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Optimal price and output in Internet + Agricultural Supply Chain

Yuting Xu*

College of Management, Shanghai University, Shanghai 200444, China
**Corresponding author e-mail: xytrue@shu.edu.cn*

ABSTRACT. *Under the innovative model of "Internet + Agriculture", selling agricultural products through e-commerce platforms is already a new way of agricultural development. Considering the heterogeneity of consumers' preference for agricultural products quality, this article studies the output and optimal pricing of agricultural products in the agricultural supply chain composed of e-commerce platforms and farmers. We build mathematical models for problems and obtain analytical solutions. We found that when the market demand is low and the quality of agricultural products is high, both farmers and platforms can get high profit remuneration, and when factors such as abundant funds or vast geographical areas lead to large agricultural products, the quality requirements can be appropriately relaxed. However, if the quality of agricultural products is low, farmers' profits will be squeezed indefinitely by the platform, resulting in no profit. At this time, farmers will not participate in the cooperation. When the market demand is infinite, although a seller's market will be formed, if the output is not limited by geographical restrictions and the output is also infinite, then the cost will be too high and it will not be profitable.*

KEYWORDS: *Internet + Agriculture supply chain, Optimal price, output of agricultural products, agricultural products quality, consumer utility*

1. Introduction

Due to the rapid development of the Internet, the concept of "Internet +" appeared for the first time in 2015, which is essentially the online and digitalization of traditional industries. Under the innovative industry model of "Internet + modern agriculture", more and more enterprises are involved in the production and operation of agricultural products, but there are still problems of low quality and difficult sales of agricultural products.

Around the world, farmers are increasingly being encouraged to join marketing cooperatives [1]. According to a publication of the International Labour Office, more than 50% of global agricultural output is sold through cooperatives in

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Finland, Italy and the Netherlands [2]. Reardon et al. (2009) indicated that since the main agricultural production in developing countries is smallholder farmers, supermarkets are forced to consider purchasing from smallholder farmers. Irrigation conditions, cooperative organizations, agricultural facilities and transportation conditions are the key factors to be considered in the bidding of agricultural products procurement by supermarkets [3]. Stokke (2009) analyzed the impact of "agricultural supermarket docking" on the agriculture of developing countries and pointed out that whether farmers can benefit from "agricultural supermarket docking" depends on their production capacity and market transaction capacity. Supermarkets are willing to help farmers join the "agricultural supermarket docking". Although in the short term, supermarkets help farmers increase their costs, but in the long run, supermarkets can gain returns through the improvement of farmers' production skills [4].

Compared with the direct marketing market, farmers choose more stable and profitable cooperatives or agricultural super platforms to sell agricultural products [5]. However, how to make use of the platform and efficiency of the Internet to enable farmers to directly connect with consumers and obtain more profits is an important topic that we need to study in depth. This article considers product quality and price, purchases agricultural products from farmers through the platform and sells them directly to consumers, in order to maximize the profits of supply chain companies.

The rest of this article is organized as follows. In Section 2, we describe the relevant symbols and formulate the problem as a mathematical optimization model. In Section 3, we solved the model and obtained some conclusions. In Section 4, we conclude this article.

2. Symbols and model

2.1 Symbols description

p : The selling price of agricultural products on the platform

π_f : Total profit of farmers

π_p : Total profit of the platform

γ : The platform promises that the purchase price of agricultural products is γ times the selling price, $0 < \gamma < 1$

m : Agricultural production area, $0 < m < \overline{m}$

n : Production cost per unit are

q : Objective quality of agricultural products

u : The utility function of consumers

D : Consumer demand, purchase of agricultural products.

2.2 Related assumptions

For the convenience of research, we normalized the number of potential consumers in the agricultural product market to 1. What directly affects consumer utility is the quality and price of the product. In addition, it is assumed that the sensitivity β of consumers to the quality of agricultural products obeys a uniform distribution between 0 and 1 [6], the consumer utility function can be expressed as $u = \beta q - p$. It is also assumed that the retention utility of consumers is zero, that is, as long as agricultural products provide consumers with non-negative utility, consumers will choose to buy. So the probability of consumers buying agricultural products is $1-\frac{p}{q}$, consumer demand for agricultural products is $D = 1-\frac{p}{q}$, to ensure that demand is positive, this article assumes that the price $p < q$. If the productivity level of the land is $\alpha > 0$, then the production area is $m = \frac{D}{\alpha}$, considering geographical factors and capital costs, set the maximum planting acres as $\overline{m}$.

2.3 Mathematical Model

In the agricultural supply chain, the platform determines the selling price of agricultural products, and farmers produce according to market demand. If market demand is greater than the maximum output, they will be produced according to the maximum output. According to the above assumptions, farmers are described as followers, and the profit functions of the platform and farmers are as follows:

$$\pi_p = (1-\gamma) p \min\left\{D, \alpha\overline{m}\right\} = (1-\gamma) p \min\left\{1-\frac{p}{q}, \alpha\overline{m}\right\} \tag{1}$$

$$\pi_f = \gamma p \min\left\{D, \alpha\overline{m}\right\} - \min\left\{\frac{D}{\alpha}, \overline{m}\right\} n = \gamma p \min\left\{1-\frac{p}{q}, \alpha\overline{m}\right\} - \min\left\{\frac{1-\frac{p}{q}}{\alpha}, \overline{m}\right\} n \tag{2}$$

$$s.t. \qquad 0 < p < q$$

3. Solutions

In this section, we use the reverse order solution method to solve the model and draw various conclusions.

Situation 1: Market demand is less than the upper limit of output, that is $1-\frac{p}{q}\le \alpha\overline{m}$, farmers produce according to market demand, and the value range of price p is $\max\left\{0,q(1-\alpha\overline{m})\right\}<p<q$.

First, ensure that farmers' profits are positive. Let $\pi_f=\gamma pD-mn=\gamma p(1-\frac{p}{q})-\frac{1-\frac{p}{q}}{\alpha}n=-\frac{\gamma}{q}p^2+(\gamma+\frac{n}{\alpha q})p-\frac{n}{\alpha}>0$, we have the following lemma.

Lemma 1: When $q>\frac{n}{\alpha\gamma}$, the value range of the decision variable price p is $\max\left\{\frac{n}{\alpha\gamma},q(1-\alpha\overline{m})\right\}<p<q$; when $q<\frac{n}{\alpha\gamma}$, if the demand is positive, that is $0<p<q$, the farmer's profit is less than 0 and will not participate in this cooperation.

Proof: Through $\Delta=(\gamma+\frac{n}{\alpha q})^2-4(-\frac{\gamma}{q})(-\frac{n}{\alpha})=(\gamma-\frac{n}{\alpha q})^2\ge 0$, we get that π_f has two real roots about p, $p_1=\frac{n}{\alpha\gamma}$ and $p_2=q$. If $q>\frac{n}{\alpha\gamma}$, then $\pi_f>0$ is satisfied when $\frac{n}{\alpha\gamma}<p<q$; if $q<\frac{n}{\alpha\gamma}$, then $\pi_f>0$ is satisfied when $q<p<\frac{n}{\alpha\gamma}$. It can be seen that when $q>\frac{n}{\alpha\gamma}$, the value range of p is $\max\left\{\frac{n}{\alpha\gamma},q(1-\alpha\overline{m})\right\}<p<q$; when $q<\frac{n}{\alpha\gamma}$, to ensure that the demand is positive, that is $0<p<q$, the farmer's profit is less than zero.

The platform profit $\pi_p=(1-\gamma)pD=(1-\gamma)p(1-\frac{p}{q})=-\frac{1-\gamma}{q}p^2+(1-\gamma)p$ is a concave function about the price p. Find the first and second derivatives of π_p with respect to p, We can get $\pi'(p)=-\frac{2(1-\gamma)}{q}p+(1-\gamma)$, $\pi''(p)=-\frac{2(1-\gamma)}{q}<0$, let $\pi'(p)=0$ get the maximum point $\frac{(1-\gamma)q}{4}$ of $\pi(p)$, get $p=\frac{q}{2}$.

Next, we can classify the discussion by comparing the sizes of $\frac{n}{\alpha\gamma}$, $q(1-\alpha\overline{m})$ and $\frac{q}{2}$, which can be divided into $0<\alpha\overline{m}<\frac{1}{2}$ and $\alpha\overline{m}>\frac{1}{2}$, and we can get the following propositions.

Propositions 1: When $0<\alpha\overline{m}<\frac{1}{2}$, combined with Lemma 1, we can see that when $q>\frac{n}{\alpha\gamma(1-\alpha\overline{m})}$, the optimal price $p^*=q(1-\alpha\overline{m})$ is obtained, the platform obtains the maximum profit as $\pi_p=q\alpha\overline{m}(1-\gamma)(1-\alpha\overline{m})$, and the farmer's

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maximum profit is $\pi_f = \alpha\overline{m}\gamma q(1-\alpha\overline{m}) - \overline{m}n$; when $\frac{n}{\alpha\gamma} < q < \frac{n}{\alpha\gamma(1-\alpha\overline{m})}$, the optimal price is obtained as $p^* = \frac{n}{\alpha\gamma}$, and the platform obtains the maximum profit $\pi_p = \frac{n(1-\gamma)}{\alpha\gamma}(1+\frac{n}{\alpha\gamma q})$, At this time, the farmer's profit is 0; when $q < \frac{n}{\alpha\gamma}$, the farmer's profit is negative at this time and does not participate in the cooperation.

Proof: When $0 < \alpha\overline{m} < \frac{1}{2}$, at this time $\frac{1}{2} < 1-\alpha\overline{m} < 1$, get $q(1-\alpha\overline{m}) > \frac{q}{2}$, only need to compare $\frac{n}{\alpha\gamma}$ and $q(1-\alpha\overline{m})$. If $\frac{n}{\alpha\gamma} < q(1-\alpha\overline{m})$, then $q > \frac{n}{\alpha\gamma(1-\alpha\overline{m})}$, at this time the optimal price is $p^* = q(1-\alpha\overline{m})$, platform profit is $\pi_p = q\alpha\overline{m}(1-\gamma)(1-\alpha\overline{m})$, and farmers' profit is $\pi_f = \alpha\overline{m}\gamma q(1-\alpha\overline{m}) - \overline{m}n$; if $q(1-\alpha\overline{m}) < \frac{n}{\alpha\gamma} < q$, then $\frac{n}{\alpha\gamma} < q < \frac{n}{\alpha\gamma(1-\alpha\overline{m})}$ x, at this time the optimal price is $p^* = \frac{n}{\alpha\gamma}$, platform profit is $\pi_p = \frac{n(1-\gamma)}{\alpha\gamma}(1+\frac{n}{\alpha\gamma q})$, and farmers' profit is $\pi_f = 0$.

Proposition 1 indicates that when the output of agricultural products is limited due to financial constraints or geographical factors, when the quality of agricultural products is high, both farmers and the platform can get more satisfactory profit rewards; when the quality of agricultural products is low, the farmers' profits will be squeezed infinitely by the platform, and the farmers Do not participate in this cooperation. For the government, it can increase farmers' profits by appropriately subsidizing farmers and encourage farmers to participate in supply chain cooperation to achieve the goal of targeted poverty alleviation.

Proposition 2: When $\alpha\overline{m} > \frac{1}{2}$, combined with Lemma 1, when $q > \frac{2n}{\alpha\gamma}$, the optimal price $p^* = \frac{q}{2}$ is obtained, the platform obtains the maximum profit $\pi_p = \frac{(1-\gamma)q}{4}$, and the farmer obtains the maximum profit $\pi_f = \frac{\gamma q}{4} - \frac{n}{2\alpha}$; when $\frac{n}{\alpha\gamma} < q < \frac{2n}{\alpha\gamma}$, the optimal price $p^* = \frac{n}{\alpha\gamma}$ is obtained, and the platform obtains the maximum profit $\pi_p = \frac{n(1-\gamma)}{\alpha\gamma}(1+\frac{n}{\alpha\gamma q})$, and the farmer's profit is 0; when $q < \frac{n}{\alpha\gamma}$, the farmer's profit is negative and he does not participate in the cooperation.

Proof: When $\alpha\overline{m} > \frac{1}{2}$, at this time $1-\alpha\overline{m} < \frac{1}{2}$, get $q(1-\alpha\overline{m}) < \frac{q}{2}$, only need to compare $\frac{n}{\alpha\gamma}$ and $\frac{q}{2}$. If $\frac{n}{\alpha\gamma} < \frac{q}{2}$, then $q > \frac{2n}{\alpha\gamma}$, the optimal price is $p^* = \frac{q}{2}$ at this time, the platform profit is $\pi_p = \frac{(1-\gamma)q}{4}$, and the farmer's profit is

$\pi_f = \frac{\gamma q}{4} - \frac{n}{2\alpha}$; if $\frac{q}{2} < \frac{n}{\alpha\gamma} < q$, then $\frac{n}{\alpha\gamma} < q < \frac{2n}{\alpha\gamma}$, at this time the optimal price is $p^* = \frac{n}{\alpha\gamma}$, the platform profit is $\pi_p = \frac{n(1-\gamma)}{\alpha\gamma}(1+\frac{n}{\alpha\gamma q})$, and the farmer's profit is $\pi_f = 0$.

Situation 2: Market demand is greater than the upper limit of output, that is $1-\frac{p}{q} \geq \alpha\overline{m}$, farmers produce according to the maximum output. We get the following lemma.

Lemma 2 If $0 < \alpha\overline{m} < 1$, the value range of price p is $0 < p < q(1-\alpha\overline{m})$. If $\alpha\overline{m} \geq 1$, then price p is negative, and no member of the supply chain participates in the cooperation.

To ensure that farmers' profits are positive $\pi_f = \gamma p\alpha\overline{m} - \overline{m}n > 0$, the price is required to satisfy $p > \frac{n}{\alpha\gamma}$ at this time. Platform profit $\pi_p = (1-\gamma)\alpha\overline{m}p$ is a linear function of price p.

Proposition 3: Combined with Lemma 2, when $0 \leq \alpha\overline{m} \leq 1$, if $0 < q < \frac{n}{\alpha\gamma(1-\alpha\overline{m})}$, the farmer's profit is less than 0; if $q > \frac{n}{\alpha\gamma(1-\alpha\overline{m})}$, the value range of the price p is $\frac{n}{\alpha\gamma} < p < q(1-\alpha\overline{m})$, the optimal price $p^* = q(1-\alpha\overline{m})$ is obtained, the maximum profit obtained by the platform is $\pi_p = q\alpha\overline{m}(1-\gamma)(1-\alpha\overline{m})$, and the maximum profit of the farmer is $\pi_f = \alpha\overline{m}\gamma q(1-\alpha\overline{m}) - \overline{m}n$; When $\alpha\overline{m} \geq 1$, the price p is negative at this time, and neither the farmer nor the platform can make a profit.

Proposition 3 shows that when the market demand is greater than the maximum output of agricultural products, there is a threshold for the quality of agricultural products. If the quality of agricultural products is not high due to the geographical environment, farmers will not be able to profit; but when the quality of agricultural products is high, a seller's market will be formed and the platform will establish Higher prices enable members of the supply chain to obtain the maximum profit; when the maximum output is particularly large, the profit will be negative due to the higher cost.

4. Conclusion and managerial implication

This article studies the agricultural supply chain composed of farmers and platforms. With the goal of maximizing their respective profits, the platform determines the price of agricultural products, and farmers produce according to

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market demand. In the case of low market demand, when the quality of agricultural products is high, farmers and platforms can obtain relatively satisfactory profit remuneration, and when factors such as abundant funds or wide geographical areas lead to large agricultural products, the quality requirements can be appropriately relaxed. However, if the quality of agricultural products is low, farmers' profits will be squeezed indefinitely by the platform, resulting in farmers unable to make profits, and farmers will not participate in the cooperation at this time. Surprisingly, when the market demand is infinite, although a seller's market will be formed, if the output is also infinite without geographical restrictions, at this time, the cost will be too high and it will not be profitable.

This article brings some suggestions. For the government, it can increase farmers' profits by appropriately subsidizing farmers and encourage farmers to participate in supply chain cooperation to achieve the goal of precise poverty alleviation. For agricultural science and technology companies, they can join the supply chain cooperation and introduce agricultural technology to improve the quality of agricultural products and increase their competitiveness in response to the low quality of agricultural products.

This article has some limitations. First, the productivity of this article is fixed and can be assumed to be random. Secondly, the agricultural supply chain in this article consists only of farmers and platforms. Technology suppliers can be introduced to improve the quality of agricultural products and increase farmers' decision-making power.

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