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Agricultural Production Mode Selection With Heterogeneous Customer

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Abstract

This paper constructs agribusiness model of coping strategies in the face of heterogeneous consumer groups with different green agricultural preferences. We assume that agribusiness will make a choice in the three modes of production: green production mode, non-green production mode and hybrid production mode; and consumers get their utility through their own preferences and retail price of the two agricultural products, and then determine to purchase a higher utility agricultural products. We make quantitative analyze on production modes selection, pricing strategy and yield of the two products of green supply chain, and get that the existence of hybrid production mode needs to meet certain conditions, and its presence can lead to higher profits. At the same time, we find that the distribution of heterogeneous customer, ratio of real green agricultural products, the unit cost of green products and the value of the discount factor will have an impact on the production modes selection, and the use of numerical analysis further validate the conclusions.

Key words: Heterogeneous customer; Green agricultural products; Production mode

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INTRODUCTION

With the rapid development of the national economy, the living standard of consumers has been improved and consumers no longer just pursue the satisfaction of daily needs, but begin to pay attention to the quality of life. After the emergence of Hogwash oil, lean meat powder, poisoned rice and other food trust crisis, people pay more and more attention on these food safety issues and the consumption of green agricultural products has become a trend. However, different with the popular situation in other countries, green agricultural products in China faced with various problems and develop slowly. First of all, there is a problem of excessive pricing. From the perspective of agricultural enterprises, in order to deal with those problems such as small target consumers, high supermarket admission fee and other costs, they have to increase sales prices, which lead to that the price of green agricultural products are generally higher than the average price of non-green agricultural products 2-3 times. Though consumers are very willing to pay extra for green agricultural products, but the premium should be maintained at 10%-20%. Secondly, agribusiness is caught in production mode selection including green production mode, non-green production mode and hybrid production mode.

The dilemma of enterprise has aroused wide attention from academic circles. Price strategy is helpful to improve the operation quality and benefit of the supply chain, and realize the coordination of green supply chain. Some scholars put forward the value of the discount factor to represent the price interval that consumers willing to pay more for the green products because they have a preference for it and get the optimal price of green products by discussion, and make the profits of green supply chain to maximize (Zheng et al., 2013; Zhang et al., 2014; Jiao et al., 2007). However, the above papers only research on single production mode, and lack the in-depth analysis of the hybrid production mode. Groznik (2010) constructs a pricing model of store brand and national brand which directly competing with each other, and pointed out that selling the two kinds of products at the same time can improve the negotiation ability of retailer and gain extra profits. Hybrid production mode providing higher profits have become a consensus (Xiao et al., 2010; Wang et al., 2013).

And also in recent years, the distribution of heterogeneous customer has become a major focus among strategy researchers and practitioners as an essential element of a firm's competitive strategy.

We show that it is imperative for managers to know whether customers are price or lead time sensitive based on the simultaneous dependence of price and demand on delivery time before selecting a time-based competitive strategy. Considering consumer heterogeneity in product attribute preferences and scholars find that the equilibrium outcome depends on the cost efficiencies of the production technologies as well as the consumer sensitivity to product fit (Ray, 2004). Also, the research finds the exists of heterogeneous customer relieves the price pressure for the firm as it satisfies consumer needs better and enables higher price premiums (Xia et al., 2009).

In view of the above problems, we introduce the assumptions of the model and its rationality in the second part. And we discuss the profits of three production models under centralized and decentralized conditions in the next three parts. Furthermore, we analyze the effects of parameters on production mode selection and make numerical analysis in the next two parts.

1. MODEL DEVELOPMENT AND ANALYSIS

Using Chiang et al. (2003) and Zhang et al. (2014) for reference, we denote the consumers' value for green agricultural products by , and let $\theta_v(0<\theta<1)$ denote the consumers' valuation for non-green agricultural products. Moreover, we assume v is subject to uniform distribution of [0,1], and has a continuous probability density function, $f(v)$, and a cumulative distribution function, $f(v)$. At the market, the retailer sells the green agricultural products at retail price, and the non-green agricultural products is sold at retail price . Therefore, a consumer's utility by buying green agricultural products is given as

$$U_g=v\text{-}P_g, \quad (1)$$

and the utility that a consumer buys agricultural products is described as

$$U_n=\theta v\text{-}P_n. \quad (2)$$

Considering the heterogeneity of customer problems, assuming that in the market there is some consumers hold a questioning attitude to green agricultural products which accounted for, and the other consumers believe that green agricultural products are all green agricultural products really which accounted for, thus we can know consumers can be divided as follows:

α: $$U_g=k(v\text{-}P_g)+(1\text{-}k)(\theta v\text{-}P_g),$$ $$U_n=\theta v\text{-}P_n.$$

$1\text{-}\alpha$: $$U_g=v\text{-}P_g,$$ $$U_n=\theta v\text{-}P_n.$$

We assume that agricultural enterprise offers supermarket the green and non-green agricultural products at w_g and w_n, and the unit cost of green agricultural products is C_g, and the unit cost of non-green agricultural products is zero, while the rest of the processing cost is zero. In addition, we assume that the two kinds of agricultural products the unit consumption on the production capacity is equal, and the above information for the members of the whole supply chain is a total information.

According to the above assumptions, in the market there are two kinds of consumers, and some consumers will buy green agricultural products for the utility it brought is greater than zero and greater than the non-green agricultural products brought; and the other part of consumers will buy non-green agricultural products for similar reason. The relationship between consumer utility and demand is illustrated in Figure 1.

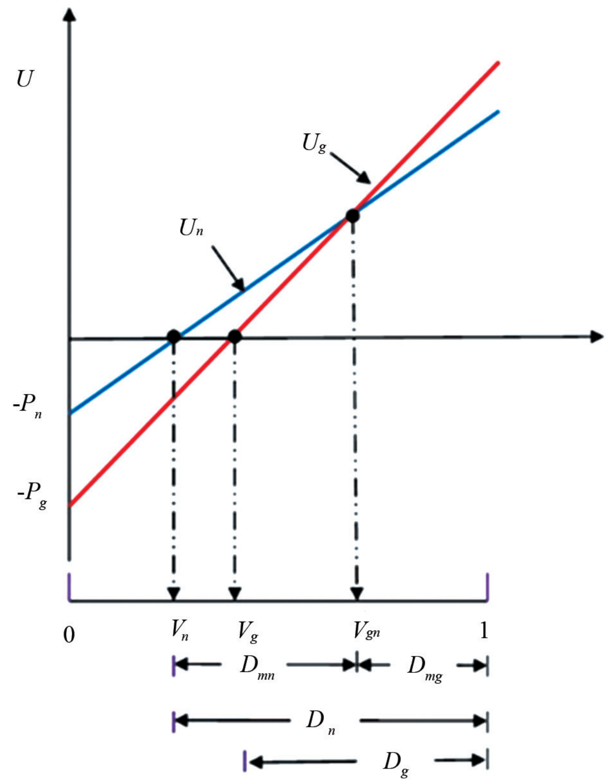

Figure 1
The Relationship Between Consumer Utility and Demand

The agricultural enterprises supplies the green and non-green agricultural products to the retailer at a wholesale price, w_g and w_n, and incurs a unit cost, C_g and 0, respectively. In addition, we assume that $C_n \le \theta$. We assume that the agricultural enterprise is the leader of the Stackelberg game, and the order of this decision model is as follows: Agricultural enterprise first determines the wholesale price as the demand forecasted in the market considered, then the supermarket determines the retail price according to the determined wholesale price. The decision model is to get the optimal production mode and sale prices at the condition that every member in the supply chain gain its optimal profits. The retailer's profits are determined by

$$\pi_r=D_g\,(P_g-\omega_g)+D_n\,(P_n-\omega_n)\ ,$$

The agricultural enterprises' profits are determined by

$$\pi_s=D_g\,(\omega_g-C_g)+D_n\,\omega_n.$$

2. SINGLE GREEN PRODUCTION MODE (GM)

In the case of producing single green agricultural products, we consider the sequential decision model of supply chain of the agricultural enterprise and supermarket. For the part customers who have the questioned attitude to green agricultural products, the utility that green agricultural products bring is $U_g=k(v-P_g)+(1-k)(\theta v-P_g)$; and for the other $\beta=1-\alpha$ part hold firmly believe attitude of green agricultural products, the utility of green agricultural products is $U_g=v-P_g$; the two parts of the customers will buy green agricultural products only in the condition that the utility of green agricultural products is positive, then we can get the demand of green agricultural products as follows:

$$D_g=\alpha D_{g\alpha}+\beta D_{g\beta}$$

in which

$$D_{g\alpha}=1\times\int_{\frac{P_g}{k+(1-k)\theta}}^{1}1\,dv=1-\frac{P_g}{k+(1-k)\theta},$$

$$D_{g\beta}=1\times\int_{P_g}^{1}1\,dv=1-P_g\,.$$

We first consider the centralized decision-making model, the optimal pricing strategy of green agricultural products in the perspective of supply chain:

Max

$$\text{Max}\ \ \pi_{sc}=D_g(P_g-C_g)=\left(\alpha\left(1-\frac{P_g}{k+(1-k)\theta}\right)+(1-\alpha)(1-P_g)\right)(P_g-C_g)$$

we have

$$\frac{\partial\pi_{sc}^{GC}}{\partial P_g}=1-\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)(2P_g-C_g),$$

$$\frac{\partial^2\pi_{sc}^{GC}}{\partial {P_g}^2}=-2\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)<0,$$

which shows that π_{sc}^{GC} is concave in P_g , then it is obvious that

$$P_g^*=\frac{k+(1-k)\theta}{2\alpha+2(1-\alpha)(k+(1-k)\theta)}+\frac{C_g}{2}$$

satisfy the first order conditions, therefore we have

$$D_g^*=\frac{1-C_g+\alpha C_g}{2}-\frac{\theta+\alpha C_g}{2(k+(1-k)\theta)}$$

and the profit of the whole supply chain is

$$\pi_{sc}^{GC}=\frac{\big(k+(1-k)\theta-\big(\alpha+(1-\alpha)(k+(1-k)\theta)\big)C_g\big)^2}{4(k+(1-k)\theta)\big(\alpha+(1-\alpha)(k+(1-k)\theta)\big)}.$$

Furthermore, in decentralized decision making model, we obtain the following sequential decision model:

$$\text{Max}\ \ \pi_s^{GD}=\left(1-\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)P_g\right)(\omega_g-C_g)$$

$$\begin{cases}\pi_m^{GD}=\left(1-\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)P_g\right)(P_g-\omega_g)\\ 0<\omega_g<P_g<1\end{cases}.$$

Proposition 1. *In decentralized decision making model, the corresponding optimal profits of the supermarket, the agricultural enterprise and the whole supply chain are:*

$$\pi_m^{GD*}=\frac{\big(k+(1-k)\theta-\big(\alpha+(1-\alpha)(k+(1-k)\theta)\big)C_g\big)^2}{16(k+(1-k)\theta)\big(\alpha+(1-\alpha)(k+(1-k)\theta)\big)},$$

$$\pi_s^{GD*}=\frac{\big(k+D(1-k)\theta-\big(\alpha+(1-\alpha)(k+(1-k)\theta)\big)C_g\big)^2}{8(k+(1-k)\theta)\big(\alpha+(1-\alpha)(k+(1-k)\theta)\big)},$$

$$\pi_{SC}^{GD*}=\frac{3\big(k+(1-k)\theta-\big(\alpha+(1-\alpha)(k+(1-k)\theta)\big)C_g\big)^2}{16(k+(1-k)\theta)\big(\alpha+(1-\alpha)(k+(1-k)\theta)\big)}.$$

3. SINGLE NON-GREEN PRODUCTION MODE (NM)

In the case of producing single non-green agricultural products, we consider the sequential decision model of supply chain of the agricultural enterprise and supermarket. For the α part customers who have the questioned attitude to non-green agricultural products, the utility that non-green agricultural products bring is equivalent to the utility of the other $\beta=1-\alpha$ part hold firmly believe attitude of green agricultural products, which is $U_n=\theta v-P_n$; the two parts of the customers will buy green agricultural products only in the condition that the utility of non-green agricultural products is positive, then we can get the demand of non-green agricultural products as follows:

$$D_n=\alpha D_{n\alpha}+\beta D_{n\beta}$$

in which $D_{n\alpha}=D_{n\beta}=1\times\int_{\frac{P_n}{\theta}}^{1}1\,dv=1-\frac{P_n}{\theta}$.

We first consider the centralized decision-making model, the optimal pricing strategy of non-green agricultural products in the perspective of supply chain:

$$\text{Max}\pi_{SC}^{NC}=D_nP_n=\left(1-\frac{P_n}{\theta}\right)P_n.$$

We have $\frac{\partial\pi_{SC}^{NC}}{\partial P_n}=1-\frac{2P_n}{\theta}$, $\frac{\partial^2\pi_{SC}^{NC}}{\partial {P_n}^2}=-\frac{2}{\theta}<0$, which shows that π_{SC}^{NC} is concave in P_n, then it is obvious that $P_n^*=\frac{\theta}{2}$ satisfy the first order conditions, therefore we have $D_n^*=\frac{1}{2}$ and the profit of the whole supply chain is $\pi_{sc}^{NC}=\frac{\theta}{4}$.

Furthermore, in decentralized decision making model, we obtain the following sequential decision model:

$$\text{Max}\pi_s^{NC} = \left(1 - \frac{P_n}{\theta}\right)\omega_n.$$

$$\begin{cases}\pi_m^{NC} = \left(1 - \frac{P_n}{\theta}\right)(P_n - \omega_n) \\ 0 < \omega_n < P_n < 1\end{cases}.$$

Proposition 2. *In decentralized decision making model, the corresponding optimal profits of the supermarket, the agricultural enterprise and the whole supply chain are:*

$$\pi_m^{ND*} = \frac{\theta}{16},\ \pi_s^{ND*} = \frac{\theta}{8},\ \pi_{SC}^{ND*} = \frac{3\theta}{16}.$$

4. HYBRID PRODUCTION MODE (HM)

We consider the sequential decision-making model in the food supply chain consist with supermarket and agricultural enterprise under the condition of producing green and non-green agricultural products at the same time. For the part customers who have the questioned attitude to green agricultural products, they will buy green agricultural products only in the condition that the utility of green agricultural products is positive and bigger than that the utility of non-green agricultural products, which is $U_{g\alpha}>U_{n\alpha}$ and $U_{g\alpha}=k(v-P_g)+(1-k)(\theta_v-P_g)>0$, while $U_{n\alpha}=\theta_v-P_n$, then we can get the demand of green agricultural products as follows:

$$D_{g\alpha} = 1 \times \int_{\frac{P_g-P_n}{(1-\theta)k}}^{1} 1\,dv = 1 - \frac{P_g - P_n}{(1-\theta)k}.$$

In the same way we can know the demand of non-green agricultural products in the hybrid mode:

$$D_{n\alpha} = 1 \times \int_{\frac{P_n}{\theta}}^{\frac{P_g-P_n}{(1-\theta)k}} 1\,dv = \frac{P_g - P_n}{(1-\theta)k} - \frac{P_n}{\theta}.$$

And for the other β=1-α part hold firmly believe attitude of green agricultural products, we have

$$D_{g\beta}=1 \times \int_{\frac{P_g-P_n}{1-\theta}}^{1} 1\,dv = 1 - \frac{P_g-P_n}{1-\theta},$$

$$D_{n\beta}=1 \times \int_{\frac{P_n}{\theta}}^{\frac{P_g-P_n}{1-\theta}} 1\,dv = \frac{P_g-P_n}{1-\theta} - \frac{P_n}{\theta}.$$

It can be known that the demand of green and non-green agricultural products in hybrid mode are as follows:

$$\begin{cases} D_g = 1 - \dfrac{(P_g - P_n)(k + \alpha - \alpha k)}{(1-\theta)k} \\ D_n = \dfrac{(P_g - P_n)(k + \alpha - \alpha k)}{(1-\theta)k} - \dfrac{P_n}{\theta}\end{cases}.$$

We first consider the optimal pricing strategy of green and non-green agricultural products under the centralized decision-making model:

$$\text{Max}\ \pi_{sc}^{HC} = D_g(P_g - C_g) + D_n P_n,$$

we have

$$\frac{\partial \pi_{sc}^{HC}}{\partial P_g} = 1 - \frac{2P_g - 2P_n - C_g}{(1-\theta)k}(k + \alpha - \alpha k),$$

$$\frac{\partial \pi_{sc}^{HC}}{\partial P_n} = \frac{2P_g - 2P_n - C_g}{(1-\theta)k}(k + \alpha - \alpha k) - \frac{2P_n}{\theta},$$

$$\frac{\partial^2 \pi_{sc}^{HC}}{\partial P_g \partial P_n} = \frac{2(k+\alpha-\alpha k)}{(1-\theta)k}, \frac{\partial^2 \pi_{sc}^{HC}}{\partial {P_g}^2} = -\frac{2(k+\alpha-\alpha k)}{(1-\theta)k},$$

$$\frac{\partial^2 \pi_{sc}^{HC}}{\partial P_n \partial P_g} = \frac{2(k+\alpha-\alpha k)}{(1-\theta)k},$$

$$\frac{\partial^2 \pi_{sc}^{HC}}{\partial {P_n}^2} = -\frac{2(k+\alpha-\alpha k)}{(1-\theta)k} - \frac{2}{\theta},$$

and hessian matrix is

$$H(P_g, P_n) = \begin{Bmatrix} \dfrac{\partial^2 \pi_{sc}^{HC}}{\partial {P_g}^2} & \dfrac{\partial^2 \pi_{sc}^{HC}}{\partial P_g \partial P_n} \\ \dfrac{\partial^2 \pi_{sc}^{HC}}{\partial P_n \partial P_g} & \dfrac{\partial^2 \pi_{sc}^{HC}}{\partial {P_n}^2}\end{Bmatrix}.$$

While

$$\frac{\partial^2 \pi_{sc}^{HC}}{\partial {P_g}^2} = -\frac{2(k+\alpha-\alpha k)}{(1-\theta)k} < 0.$$

And

$$\begin{vmatrix} \dfrac{\partial^2 \pi_{sc}^{HC}}{\partial {P_g}^2} & \dfrac{\partial^2 \pi_{sc}^{HC}}{\partial P_g \partial P_n} \\ \dfrac{\partial^2 \pi_{sc}^{HC}}{\partial P_n \partial P_g} & \dfrac{\partial^2 \pi_{sc}^{HC}}{\partial {P_n}^2}\end{vmatrix} = \frac{4(k+\alpha-\alpha k)}{(1-\theta)\theta k} > 0.$$

so we can see that hessian matrix is negative definite matrix. We have

$$P_g^* = \frac{(1-\theta)k}{2(k+\alpha-\alpha k)} + \frac{\theta + C_g}{2},$$

$$P_n^* = \frac{\theta}{2},$$

$$\pi_{sc}^{HM*} = \frac{\theta}{4} + \frac{\left((1-\theta)k - (k+\alpha-\alpha k)C_g\right)^2}{4(k+\alpha-\alpha k)k(1-\theta)}.$$

Furthermore, in decentralized decision making model, we obtain the following sequential decision model:

$$\pi_s^{HD} = D_g(w_g - C_g) + D_n w_n$$

$$\text{s.t.}\begin{cases}\pi_m^{HD} = D_g(P_g - w_g) + D_n(P_n - w_n) \\ 0 < w_g < P_g < 1,\ 0 < w_n < P_n < 1\end{cases}.$$

Proposition 3. *In decentralized decision making model, the corresponding optimal profits of the supermarket, the agricultural enterprise and the whole supply chain are:*

$$\pi_m^{HD*} = \frac{\theta}{16} + \frac{\left((1-\theta)k - (k+\alpha-\alpha k)C_g\right)^2}{16(k+\alpha-\alpha k)k(1-\theta)},$$

$$\pi_s^{HD*} = \frac{\theta}{8} + \frac{\left((1-\theta)k - (k+\alpha-\alpha k)C_g\right)^2}{8(k+\alpha-\alpha k)k(1-\theta)},$$

$$\pi_{SC}^{HD*} = \frac{3\theta}{16} + \frac{3\left((1-\theta)k - (k+\alpha-\alpha k)C_g\right)^2}{16(k+\alpha-\alpha k)k(1-\theta)}.$$

5. EFFECTS OF PARAMETERS ON PRODUCTION MODE SELECTION

In order to analyze the effects of various parameters for production mode selection, we first use the control variable method to focus on the influence of unit production cost with fixed distribution of heterogeneous customer α, ratio of real green agricultural products k and value discount coefficient θ. Thus, we have Proposition4 as follows.

Proposition 4*. When α and θ is fixed, there are:*

(i) *if* $\frac{k+(1-k)\theta}{\alpha+(1-\alpha)(k+(1-k)\theta)} - \sqrt{\frac{(k+(1-k)\theta)\theta}{\alpha+(1-\alpha)(k+(1-k)\theta)}} > C_g > \frac{(1-\theta)k}{k+\alpha-\alpha k}$, *if then hybrid production mode is infeasible and the agricultural enterprise will choose the single green production mode*;

(ii) *if* $0 < C_g < \frac{(1-\theta)k}{k+\alpha-\alpha k}$, *then hybrid production mode is available and the agricultural enterprise will choose the hybrid production mode*;

(iii) *if* $C_g > \frac{(1-\theta)k}{k+\alpha-\alpha k}$ *and* $C_g > \frac{k+(1-k)\theta}{\alpha+(1-\alpha)(k+(1-k)\theta)} - \sqrt{\frac{(k+(1-k)\theta)\theta}{\alpha+(1-\alpha)(k+(1-k)\theta)}}$, *hybrid production mode is infeasible and the agricultural enterprise will choose the single normal production mode.*

6. NUMERICAL ANALYSIS

In this part, we analyze the effects of the distribution of heterogeneous customer, the ratio of real green agricultural products , the unit production cost and value discount coefficient on the selection of production mode, in which the agricultural enterprise by comparing the profits of three kinds of production mode to choose the optimal production mode.

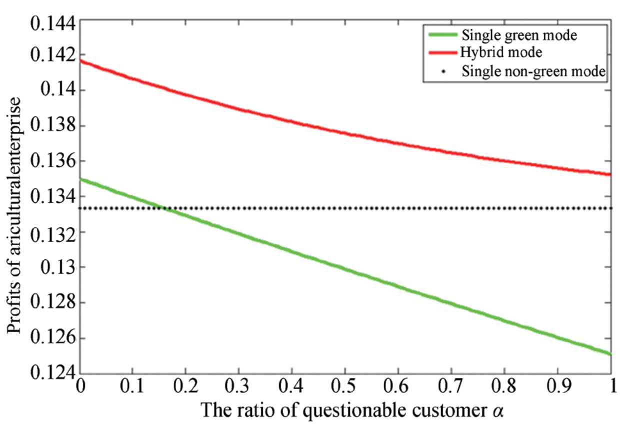

Figure 2
The Relationship Between and Profits

The relationship between α and profits are shown in Figure 2. We use the ratio of questionable customer α to represent the distribution of heterogeneous customer and we assume that θ=0.7, k=0.7 and C_g=0.1. Obviously, α irrelevant to the profits of single non-green mode. We can see from Figure 2 that, the higher the ratio of questionable customer is, the lower the profits for both hybrid and single green mode will be. This result is intuitive that the larger α represents higher ratio of questionable customer and the lower utility that green products brings which lead to lower profits of hybrid and single green mode.

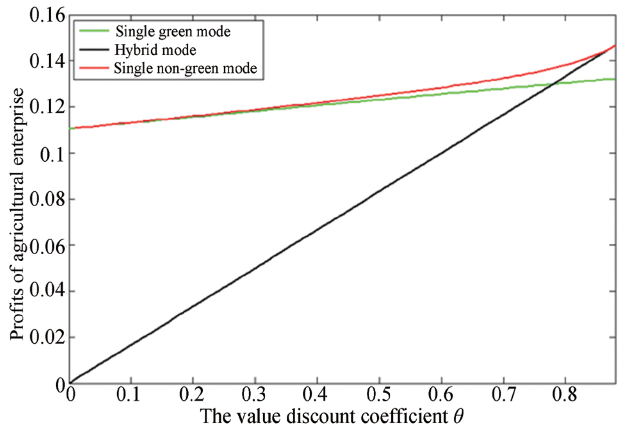

Figure 3
The Relationship Between and Profits

The relationship between θ and profits are shown in Figure 3. We use the value discount coefficient θ to represent the preference of customer for non-green agricultural products and we assume that α=0.7, k=0.8 and C_g=0.1. Clearly, the linear relationship between θ and the profits of single non-green mode lead to the result that the larger θ is, the higher the profits. We can also see from Figure 3 that, it could be a solid for the other two modes. This result opens doors to reveal that the higher the value discount coefficient θ is, the higher utility that non-green products bring and customer will buy more productions which lead to higher profits.

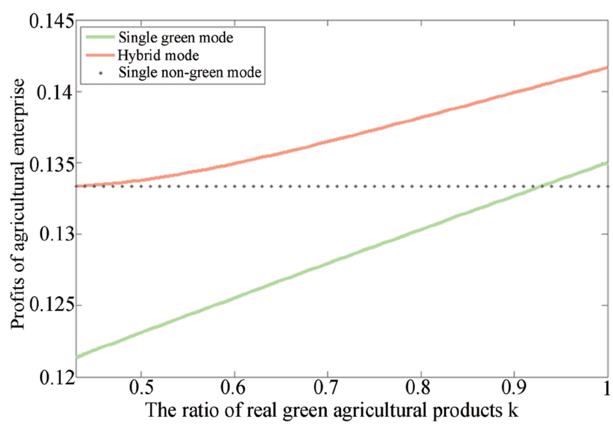

Figure 4
The Relationship Between and Profits

The relationship between k and profits are shown in Figure 4. We use the ratio of real green agricultural products k to represent the distribution of real green agricultural products in the market and we assume that θ=0.8, α=0.7 and C_g=0.1. We can see from Figure 4 that, the higher the ratio of real green agricultural products k is, the higher the profits for both hybrid and single green mode will be, and have no effect on single non-green mode. This result is intuitive that the larger k represents higher ratio of real green agricultural products and the higher utility that green products brings which lead to higher profits of hybrid and single green mode.

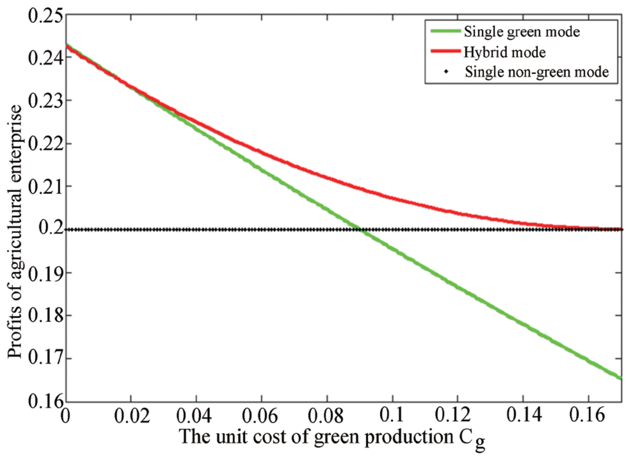

Figure 5
The Relationship Between and Profits

The relationship between C_g and profits are shown in Figure 5. We assume that α=0.7, k=0.8 and θ=0.8, and in this condition, if hybrid production mode is available, there must be $C_g < C_g^c = \frac{(1-\theta)k}{k+\alpha-\alpha k} = 0.17$, in which C_g^c is the critical value. We can see that in the four figures, when hybrid production mode is available and the profits it brings to agricultural enterprise is higher than other two production modes and it is irrelevant to the parameters. And we can easily get that the higher the unit cost of green production C_g is, the lower the profits that green product brings.

CONCLUSION

In the market, agricultural enterprises have been plagued with the production mode selection and how to reasonable pricing of two different quality agricultural products for a long time. In this paper, we assume that the preference for green agricultural product of consumer is uniform distribution in the market, and discuss the optimal mode of production under the condition of considering the distribution of heterogeneous customer, ratio of real green agricultural products, the unit cost of green products and the value discount coefficient. After quantitative analysis on the effects of parameters, we offer the optimal strategy on production mode, pricing and yield of the two products of green supply chain under various conditions. And we investigate the optimal policy and provide managerial insights based on our analysis. It will help the agricultural enterprises in producing and get profits improved.

The results can be improved in the following aspects in the future: This paper only considers the preference for green agricultural product of consumer is uniform distribution in the market, and normal distribution can be considered in the further. In addition, this paper only considers the profits of the whole supply chain under the condition that agricultural enterprises as the Stackelberg game leader, but did not consider the welfare function of the whole supply chain and society. Furthermore, this paper only considers the situation of one agricultural enterprise in the market, and does not consider the price strategy and mode selection when there are many agricultural enterprises competing with each other.

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APPENDICES

Proposition 1: According to

$$\pi_m^{GD} = \left(1-\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)P_g\right)(P_g-\omega_g) \ ,$$

we have

$$\frac{\partial\pi_m^{GD}}{\partial P_g} = 1-\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)(2P_g-\omega_g),$$

$$\frac{\partial^2\pi_m^{GD}}{\partial {P_g}^2} = -2\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)<0,$$

which shows that π_m^{GD} is concave in P_g, then it is obvious that

$$P_g^* = \frac{k+(1-k)\theta}{2(\alpha+(1-\alpha)(k+(1-k)\theta))}+\frac{\omega_g}{2}$$

satisfy the first order conditions, then we have

$$\pi_s^{GD} = \left(1-\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)P_g\right)(\omega_g-C_g) = \frac{1}{2}\left(1-\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)\omega_g\right)(\omega_g-C_g),$$

Then

$$\frac{\partial\pi_s^{GD}}{\partial\omega_g} = 1-\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)(2\omega_g-C_g),$$

$$\frac{\partial^2\pi_s^{GD}}{\partial{\omega_g}^2} = -2\left(1-\alpha+\frac{\alpha}{k+(1-k)\theta}\right)<0,$$

which shows that π_s^{GD} is concave in ω_g, then it is obvious that

$$\omega_g^* = \frac{k+(1-k)\theta}{2(\alpha+(1-\alpha)(k+(1-k)\theta))}+\frac{C_g}{2}$$

satisfy the first order conditions, therefore we have

$$P_g^* = \frac{3(k+(1-k)\theta)}{4(\alpha+(1-\alpha)(k+(1-k)\theta))}+\frac{C_g}{4}$$

and the supermarket, the agricultural enterprise and the whole supply chain are:

$$\pi_m^{GD*} = \frac{\left(k+(1-k)\theta-(\alpha+(1-\alpha)(k+(1-k)\theta))C_g\right)^2}{16(k+(1-k)\theta)(\alpha+(1-\alpha)(k+(1-k)\theta))},$$

$$\pi_s^{GD*} = \frac{\left(k+D(1-k)\theta-(\alpha+(1-\alpha)(k+(1-k)\theta))C_g\right)^2}{8(k+(1-k)\theta)(\alpha+(1-\alpha)(k+(1-k)\theta))},$$

$$\pi_{SC}^{GD*} = \frac{3\left(k+(1-k)\theta-(\alpha+(1-\alpha)(k+(1-k)\theta))C_g\right)^2}{16(k+(1-k)\theta)(\alpha+(1-\alpha)(k+(1-k)\theta))} \ .$$

Proposition 2: According to $\pi_m^{ND} = \left(1-\frac{P_n}{\theta}\right)(P_n-\omega_n)$, we have

$$\frac{\partial\pi_m^{ND}}{\partial P_n} = 1-\frac{2P_n}{\theta}+\frac{\omega_n}{\theta},\quad \frac{\partial^2\pi_m^{ND}}{\partial {P_n}^2} = -\frac{2}{\theta}<0\ ,$$

which shows that π_m^{NC} is concave in P_n, then it is obvious that $P_n^* = \dfrac{\theta+\omega_n}{2}$ satisfy the first order conditions, then we have

$$\pi_s^{ND} = \left(1 - \frac{P_n}{\theta}\right)\omega_n, \text{ then} \frac{\partial \pi_s^{ND}}{\partial \omega_n} = \frac{1}{2} - \frac{\omega_n}{\theta}, \ \frac{\partial^2 \pi_s^{ND}}{\partial {\omega_n}^2} = -\frac{1}{\theta} < 0,$$

which shows that π_s^{ND} is concave in ω_n, then it is obvious that $\omega_n^* = \frac{\theta}{2}$ satisfy the first order conditions, therefore we have $P_n^* = \frac{3\theta}{4}$ and the supermarket, the agricultural enterprise and the whole supply chain are:

$$\pi_m^{ND*} = \frac{\theta}{16}, \pi_s^{ND*} = \frac{\theta}{8}, \pi_{SC}^{ND*} = \frac{3\theta}{16}.$$

Proposition 3: According to

$$\pi_m^{HD} == \left(1 - \frac{(P_g - P_n)(k + \alpha - \alpha k)}{(1-\theta)k}\right)(P_g - \omega_g) + \left(\frac{(P_g - P_n)(k + \alpha - \alpha k)}{(1-\theta)k} - \frac{P_n}{\theta}\right)(P_n - \omega_n),$$

we have

$$\frac{\partial \pi_m^{HD}}{\partial P_g} = 1 - \frac{2P_g - 2P_n - \omega_g + \omega_n}{(1-\theta)k}(k + \alpha - \alpha k),$$

$$\frac{\partial \pi_m^{HD}}{\partial P_n} = \frac{2P_g - 2P_n - \omega_g + \omega_n}{(1-\theta)k}(k + \alpha - \alpha k) - \frac{2P_n - \omega_n}{\theta},$$

$$\frac{\partial^2 \pi_m^{HD}}{\partial P_g \partial P_n} = \frac{2(k+\alpha-\alpha k)}{(1-\theta)k},$$

$$\frac{\partial^2 \pi_m^{HD}}{\partial {P_g}^2} = -\frac{2(k + \alpha - \alpha k)}{(1-\theta)k},$$

$$\frac{\partial^2 \pi_m^{HD}}{\partial P_n \partial P_g} = \frac{2(k + \alpha - \alpha k)}{(1-\theta)k},$$

$$\frac{\partial^2 \pi_m^{HD}}{\partial {P_n}^2} = -\frac{2(k+\alpha-\alpha k)}{(1-\theta)k} - \frac{2}{\theta},$$

and hessian matrix is

$$\mathrm{H}(P_g, P_n) = \begin{Bmatrix} \frac{\partial^2 \pi_m^{HD}}{\partial {P_g}^2} & \frac{\partial^2 \pi_m^{HD}}{\partial P_g \partial P_n} \\ \frac{\partial^2 \pi_m^{HD}}{\partial P_n \partial P_g} & \frac{\partial^2 \pi_m^{HD}}{\partial {P_n}^2} \end{Bmatrix},$$

While

$$\frac{\partial^2 \pi_m^{HD}}{\partial {P_g}^2} = -\frac{2(k + \alpha - \alpha k)}{(1-\theta)k} < 0,$$

$$\begin{vmatrix} \frac{\partial^2 \pi_m^{HD}}{\partial {P_g}^2} & \frac{\partial^2 \pi_m^{HD}}{\partial P_g \partial P_n} \\ \frac{\partial^2 \pi_m^{HD}}{\partial P_n \partial P_g} & \frac{\partial^2 \pi_m^{HD}}{\partial {P_n}^2} \end{vmatrix} = \frac{4(k + \alpha - \alpha k)}{(1-\theta)\theta k} > 0,$$

so we can see that hessian matrix is negative definite matrix. We have

$$P_g^* = \frac{(1-\theta)k}{2(k+\alpha-\alpha k)} + \frac{\theta+\omega_g}{2}, \ \ P_n^* = \frac{\theta+\omega_n}{2},$$

satisfy the first order conditions, then we have

$$\pi_s^{HD} = D_g(w_g - C_g) + D_n w_n = \left(1 - \frac{(P_g - P_n)(k + \alpha - \alpha k)}{(1-\theta)k}\right)(w_g - C_g) + \left(\frac{(P_g - P_n)(k + \alpha - \alpha k)}{(1-\theta)k} - \frac{P_n}{\theta}\right)\omega_n$$

$$= \left(\frac{1}{2} - \frac{(w_g - w_n)(k + \alpha - \alpha k)}{2(1-\theta)k}\right)(w_g - C_g) + \left(\frac{(w_g - w_n)(k + \alpha - \alpha k)}{2(1-\theta)k} - \frac{w_n}{2\theta}\right)\omega_n,$$

we have

$$\frac{\partial \pi_s^{HD}}{\partial \omega_g} = \frac{1}{2} - \frac{2\omega_g - 2\omega_n - C_g}{2(1-\theta)k}(k+\alpha-\alpha k),$$

$$\frac{\partial \pi_s^{HD}}{\partial \omega_n} = \frac{2\omega_g - 2\omega_n - C_g}{2(1-\theta)k}(k+\alpha-\alpha k) - \frac{\omega_n}{\theta},$$

$$\frac{\partial^2 \pi_s^{HD}}{\partial \omega_g \partial \omega_n} = \frac{k+\alpha-\alpha k}{(1-\theta)k},$$

$$\frac{\partial^2 \pi_s^{HD}}{\partial {\omega_g}^2} = -\frac{k+\alpha-\alpha k}{(1-\theta)k},$$

$$\frac{\partial^2 \pi_s^{HD}}{\partial \omega_g \partial \omega_n} = \frac{k+\alpha-\alpha k}{(1-\theta)k},$$

$$\frac{\partial^2 \pi_s^{HD}}{\partial {\omega_n}^2} = -\frac{k+\alpha-\alpha k}{(1-\theta)k} - \frac{1}{\theta},$$

and hessian matrix is

$$\mathrm{H}(w_g, \omega_n) = \begin{Bmatrix} \frac{\partial^2 \pi_s^{HD}}{\partial {w_g}^2} & \frac{\partial^2 \pi_s^{HD}}{\partial w_g \partial \omega_n} \\ \frac{\partial^2 \pi_s^{HD}}{\partial \omega_n \partial w_g} & \frac{\partial^2 \pi_s^{HD}}{\partial {\omega_n}^2} \end{Bmatrix}.$$

While

$$\frac{\partial^2 \pi_s^{HD}}{\partial {\omega_g}^2} = -\frac{k+\alpha-\alpha k}{(1-\theta)k} < 0$$

and

$$\begin{vmatrix} \frac{\partial^2 \pi_s^{HD}}{\partial {w_g}^2} & \frac{\partial^2 \pi_s^{HD}}{\partial w_g \partial \omega_n} \\ \frac{\partial^2 \pi_s^{HD}}{\partial \omega_n \partial w_g} & \frac{\partial^2 \pi_s^{HD}}{\partial {\omega_n}^2} \end{vmatrix} = \frac{k+\alpha-\alpha k}{(1-\theta)\theta k} > 0,$$

so we can see that hessian matrix is negative definite matrix. We have

$$w_g^* = \frac{(1-\theta)k}{2(k+\alpha-\alpha k)} + \frac{\theta+C_g}{2}, \quad w_n^* = \frac{\theta}{2},$$

we have

$$\pi_m^{HD*} = \frac{\theta}{16} + \frac{\left((1-\theta)k - (k+\alpha-\alpha k)C_g\right)^2}{16(k+\alpha-\alpha k)k(1-\theta)},$$

$$\pi_s^{HD*} = \frac{\theta}{8} + \frac{\left((1-\theta)k - (k+\alpha-\alpha k)C_g\right)^2}{8(k+\alpha-\alpha k)k(1-\theta)},$$

$$\pi_{SC}^{HD*} = \frac{3\theta}{16} + \frac{3\left((1-\theta)k - (k+\alpha-\alpha k)C_g\right)^2}{16(k+\alpha-\alpha k)k(1-\theta)}.$$

Proposition 4: According to

$$\begin{cases} D_g = 1 - \frac{(P_g-P_n)(k+\alpha-\alpha k)}{(1-\theta)k} \\ D_n = \frac{(P_g-P_n)(k+\alpha-\alpha k)}{(1-\theta)k} - \frac{P_n}{\theta} \end{cases},$$

$$\pi_s^{ND*} = \frac{\theta}{8},$$

$$\pi_s^{HD*} = \frac{\theta}{8} + \frac{\left((1-\theta)k - (k+\alpha-\alpha k)C_g\right)^2}{8(k+\alpha-\alpha k)k(1-\theta)}$$

and

$$\pi_S^{GD*} = \frac{\left(k + D(1-k)\theta - \left(\alpha + (1-\alpha)(k + (1-k)\theta)\right)C_g\right)^2}{8(k + (1-k)\theta)\left(\alpha + (1-\alpha)(k + (1-k)\theta)\right)} \ ,$$

we know that when hybrid production mode is available, there must be $D_g>0$ and $D_n>0$, then we have $0 < C_g < \frac{(1-\theta)k}{k+\alpha-\alpha k}$, and as we know, $\pi_S^{HD*} - \pi_S^{GD*} \geq 0$, that is when hybrid production mode is available, its profits is better than other mode, and the agricultural enterprise will choose the hybrid production mode. And solve the inequality $\pi_S^{GD*} - \pi_S^{ND*} > 0$, we have

$$\frac{k + (1-k)\theta}{\alpha + (1-\alpha)(k + (1-k)\theta)} - \sqrt{\frac{(k + (1-k)\theta)\theta}{\alpha + (1-\alpha)(k + (1-k)\theta)}} > C_g \, ,$$

then if

$$\frac{k + (1-k)\theta}{\alpha + (1-\alpha)(k + (1-k)\theta)} - \sqrt{\frac{(k + (1-k)\theta)\theta}{\alpha + (1-\alpha)(k + (1-k)\theta)}} > C_g > \frac{(1-\theta)k}{k+\alpha-\alpha k} \ ,$$

then hybrid production mode is infeasible and the agricultural enterprise will choose the single green production mode. Otherwise, the agricultural enterprise will choose the single normal production mode.

