^{-\lambda t_n}-e^{-\lambda T})}{4\alpha\lambda^2 p_0(T-t_n)-4\lambda\beta q_0(e^{-\lambda t_1}-e^{-\lambda T})}$$
$$+\frac{(h\gamma(T-t_n)+nc_p\gamma+w+c_t)[\lambda p_0\alpha(T-t_n)-\beta q_0(e^{-\lambda t_n}-e^{-\lambda T})]}{2\alpha\lambda\gamma p_0(T-t_n)-2\beta q_0\gamma(e^{-\lambda t_1}-e^{-\lambda T})} \quad (21)$$

IV NUMERICAL EXAMPLE

Assuming that the supermarket have 5 branches. Firstly, we analysis one price adjustment. And parameters involved are as follows: $\varepsilon=0.8$, $\alpha=3$, $\beta=3$, $q_0=1$, $T=10$, $t_1=7$, $w=5$, $c_t=0.7$ $c_t=0.7$, $c_p=0.2$, $h=0.2$, $\theta=0.6$, $\gamma=0.8$, $\lambda=0.005$, $p_0=15$.

We can get the relationship between parameters

$$\theta^*=\frac{76.4p-8}{9p^2-8.6p}-\frac{301.5-45p}{72p^2-69p}$$

$$\theta^*=\frac{0.1125+0.000675\alpha-0.000053\beta}{0.0675\alpha-0.00432}+\frac{0.10051\beta-1.5705}{5.4\alpha-0.3456\beta},$$

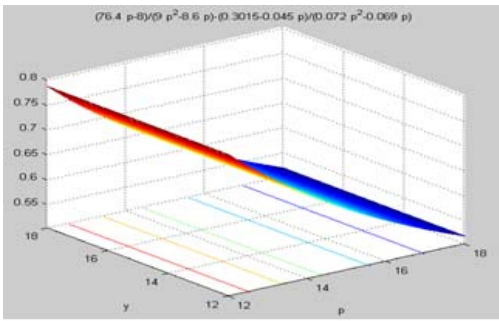

FIGURE I. THE RELATIONSHIP BETWEEN θ^* AND P.

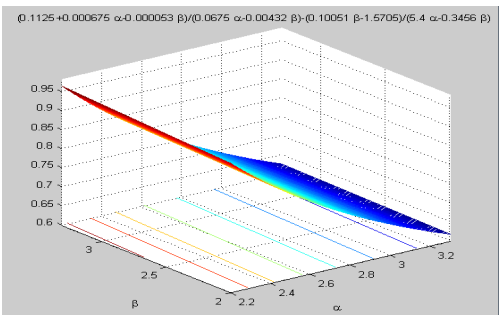

FIGURE II. THE RELATIONSHIP AMONG θ^*, α AND β

As can be seen from the graphics, the relationship between the initial price of the product and θ^* are inversely proportional, the relationship among θ^*, T, t_1 is not particularly evident. In the same way, we can get the relationship between θ^* and the other parameters, Further, we also can analysis the effect of the optimal price discount to distributors' profits. The process of analysis is shown in the following table:

TABLE I. ONE-TIME PRICE ADJUSTMENT.

store	y_0	α	β	Q^*	θ^*	$\Delta\pi$
store1	50	3.2	3.2	192	0.64	30.8
store2	50	3	3	212	0.69	66.2
store3	50	2.8	2.8	231	0.74	105.9
store4	50	2.5	2.5	261	0.83	173.6
store5	50	2.3	2.3	280	0.90	227.1

①With the decrease of the fresh agriculture products' price elasticity and perceived quality elasticity, which indicates that the higher the price elasticity of fresh agricultural products, the lower the retailer's optimal order quantity.②With the decrease of the fresh agriculture products' price elasticity and perceived quality elasticity, the optimal price discount of fresh agricultural products θ^* gradually increased; ③And along with the increase of the θ^* and Q^*.

The analysis of depreciation in several times also can be obtained. Just taking an example for depreciation twice there, and h =0.2.

TABLE II. TWO TIMES PRICE ADJUSTMENT.

store	y_0	α	β	Q^*	p_1	p_2	p_2^*	$\Delta\pi$
store1	50	3.2	3.2	2473	11	5	5.82	30.8
store2	50	3	3	2364	11	5	5.86	66.2
store3	50	2.8	2.8	2255	11	5	5.90	105.9
store4	50	2.5	2.5	2089	11	5	5.97	173.6
store5	50	2.2	2.2	1926	11	5	6.07	227.1

①As the fresh agriculture products' price elasticity and perceived quality elasticity decreased, the optional pricing of fresh agriculture product gradually increased;②with the decrease of the fresh agriculture products' price elasticity and perceived quality elasticity, the optimal order quantity also gradually decrease. ③ under the two times price adjustment, the retailers can obtain different maximum profits under different optimal order quantity Q^* and different optimal price discount p_2^*.

V CONCLUSIONS

We can concluded that:① In the price adjustment of one time and two times, the retailers both have the optimal order quality and optimal price discount; ②The higher of the initial price, the lower of the price discount; ③ The fresh agriculture product 's having higher price elasticity and perceived quality elasticity, should develop the lower price discount.

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