

Research Article

Integrated Pricing and Distribution Planning for Community Group Purchase of Fresh Agricultural Products

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As a new social e-commerce model, community group purchase of fresh agricultural products has been gradually welcomed by the public. However, its development and operation still face homogeneous competition problems. In order to enhance competitive advantages of operators, this paper proposes a collaborative optimization mechanism, including a new pricing model and a new cold chain vehicle route planning model. It aims to ensure the quality of fresh products, reduce logistics costs, and improve enterprise profitability. The model takes into account not only the quality of fresh products and their impact on price and demand but also the impact of quality changes on total distribution costs. A two-layer programming method is applied to realize the collaborative optimization mechanism, and then the upper and lower models are solved by mathematical derivation, proof methods, and optimization procedures, respectively. Finally, the feasibility and effectiveness of the model are verified by combining with specific examples, and the following conclusions are obtained: price, delivery quality, and total profit increase with the increase of potential market demand rate. The lower the refrigeration temperature of the vehicle we choose within a certain range, the higher the quality can be obtained. In order to obtain the highest profit, community group purchase operators can choose a higher distribution temperature on the premise that they can guarantee that the quality of fresh agricultural products can be at an appropriate level.

1. Introduction

Online sales of fresh agricultural products in China are developing rapidly, but the penetration rate is still less than 3%, far lower than that of clothing, electronic products, and so on. For the fact that fresh local products are always with short shelf life and perishability, under the traditional online sales model it has greatly increased the distribution cost of cold chain distribution. The development of fresh agricultural e-commerce has its unique driving force due to the unique nature of fresh agricultural products but also faces many problems that have not occurred in the online sales of other categories of products, such as a higher retail price and uneven product quality. However, the community group purchase has emerged in recent years and has brought hope to deal with these problems.

Community group purchase is a new business model in the context of e-commerce gathering consumers from a real

community with the same needs and forming a scale that meets the bargaining power of the supplier. In this business model, customer can always obtain the corresponding product at a large discount. The head of the group establishes a community WeChat group and publishes the product information of the group purchase in a timely manner. The residents can purchase through an online application program. The advantages of community group purchase are helpful to solve the important problems of high distribution cost and unqualified quality in the process of online sales of fresh agricultural products. At the same time, community group purchase can realize the aggregation of space and time by customer demands, which can maximize the utilization rate of cold chain facilities and equipment and simultaneously increase economies of scale. As a result, the unit cold chain logistics costs can be reduced. In addition, the economies of scale brought about by the space and time aggregation of customer demands provide the internal

motivation for logistics companies to adopt the entire cold chain, which is conducive to reducing losses. However, because the technical threshold of community group purchase is relatively low, it is easy to be copied.

Reasonable pricing is of great practical significance for increasing the attractiveness of fresh agricultural products community group purchase. In order to grab market share, sellers usually adopt certain promotional methods, of which price discounts are one of the most effective means. Reasonable pricing of group purchase is the key to increasing consumer appeal and helping e-commerce enterprises increase their profit. If the price is too high, too many customers with low reservation prices will be lost, which will reduce the attractiveness of community group purchase. But if the price is too low, the profit margin will be small, which is not conducive to the long-term sustainable development of community group purchase.

Proper distribution plan arrangements play an important role in enhancing the competitive advantage of the community group operators. On the one hand, the distribution plan affects the cost of cold chain distribution and the profit of the enterprise and thus directly affects pricing decisions. On the other hand, the effectiveness of distribution plans affects quality of the fresh agricultural products. At the same time, the quality of fresh products has a strong correlation with the demand. Therefore, the reasonable determination of the distribution plan is not only related to the success or failure of the operator to carry out the community group purchase but also related to the sustainable development of the community group purchase model.

Pricing is an important decision-making content for carrying out online community group purchase, and reasonable pricing is the key to the success of fresh agricultural products community group purchase. Zhang et al. [1] analysed the pricing mechanism of online group purchase and compared it with the pricing mechanism for individual sales. The study pointed out that the price change of online group purchase pricing is driven by the number of purchases. The dynamic pricing mechanism originated from foreign researches on online group purchase pricing. Kauffman and Wang [2] are the first scholars to study the dynamic pricing mechanism of online group purchase. The study analysed the changes in the number of orders over time under the dynamic pricing mechanism of online group purchases. Chen et al. [3, 4] used game theory to analyse the supplier's dynamic pricing strategy and the retailer's purchasing decision problem under the circumstance where the supplier and retailer adopted the group purchase sales model and then studied the effects of economies of scale and risk preference of decision-makers on discount prices and quantities under the condition that demand arrivals obey Poisson distribution. Sharif Vaghefi et al. [5] believed that the waiting time of customer is an inherent attribute of group purchase auctions and proposed a dual-market pricing model with the help of game theory concepts. Gu and Cai [6] studied the dynamic group purchase pricing mechanism of suppliers to retailers in a B2B environment and compared the profits of suppliers under traditional fixed

pricing, quantity discounts, and group purchase pricing. Based on the static pricing mechanism, some scholars conducted group purchase pricing strategies or research on specific pricing methods from different perspectives such as different channels, consumer behaviour, supplier capabilities, customer waiting time, immediate supply of goods, group purchase duration, and waiting cost. Tang and Chai [7] designed a network-based catering enterprise group purchase pricing model. They took different consumers into consideration, including loyal customers and random customer groups, as well as two sales channels for individual purchase channel and group purchase channel. Qian and Su. [8] studied the joint decision of online group purchase pricing and advertising investment under the cross-demand mechanism by establishing a decision model that analysed the relationship between advertising investment and pricing.

Cold chain distribution cost optimization is mainly based on the traditional vehicle routing problem, considering the decay characteristics of fresh agricultural product quality and energy consumption to maintain a certain temperature environment. The pure cold chain vehicle routing problem has formed more detailed research directions such as soft time windows and hard time windows, single-objective and multi-objective, multi-temperature codistribution and single temperature distribution, single yard and multiple yards, and single target and multiple targets. Based on the traditional VRP with time window limitation, Hsu et al. [9] considered the random transportation time, capacity consumption, and perishable characteristics of the distribution process caused by traffic congestion and established a random soft time window constrained VRP model and then solved it with the nearest neighbour search algorithm based on time. Osvald and Stirn [10] established a path optimization model with the consideration of quality loss costs, transportation costs, and soft time window constraints with minimum time and used a tabu search algorithm to solve it. Amorim et al. [11] considered the transportation cost, vehicle rental cost, and driver cost, established a cold chain distribution route optimization model with time window constraints for multiple models, and solved it by using a large-scale domain search algorithm. Estrada-Moreno et al. [12] established a multi-yard cold chain distribution route optimization model, which was solved by BRT (biased-randomization techniques) algorithm. Wang et al. [13] established a multi-objective path optimization model with the minimum cost and maximum average freshness with time window limitation and designed a two-stage heuristic algorithm to solve it. But there are not many studies on the optimization of the distribution route, distribution temperature, and vehicle type at the same time. Hsiao et al. took meat [14], fresh fruits, and vegetables [15] as the research objects, considering the fuel cost, carbon emission cost, cooling cost, personnel cost, out-of-stock cost, and vehicle cost and studied the multi-temperature colocated vehicle routing optimization problem. In recent years, metaheuristic algorithms have been widely used to solve different NP-hard problems such as berth allocation and vehicle route problem optimization. Zhen [16] used metaheuristic algorithm to solve a mixed-

integer programming model. In his later research [17], metaheuristic algorithm is used to solve a stochastic programming model and a robust programming model related to tactical BAP problem. Such improved metaheuristic algorithms played important roles in solving cold chain vehicle routing problem in previous studies as we introduced above.

Many scholars have carried out a lot of researches around group purchase pricing and cold chain distribution cost optimization and have achieved rich research results. However, the current research does not meet the needs of group purchase pricing of fresh agricultural products. Firstly, the quality of fresh agricultural products after production decreases with time. The storage and transportation environment at a certain temperature can effectively delay the decline of quality, but the cost of maintaining a specific temperature is very high. Existing researches do not consider the impact of this feature on fresh agricultural product group purchase pricing. Secondly, the community group purchase can realize the time and space gathering of the distribution needs of fresh agricultural products, thereby reducing the unit cold chain distribution costs. Existing cold chain distribution cost optimization models lack the consideration of the impact of the time and space aggregation characteristics of distribution demand. Finally, the cost of cold chain distribution is an important component of the total cost of fresh agricultural products community group purchases and it is a decisive factor. The selection of the distribution path of fresh agricultural products, the refrigerated vehicle type, and the distribution temperature have an important impact on the distribution cost and quality assurance, which in turn affects the price setting. This is the inevitable inherent requirement of collaborative optimization between the community group purchase pricing and the cold chain distribution cost. Existing researches on group purchase pricing rarely consider the optimization of cold chain distribution parameters, while most researches on distribution cost optimization assume that prices are fixed and known input parameters and are not related to the price setting process.

Therefore, in this article, we establish a collaborative optimization mechanism for community group purchase. It is based on the improved community group purchase pricing model and cold chain distribution cost optimization model. This collaborative optimization mechanism combines the characteristics of the short shelf life of fresh agricultural products, high cold chain distribution costs, and the time and space aggregation of community group purchase. It is based on the existing food quality decay theory and also takes online group purchase pricing theory and cold chain distribution cost optimization methods into consideration. In this paper, we take fruit and vegetable as an example to verify the effectiveness and advantages of model, algorithm, and collaborative optimization mechanism. In the model, we quantify the impact of community demand scale, geographic location, refrigerated vehicle fixed costs, variable transportation costs, refrigeration costs, price demand elasticity, quality demand elasticity, and many other factors on collaborative optimization.

The remainder of this paper is organized as follows: Section 2 introduces the descriptions and assumptions of the problems, followed by the community group purchase pricing model, cold chain distribution cost models, and the implementation of collaborative optimization mechanisms. Section 3 takes fresh fruit in an area of Yunnan Province as an example for analysis and presents the experimental settings and results. Finally, Section 4 summarizes the major conclusions of this research and gives several hints for further research.

2. Materials and Methods

2.1. Problem Description and Assumptions. The profitability of community group purchase enterprises is related to quality of the agricultural products, consumer demand, price, and production and distribution costs. Because of the characteristics of fresh agricultural product, quality is an important factor affecting price and demand, and demand is negatively correlated with price. Quality, market potential demand, and price of fresh agricultural product are the important factors affecting the actual demand. Therefore, pricing decisions are directly related to consumers' purchase intentions and enterprises' final profitability. The greater the consumer's demand is, the greater the volume of logistics distribution is. At this time, the economies of scale of distribution will be produced; thereby the unit logistics cost can be reduced. This is the key to the optimization of the cold chain logistics distribution vehicle route planning. In this article, we use the sales price as a decision variable to build an upper-level model.

The design of the distribution plan has a great impact on the quality of fresh agricultural products. Therefore, the lower-level vehicle route problem can be described as the process of planning the distribution route of the cumulative order information after a group purchase by the operator. The cold chain distribution center has different types of refrigerated distribution vehicles that can set different transportation temperatures. Each refrigerated vehicle departs from the distribution center after the assembly is completed and then passes through the demand nodes in turn to deliver the fresh products to the head of the community group. In the distribution process, it is also considered how to reduce the distribution costs, improve the quality of fresh agricultural products, and improve the consumer satisfaction.

We focused on the problem with one central yard in the process of sales and distribution of fresh agricultural products in community group purchase. $N = \{i | i = 0, 1, 2, \dots, L\}$ is a set of nodes including n customer nodes and one central depot which is denoted by "0." The VRP structure can be defined on a direct graph $G = (N, A)$. A is the set of arcs, and (i, j) represents the possibility of traveling from i to j with an associated distance or cost. There are $K = \{k | k = 0, 1, 2, \dots, V\}$, representing vehicles of different types in the central yard. The assumptions used in this paper are given as follows:

- (1) There is only one distribution center, and the distribution center has several vehicles of different

types, which fully meets the distribution volume of the market's potential demand.

- (2) Because different types of fresh agricultural products have different requirements for cold chain logistics, only a single type is selected in this paper.
- (3) The location coordinates of the center yard and the demand nodes are known.
- (4) The total order quantities of each demand node are known, and each node can only be served once by one vehicle.
- (5) The service time at each demand node is known and there is no time window restriction or sequence restriction on service time.
- (6) Once the temperature of the refrigerated vehicle container is determined, it cannot be changed.

2.2. Pricing Model. Some researchers usually use the newsvendor model to describe the relationship between the price and demand for perishable goods, which is one of the classic models on inventory management. The newsvendor problem aims to find the best order quantity that minimizes the expected loss or maximizes the expected profit in some real situations under probabilistic demand. Based on the characteristics of community group purchase in this research, operators choose to conduct unified production or purchase after collecting all of the orders in a group purchase. Thus, the purchase order quantity is consistent with the actual demand and operators will have no inventory and expected loss during the community group purchase. As community group purchase relates to operators, consumers, price, demand, product quality, etc., we build the following pricing model for fresh agricultural products in group purchase, which is widely used as an effective model for agricultural products pricing. This model is based on the price function, demand function, production cost, and cold chain logistics cost and aims to maximize profits and make decisions about different price discounts and delivery quality requirements. The demand for group purchase is a function of market potential demand, price discount, and delivery quality. The objective function (1) stands for the situation where the group purchase businesses hope to win the maximum profit $\pi(p)$. θ denotes the shared revenue proportion. C_d denotes the distribution cost and C_p denotes the production cost. p is the decision variable and it denotes the price. T denotes the duration of group purchase. D_m denotes the demand rate and it is shown in equation (2). D_0 denotes the potential market demands. In this paper, demand is affected not only by price but also by the real-time quality of fresh agricultural products. α_2 and α_3 denote the effect of price on demand coefficient and the effect of quality on demand coefficient, respectively, which are all greater than 0. M_k denotes the quality when the fresh agricultural product reaches the demand nodes. M_E denotes the quality when the consumers give up buying. Here, it means that consumers have certain requirements for the quality level of fresh agricultural products. The price function is shown as equation

(3). α_0 denotes the price constant. α_1 denotes the effect of quality on price coefficient:

$$\text{maximum } \pi(p) = [(1 - \theta)p - C_d - C_p]TD_m, \quad (1)$$

$$\text{subject to } D_m = \alpha_3 \left[\frac{(M_k - M_E)}{M_E} \right] \cdot (D_0 - \alpha_2 p), \quad (2)$$

$$p = \alpha_0 (M_k - M_E)^{\alpha_1}. \quad (3)$$

Proposition 1. *If the quality of fresh agricultural products does not meet the quality required by consumers, the sales price will be 0.*

Proof. We can know from the limit expression $\lim_{M_k \rightarrow M_E} p = 0$ that when the quality delivered to the consumer is infinitely close to the quality of the consumer giving up the purchase of the product, the sales price is infinitely close to 0. This shows that there is no market demand for this quality product at this time. And it also meets the fact that when the quality of fresh agricultural products has deteriorated, it can no longer be sold; that is, the sales price is 0. \square

Proposition 2. *The price of fresh agricultural products gradually increases with the growth of quality.*

Proof. When $M_k > M_E$, we have

$$\frac{d_p}{d_M} = \alpha_0 \alpha_1 (M_k - M_E)^{\alpha_1 - 1} > 0, \quad (4)$$

$$\frac{d_p^2}{d_M^2} = \alpha_0 \alpha_1 (\alpha_1 - 1) (M_k - M_E)^{\alpha_1 - 2} < 0,$$

which means that we can observe from the expression of the derivative function that on $M_k > M_E$ the price of fresh agricultural products gradually increases with the growth of quality. Figure 1 depicts the impact of quality on price. Its growth trend is gradually decreasing, and this trend is also in line with the general trend in the sales price of fresh agricultural products. \square

Proposition 3. *When the quality approaches a level that consumers cannot accept, no matter how other factors change, demand will approach 0.*

Proof. We can know from the limit expression,

$$\lim_{M_k \rightarrow M_E} D_m = 0, \quad (5)$$

that when the quality delivered to the consumer is infinitely close to the quality of the consumer who gave up buying the product, its market demand is close to 0. Figure 2 demonstrates the impact of quality on demand. It is consistent with the actual situation where consumers will not choose to buy products with degraded quality and merchants are not allowed to sell. \square

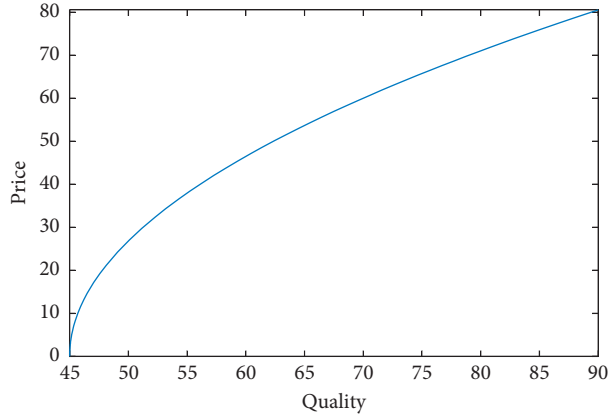


FIGURE 1: Change curve of optimal price with quality.

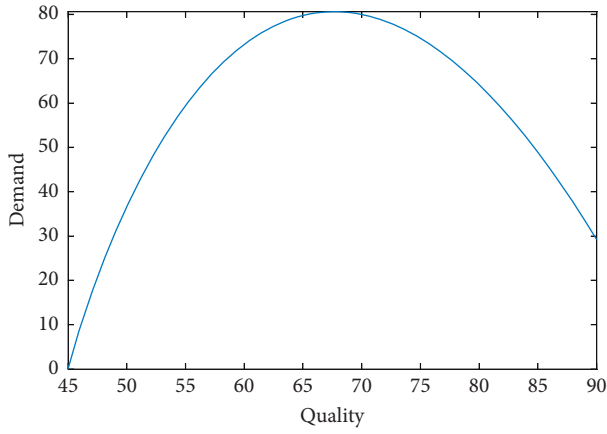


FIGURE 2: Change curve of demand with the quality.

Proposition 4. *The higher the quality of fresh agricultural products is, the more buying consumers it will attract. When the quality is accompanied by high prices, many consumers will be discouraged, resulting in a reduction in demand.*

Proof. Take the first order of derivative D_m with respect to M_k ; we have

$$p^* = \frac{(\alpha_1 + 1)[(1 - \theta)\alpha_0 D_0 + \alpha_0 \alpha_2 (C_d + C_p)]}{2(2\alpha_1 + 1)(1 - \theta)\alpha_0 \alpha_2} + \frac{\sqrt{(\alpha_1 + 1)^2 [(1 - \theta)\alpha_0 - D_0 \alpha_0 \alpha_2 (C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2 \alpha_1^2 \alpha_2 (C_d + C_p) D_0}}{2(2\alpha_1 + 1)(1 - \theta)\alpha_0 \alpha_2} \quad (10)$$

Proof. See Appendix. □

2.3. Cold Chain Logistics Distribution Cost Model

2.3.1. Objective Function. The objective of this section is to maximize the profit with considering the overall costs, which

$$\frac{d_D(p, M_k)}{d_M} = 0. \quad (6)$$

The quality when the fresh agricultural product reaches the demand nodes is

$$M_k = M_E + e^{\ln D_0 / \alpha_1 - \ln [(\alpha_1 + 1)\alpha_0 \alpha_2] / \alpha_1}. \quad (7)$$

Take the second order of derivative D_m with respect to M_k ; we have $M_k > M_E$. We can find that if demand will grow with quality,

$$M_E < M_k \leq M_E + e^{\ln D_0 / \alpha_1 - \ln [(\alpha_1 + 1)\alpha_0 \alpha_2] / \alpha_1}. \quad (8)$$

Meanwhile, if the demand will decrease with the growth of quality,

$$M_E + e^{\ln D_0 / \alpha_1 - \ln [(\alpha_1 + 1)\alpha_0 \alpha_2] / \alpha_1} < M_k < M_s. \quad (9)$$

This is consistent with the fact that consumers are more inclined to buy fresh agricultural products of better quality, but the price of fresh agricultural products will continue to rise as their quality rises, and excessively high prices will also reduce buying consumers. □

Proposition 5. *When a seller chooses a community group-buying strategy, its unique optimal solution is shown in equation (11):*

include fixed cost of distribution vehicles, variable distribution costs, cargo damage costs, refrigeration costs, labour costs, and sales losses that abandon distribution. Formula (11) is the objective function, which means to obtain the highest profit. q_i denotes the demand need to deliver to customer node i . Binary variable z_i is equal to 1 when the

customer node i is to be serviced. In this formulation, binary variable y_{ij}^k is equal to 1 when the vehicle k visits node j immediately after node i . Binary variable x_i^k is equal to 1 when the vehicle k visits node i . T_k denotes the temperature when the vehicle k is in operation. c_{ij}^k , s_{ij}^k , h_i^k , and f_k are different costs during the cold chain distribution; we will discuss each of the costs as follows:

$$\text{Max p} \sum_{i=1}^L q_i z_i - \sum_{k=1}^V \sum_{i=0}^L \sum_{j=1}^L (c_{ij}^k + s_{ij}^k) y_{ij}^k - \sum_{k=1}^V \sum_{i=1}^L h_i^k x_i^k - \sum_{k=1}^V f_k O_k. \quad (11)$$

Here c_{ij}^k denotes the variable delivery costs from i to j when we choose the vehicle k calculated by equation (12), where a_0 , b_0 , and c_0 are coefficients, and f denotes the unit fuel rate. c_{ij}^k is related to the weight of the vehicle k . w_k and w_i^k shown in equation (13) denote the weight of vehicle k and the weight when vehicle k leaves customer node i , respectively:

$$c_{ij}^k = \frac{a_0 \times (b_0 + c_0 \cdot w_i^k) d_{ij}}{w_i^k} f, \quad \forall i, j \in N, j \neq 0, k \in K, \quad (12)$$

$$w_0^k = w_k + \sum_{i=1}^L q_i x_i^k = w_k + \sum_{i=1}^L \sum_{j=1}^L q_i y_{ij}^k, \quad \forall k \in K, \quad (13)$$

where s_{ij}^k denotes the cost of refrigerant consumption of vehicle k between i and j , and it is calculated by equation (14). δ denotes the cost of unit refrigerant. λ_k denotes the coefficient determined by the vehicle k and it is shown in equation (15). μ denotes the depreciation of the vehicle. ρ denotes the coefficient of the thermal conductivity of the cabin material. In equation (16), M denotes the average surface area of the vehicle. M_W and M_N , respectively, represent the outer and inner surface areas of the vehicle. T_h denotes the environment temperature. Meanwhile T_k denotes the cooling temperature of the vehicle k and it is one of the decision variables:

$$s_{ij}^k = \delta \lambda_k \frac{d_{ij}}{v_{ij}} |T_h - T_k|, \quad \forall i, j \in N, i \neq j, k \in K, \quad (14)$$

$$\lambda_k = (1 + \mu) \times \rho \times M, \quad (15)$$

$$M = \sqrt{M_W M_N}, \quad (16)$$

where h_i^k denotes the refrigerant consumption cost of k car at customer point i , and it is the coefficient of vehicle k calculated by equation (17). η_k is a refrigerant calculation coefficient and it is calculated by equation (18). β denotes the frequency coefficient of door opening [11]. Here we suppose that when the door opening time is between 1 and 5, the value of β is 0.5. V denotes the volume of the vehicle. q_i denotes the demand at node i . v_l denotes the speed of loading and unloading. t_i denotes the loading and unloading time at node i and it is determined by q_i and v_l , shown in equation (19):

$$h_i^k = \delta \eta_k \Delta T t_i, \quad \forall k \in K, i \in N, i \neq 0, \quad (17)$$

$$\eta_k = (0.54V + 3.22) \times \beta, \quad (18)$$

$$t_i = \frac{q_i}{v_l}, \quad \forall i \in N, i \neq 0. \quad (19)$$

In the last term of (11) f_k denotes the fixed cost of the vehicle. O_k is a binary variable denoting whether the vehicle k is chosen for use.

2.3.2. Constraints. Constraint (20) indicates that each demand point that is delivered can only be delivered by one vehicle. Constraint (21) indicates that the vehicle must leave from that point after reaching a certain point. Constraint (22) indicates that if a vehicle is used, it must depart from the depot. Constraint (23) means that if a vehicle is used, it must return to the depot. Constraint (24) means to eliminate the subloop. Constraint (25) is the maximum load constraint of the vehicle. Constraint (26) means the relationship between x and y . Constraint (27) represents the relationship between the distribution temperature and other decision variables:

$$z_i - \sum_{k=1}^V x_i^k = 0, \quad \forall i \in N, i \geq 1 \quad (20)$$

$$\sum_{i=0}^L y_{ip}^k - \sum_{j=0}^L y_{pj}^k = 0, \quad \forall k \in K, p \in N, \quad (21)$$

$$O_k - \sum_{p=1}^L y_{0p}^k = 0, \quad \forall k \in K, \quad (22)$$

$$O_k - \sum_{p=1}^L y_{p0}^k = 0, \quad \forall k \in K, \quad (23)$$

$$u_i - u_j + L y_{ij}^k \leq L - 1, \quad u_i, u_j \geq 0, i, j \in N, i \neq j, j \geq 2, \quad (24)$$

$$\sum_{i=1}^L \sum_{j=1}^L q_i y_{ij}^k \leq G_k O_k, \quad \forall k \in K, \quad (25)$$

$$\text{or } \sum_{i=1}^L q_i x_i^k \leq G_k, \quad \forall k \in K,$$

$$\sum_{i=1}^L q_i x_i^k = \sum_{i=1}^L \sum_{j=1}^L q_i y_{ij}^k, \quad \forall k \in K, \quad (26)$$

$$(1 - 2O_k)(T_h - T_k) \leq 0, \quad \forall k \in V. \quad (27)$$

Constraint (28) is the requirement for delivery quality. M_k is calculated by equation (29). ε_n is the rate constant corresponding to the temperature z_k , calculated by the Arrhenius Equation (see equation (30)). M_0 denotes the initial quality. t_i^k denotes the service time of vehicle k at point

i, u_{ij}^k , denotes the transportation time of the vehicle k between i and j :

$$O_k(M_k - M^*) \geq 0, \quad \forall k \in K, \quad (28)$$

$$M_k = M_0 - \varepsilon_n \left(\sum_{i=1}^L t_i^k x_i^k + \sum_{i=1}^L \sum_{j=1}^L u_{ij}^k y_{ij}^k \right), \quad \forall k \in K, \quad (29)$$

$$k = k_0 e^{-\frac{E_a}{RT}}. \quad (30)$$

2.4. Implementation of the Collaborative Optimization Mechanism. Based on the above models, this paper implements the collaborative optimization mechanism by setting parameter iterations. The delivery quality requirement determined by the pricing model is used as the constraint of the distribution planning model. That is, the quality of products delivered to customers cannot be lower than the delivery quality requirements determined by the pricing model. The price determined by the pricing model is also used as the input parameter in the distribution planning model. The unit distribution cost obtained by the distribution planning model is used as the input parameter of the pricing model. Through iterative calculation, when the unit distribution cost obtained by the distribution planning model and the unit distribution cost of the pricing model tend to be consistent, the group purchase discount pricing strategy and cold chain distribution costs have achieved the collaborative optimization.

The iteration process is shown in Figure 3. At first, we consider an initial unit cold chain logistics cost and calculate the price, quality requirements, and market demand by the upper level. The lower level is used to obtain the distribution plan and the output unit cold chain cost under the constraints of the decision results calculated by the upper level. Then we can compare the unit cold chain logistics cost of the distribution scheme decided by the lower level with the assumed initial cold chain logistics cost. If it is consistent, iterative completion is completed. Otherwise, the unit cold chain logistics cost calculated by the lower level is used to replace the initial unit cold chain logistics cost and does the next round iteration.

3. Results and Discussion

3.1. Parameter Settings and Computation Results. In this section, the purpose price and planning are evaluated through a number of numerical tests. We develop a small-sized test set consisting of 6 orders based on the real setting of the community in Kunming. The parameter settings of the pricing model are shown in Table 1. In the actual operation situation of the community group purchase, generally the operator of the community will extract 10% of the sales. Therefore, the proportion of the operator is set as 0.1 in this paper. The initial unit cost is assumed value, and the optimal value is obtained through continuous iteration of the model. According to the community size, the potential market

demand rate is assumed to be 600. The influence of the potential market demand rate on the objective function and decision variables will be analysed later. The price constant is the average selling price of strawberries. According to curve-fitting, coefficients α_1 , α_2 , and α_3 can make the variation trend of various functions conform to the expected value within the value range. The value of group purchase time refers to the actual community group purchase sales time of 24 hours.

This paper assumes that a community group-buying enterprise sells strawberries, which is a kind of fresh agricultural product that is popular among people in different ages. It is equipped with a distribution center to carry out community group purchase activities in 6 large communities of a city and provide them with logistics and distribution services. Through the website, we obtained the information of latitude and longitude, construction age, total number of households, second-hand housing sources, rental housing sources, and other information of 100 communities in a city. Through the selection of information such as construction age, location of communities, and number of households, we finally determined 6 points as the service points of a community group-buying enterprise in this paper. The order quantity of each community is determined by the total number of households in the community, the occupancy rate combined with the online shopping utilization rate, and the proportion of fresh online shopping users who often buy fruits. Consider a real-world distribution system with the following data: $T_h = 22$, $\delta = 0.72$, $f = 0.7$, and $v_l = 30$. The other parameters of the vehicles are shown in Table 2.

In the case of small scale, we coded the above procedure using Lingo 12.0 and ran it on a PC with 3.20 GHz CPU and 8G memory to validate the efficiency of the solution method and the effectiveness of the proposed model. This section takes fresh fruit in an area of Yunnan Province as an example for analysis and presents the experimental settings and results. The optimal result can be obtained after four iterations and the process is shown in Table 3. At first, we suppose that the initial cold chain cost is 15 and we can calculate the quality and price by the upper level pricing model. Then, we put these two parameters into the lower level of the model and we can get a distribution scheme. After the first iteration, we get a unit cold chain cost which is 7.6025. Then, we use 7.6025 to replace the initial cold chain cost, 15, and make the second iteration until we can get the same value of the unit cold chain cost.

It can be seen from Table 4 that, in this group of calculation examples, the selling price of strawberries is 65.052. When we sold them at this price, if the potential market demand rate was 600, the sales profit could reach 63,440. To complete the delivery of 6 community points in the distribution center, three refrigerated vehicles are needed for the delivery of group purchase order quantity. The distribution path of vehicle 1 is 2-4-5-6, and the refrigeration temperature of the vehicle is about 2°C. Vehicle 2 just services demand node 1, and the refrigeration temperature of this vehicle is about 10°C. The distribution path of vehicle 3 is demand point 3, and the refrigeration temperature of the vehicle is about 14°C. The total delivery cost to complete the

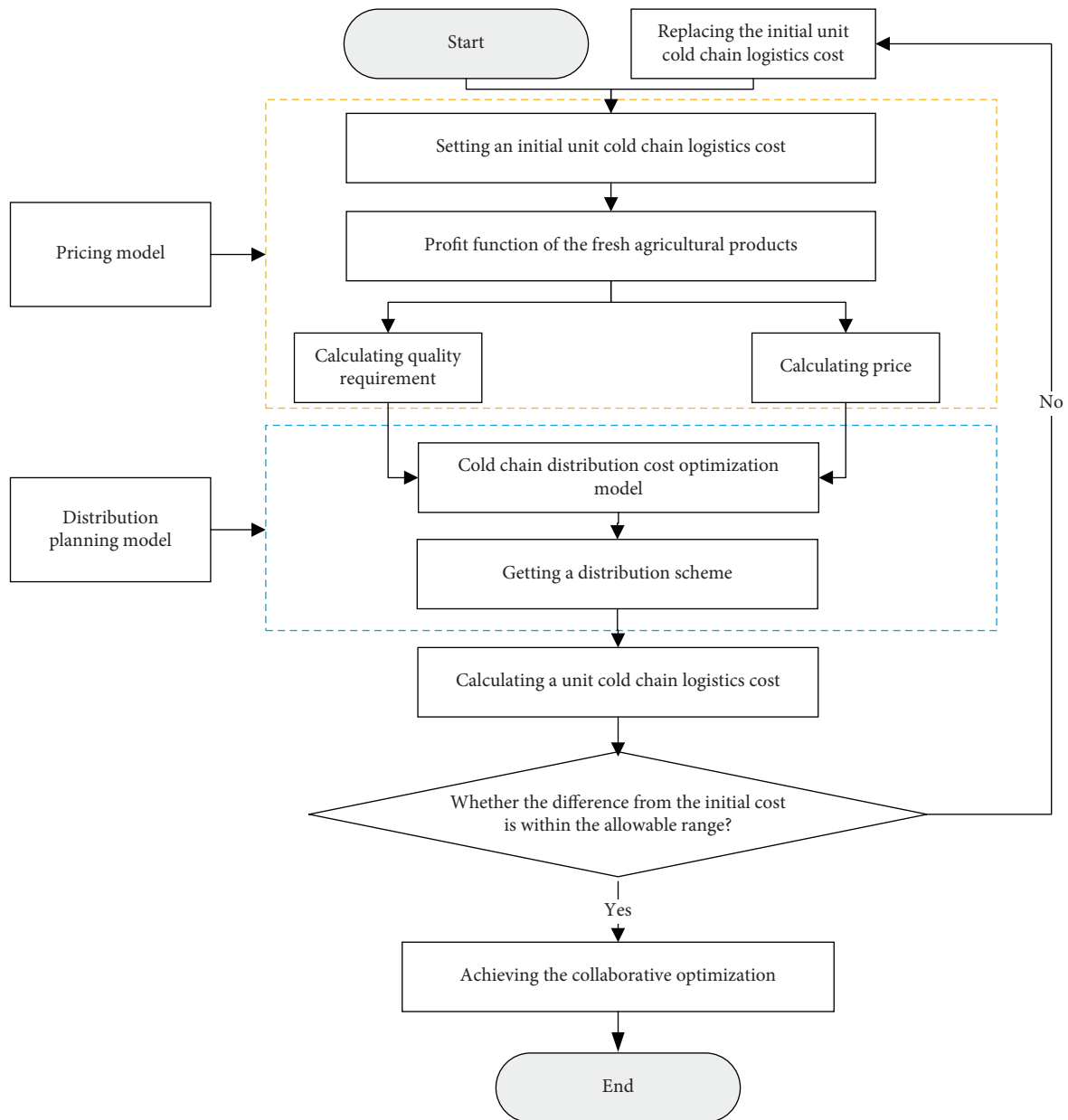


FIGURE 3: Collaborative optimization mechanism of community group purchase pricing model and cold chain distribution cost optimization model.

TABLE 1: Parameter settings of pricing model.

Parameter	Value
θ	0.1
C_d	15
C_p	16
D_0	600
α_0	12
α_1	0.5
α_2	7
α_3	0.8
M_E	45
T	24

actual order quantity of the six communities through the above distribution scheme is 3,366.

In order to illustrate the effect of the parameters on the optimal price and quality, the sensitivity analysis is performed by changing the value of only one parameter at a time and keeping the rest of the parameters at their initial values. These parameters are of significant influences on price and quality in practice but the specific impact is unknowable at present. Furthermore, the analysis of these parameters can reach valuable conclusions; thus, we can provide theoretical and practical reference for fresh agricultural community group purchase enterprises in operation.

TABLE 2: Parameter settings of distribution model.

Parameter	Value		
k	1	2	3
f	268	368	468
G	1485	3500	4830
V	12.68	22.04	23.06
a_0	0.012	1.369	1.749
b_0	0.061	0.061	0.061
c_0	0.014	0.014	0.014
w	2680	4580	4950
μ	0.08	0.08	0.08
M	49.38	68.68	75.68
ρ	0.02	0.02	0.02
η	5.034	7.5608	7.8362
λ	1.067	1.4834	1.6346
M_W	69.63	92.29	106.26
M_N	35.02	51.11	53.9

TABLE 3: Collaborative optimization process.

Upper level			Lower level					M^*	
C_d	M_k	p	Vehicle		Temperature				
			1	2	3	T_1	T_2	T_3	
Iteration 1									
15	75.210	69.956	3-4-5-6	2	1	1.27	12.30	9.75	76.210
The result of the unit cold chain cost is 7.6025. Replace the initial one									
Iteration 2									
7.6025	75.210	65.956	3-4-5-6	1	2	1.27	9.75	12.30	76.210
The result of the unit cold chain cost is 7.5730. Replace the initial one									
Iteration 3									
7.5730	74.388	65.053	2-4-5-6	1	3	1.65	10.31	14.10	75.39
The result of the unit cold chain cost is 7.5649. Replace the initial one									
Iteration 4									
7.5649	74.387	65.052	2-4-5-6	1	3	1.66	10.31	14.10	75.39
The result of the unit cold chain cost is 7.5649. End									

TABLE 4: Collaborative optimization results.

Vehicle	Route	Temperature	M^*	p^*	π	C_d
1	2-4-5-6	1.66				
2	1	10.31	75.39	65.052	63440	3366.414
3	3	14.10				

3.2. Impact of α_1 and α_2 on Price and Quality. As illustrated in Figure 4, by increasing the coefficient α_1 from 0.46 to 0.56 with an interval of 0.02, optimal price and quality will decrease. It implies that the increase in α_1 can influence the impact of quality changes on price. The quality decreases gradually; however, the price changes remain relatively stable.

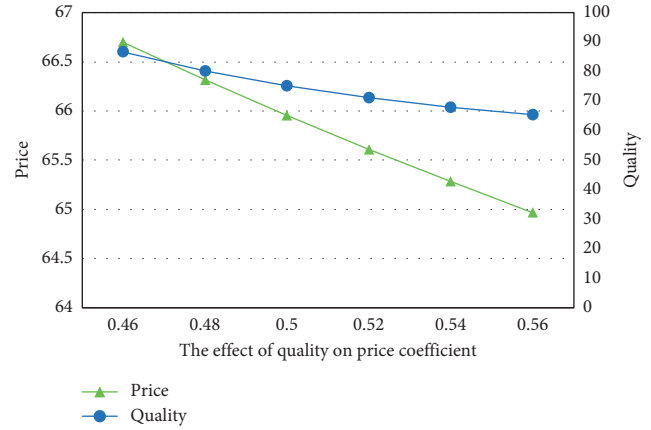


FIGURE 4: Change curves of optimal price and quality with α_1 .

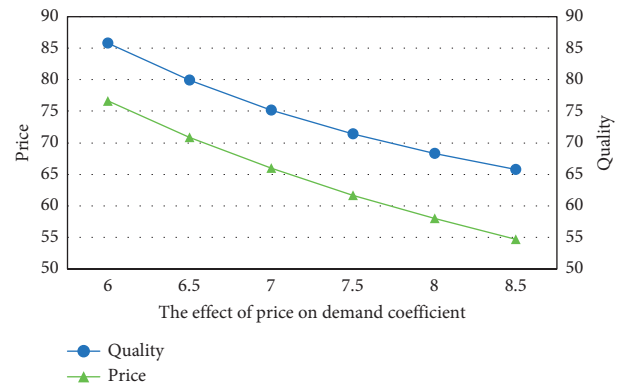


FIGURE 5: Change curves of optimal price and quality with α_2 .

The increase of α_2 means that the customer is more sensitive to the price. It is more likely that the customer will reduce purchase intention with the increase of α_2 . From Figure 5, we can observe that, by increasing α_2 from 6 to 8.5, continuous decreases in optimal price and quality can be achieved. When α_2 is small, the customer may not care about the price, and the operator will sell at a higher price in order to pursue higher profits, which in turn will guarantee a higher quality. However, in order to ensure the purchase intention of the customer, with the growth of α_2 , the operator needs not only to guarantee the corresponding quality but also to provide a lower price.

3.3. Impact of Distribution Costs on Pricing and Quality. In this section, we suppose that the unit distribution cost is increased from 4 to 20 with an interval of 2, consisting of 9 groups of data, and the changes of optimal sales pricing and quality are obtained as shown in Figure 6. It is not difficult to see that, with the increase of distribution cost, the selling price and quality of fresh agricultural products to consumers are also increasing. If the operator is willing to pay higher costs in the process of distribution, using small batches and low temperature or provide fast distribution service, the quality of the fresh agricultural products will be significantly improved, but consumers also have to pay a higher price.

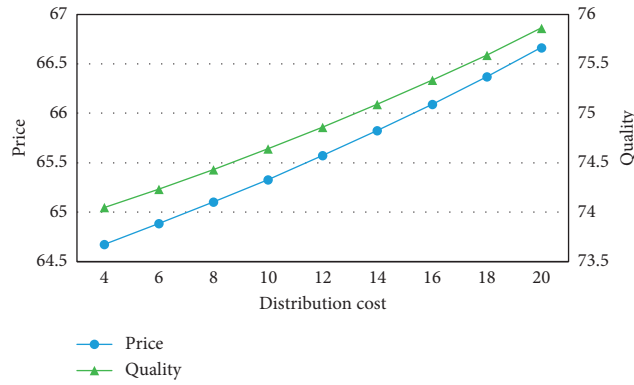


FIGURE 6: Change curves of optimal price and quality with the unit distribution cost.

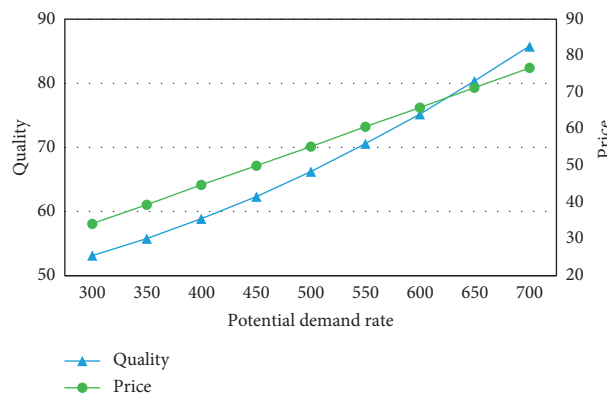


FIGURE 7: Change curves of optimal price and quality with the potential demand rate.

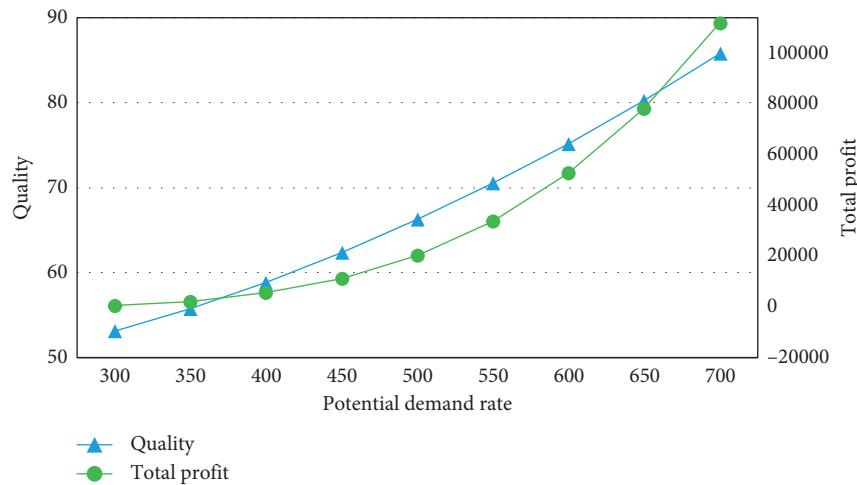


FIGURE 8: Change curves of total profit and quality with the potential demand rate.

3.4. Impact of Potential Rate on Quality, Price, and Total Profit.

In this section, we suppose that the market potential demand rate is increased from 350 to 700 with an interval of 50, which is composed of 9 groups of data. The changes of optimal price and quality are shown in Figure 7, and the changes of total profit and quality are shown in Figure 8. The

quality of fresh agricultural products increases with the increase of market potential demand rate. When the potential demand rate increases, the actual market demand will also increase. When the demand rate is too small, the demand will be far less than the distribution cost. If the vehicle with the minimum load is selected for distribution, the profit

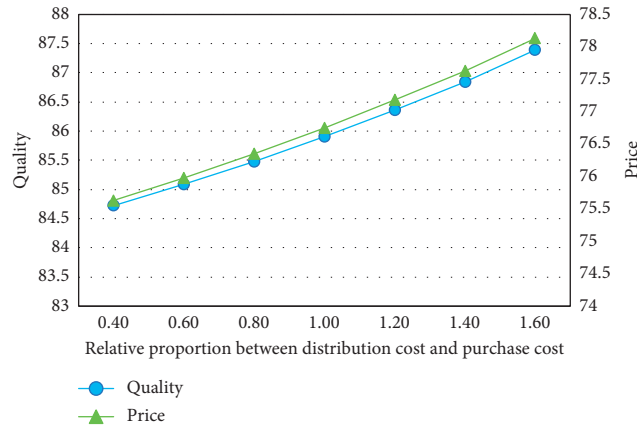


FIGURE 9: Change curves of total price and quality with relative proportion between distribution cost and purchase cost.

will be negative in such situation. When the demand is large enough to meet the maximum vehicle load, the operator will timely arrange multiple batches of distribution, so as to ensure a high level of quality. At the same time, the sales price increases with the increase of the market potential demand rate, which is consistent with the general market rules. Also, it is easy to see that the price trends are consistent with quality, which is mentioned in Proposition 2. Therefore, from the perspective of the operator’s benefits, when the demand increases, the operator should appropriately increase the sales price of fresh agricultural products to obtain the maximum profit under the potential demand during the sales period. At the same time, it can be seen from the above analysis that, in order to meet higher profits, the operators will increase the distribution cost. Therefore, it is suggested that the operators may consider sacrificing part of the profit value to reduce the total logistics cost and optimizing the logistics distribution scheme to improve customer satisfaction when making price decisions, which may result in a high total profit level.

3.5. Impact of Relative Proportion between Distribution Cost and Purchase Cost on Price and Quality. In this section, we suppose that the relative proportion between cold chain distribution cost and purchase cost is increased from 0.4 to 1.6 with an interval of 0.2, which is composed of 7 groups of data. The increase of the relative proportion between distribution cost and purchase cost can be seen from Figure 9. By comparing these two curves, it is implied that the price changes more than quality with the relative proportion between distribution cost and purchase cost. In other words, it is consistent with the real case where online fresh agricultural enterprise should raise its pricing to cope with rising costs and maintain a certain level of profitability.

4. Conclusions

The purpose of this study is to give a collaborative optimization mechanism of community group purchase pricing model and cold chain distribution cost model. Moreover, we use a two-layer mathematical programming method to

search for the optimal solution of this problem with feasibility and effectiveness. The numerical experiment of the model is implemented based on the real-world data in Kunming (China) and the optimal pricing and distribution scheme is obtained through iterations.

Through the parameters impact analysis, the following conclusions are drawn. First of all, the sales price increases with the increase of the market potential demand rate. Second, the quality and price sensitivity of fresh agricultural products have a significant impact on the price and demand and further influence the total profit. During the cold chain transportation services, the quality of fresh agricultural products will drop with the increase of the time and temperature. Third, the results show that the vast majority of cases tend to choose the cooler temperature, not only to guarantee the quality of strawberries but also to keep strawberry’s higher selling price and increase total profits. Of course, sometimes they may choose the high temperature distribution, of which vehicle is with little delivery quantity. This decision result is to satisfy the constraint conditions and objective function after the result of the decision. Under the optimal path solution, even distribution temperature is higher, but the mutual influence among sales price, distribution scheme, and quantity still can guarantee the quality of the fresh products. Finally, the selling price and quality of fresh agricultural products to consumers are also increasing with the increase of distribution cost.

Therefore, it is suggested that the community group purchase enterprise should take the factors including temperature, quality, potential demand rate, and time of duration into consideration to make a more reasonable decision on price and distribution scheme. In the future, we will apply robust optimization algorithms to solve the problem with the situation existing in more communities. We also consider presale strategy used in the community group purchase by dividing the sale into one presale period and one regular sale period.

Appendix

Proof of Proposition 5.

Proposition A.1. *When a seller chooses a community group-buying strategy, its unique optimal solution is*

$$p^* = \frac{(\alpha_1 + 1)[(1 - \theta)\alpha_0 D_0 + \alpha_0 \alpha_2 (C_d + C_p)] + \sqrt{(\alpha_1 + 1)^2 [(1 - \theta)\alpha_0 D_0 - \alpha_0 \alpha_2 (C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2 \alpha_1^2 \alpha_2 (C_d + C_p) D_0}}{2(2\alpha_1 + 1)(1 - \theta)\alpha_0 \alpha_2}. \quad (\text{A.1})$$

Proof. In order to simplify calculation, we suppose that $M = M_k - M_E$, and

$$\begin{aligned} \frac{d\pi(p)}{dM} &= \left\{ [(1 - \theta)\alpha_0 M^{\alpha_1} - C_d - C_p] T \alpha_3 \frac{M}{M_E} [D_0 - \alpha_2 \alpha_0 M^{\alpha_1}] \right\}, \\ &= \left\{ [(1 - \theta)\alpha_0 M^{\alpha_1} - C_d - C_p] \left[D_0 T \alpha_3 \frac{M}{M_E} - T \alpha_3 \alpha_2 \alpha_0 M^{\alpha_1} \frac{M}{M_E} \right] \right\}, \\ &= \left\{ (1 - \theta) D_0 T \alpha_0 \alpha_3 \frac{1}{M_E} M^{\alpha_1+1} - (C_d + C_p) D_0 T \alpha_3 \frac{M}{M_E} - (1 - \theta) T \alpha_2 \alpha_3 \alpha_0^2 M^{2\alpha_1+1} \frac{1}{M_E} + (C_d + C_p) T \alpha_2 \alpha_3 \alpha_0 M^{\alpha_1+1} \frac{1}{M_E} \right\}, \\ &= \left\{ \alpha_3 T \frac{1}{M_E} [(1 - \theta) D_0 \alpha_0 M^{\alpha_1+1} - (C_d + C_p) D_0 M - (1 - \theta) \alpha_2 \alpha_0^2 M^{2\alpha_1+1} + (C_d + C_p) \alpha_2 \alpha_0 M^{1+\alpha_1}] \right\}, \\ &= \alpha_3 T \frac{1}{M_E} [(\alpha_1 + 1)(1 - \theta) D_0 \alpha_0 M^{\alpha_1} - (C_d + C_p) D_0 - (2\alpha_1 + 1)(1 - \theta) \alpha_2 \alpha_0^2 M^{2\alpha_1} + (\alpha_1 + 1)(C_d + C_p) \alpha_2 \alpha_0 M^{\alpha_1}] \\ &= \alpha_3 T \frac{1}{M_E} \{ -(2\alpha_1 + 1)(1 - \theta) \alpha_2 \alpha_0^2 M^{2\alpha_1} + (\alpha_1 + 1)[(1 - \theta) \alpha_0 D_0 + \alpha_0 \alpha_2 (C_d + C_p)] M^{\alpha_1} - (C_d + C_p) D_0 \}. \end{aligned} \quad (\text{A.2})$$

When $d\pi(p)/dM = 0$,

$$-(2\alpha_1 + 1)(1 - \theta) \alpha_2 \alpha_0^2 M^{2\alpha_1} + (\alpha_1 + 1)[(1 - \theta) \alpha_0 D_0 + \alpha_0 \alpha_2 (C_d + C_p)] M^{\alpha_1} - (C_d + C_p) D_0 = 0. \quad (\text{A.3})$$

Suppose that $M^{\alpha_1} = x$; we can find

$$\begin{aligned}
& -(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2x^2 + (\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]x - (C_d + C_p)D_0 = 0, \\
\Delta &= \{(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]\}^2 - 4 \times [-(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2] \{-(C_d + C_p)D_0\} \\
&= (\alpha_1 + 1)^2 [(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]^2 - 4(C_d + C_p)D_0 [(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2] \\
&= (\alpha_1 + 1)^2 \left[(1 - \theta)^2\alpha_0^2D_0^2 - 2(1 - \theta)\alpha_0^2\alpha_2(C_d + C_p)D_0 + \alpha_0^2\alpha_2^2(C_d + C_p)^2 + 4(1 - \theta)\alpha_0^2\alpha_2(C_d + C_p)D_0 \right] \\
&\quad - 8(1 - \theta)\alpha_0^2\alpha_1\alpha_2(C_d + C_p)D_0 - 4(1 - \theta)\alpha_0^2\alpha_2(C_d + C_p)D_0 \\
&= (\alpha_1 + 1)^2 [(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)(\alpha_1 + 1)^2\alpha_0^2\alpha_2(C_d + C_p)D_0 \\
&\quad - 8(1 - \theta)\alpha_0^2\alpha_1\alpha_2(C_d + C_p)D_0 - 4(1 - \theta)\alpha_0^2\alpha_2(C_d + C_p)D_0 \\
&= (\alpha_1 + 1)^2 [(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2\alpha_2(C_d + C_p)D_0 [(\alpha_1 + 1)^2 - 2\alpha_1 - 1] \\
&= (\alpha_1 + 1)^2 [(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2\alpha_1^2\alpha_2(C_d + C_p)D_0 > 0, \\
x_1 &= \frac{(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)] + \sqrt{(\alpha_1 + 1)^2 [(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2\alpha_1^2\alpha_2(C_d + C_p)D_0}}{2(2\alpha_1 + 1)(1 - \theta)\alpha_0^2\alpha_2}, \\
x_2 &= \frac{(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)] - \sqrt{(\alpha_1 + 1)^2 [(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2\alpha_1^2\alpha_2(C_d + C_p)D_0}}{2(2\alpha_1 + 1)(1 - \theta)\alpha_0^2\alpha_2}.
\end{aligned} \tag{A.4}$$

M_1 can be obtained as

$$M_1 = e^{\frac{\ln \left[(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)] + \sqrt{(\alpha_1 + 1)^2 [(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2\alpha_1^2\alpha_2(C_d + C_p)D_0} \right]}{\alpha_1 - \ln [2(2\alpha_1 + 1)(1 - \theta)\alpha_0^2\alpha_2]}}. \tag{A.5}$$

Here, we find that

$$(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)] < \sqrt{(\alpha_1 + 1)^2 [(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2\alpha_1^2\alpha_2(C_d + C_p)D_0}. \tag{A.6}$$

When $M > 0$, $d\pi(p)/dM = 0$ has only one root. When $0 < M < M_1$, $\partial\pi(p)/\partial M > 0$; $\pi(p)$ is monotonically increasing. The profit increases with the increasing of M :

$$\begin{aligned}
\frac{d^2\pi(p)}{d^2M} &= \left\{ \alpha_3 T \frac{1}{M_E} \left\{ -(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2M^{2\alpha_1} + (\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]M^{\alpha_1} - (C_d + C_p)D_0 \right\} \right\}, \\
&= \alpha_3 T \frac{1}{M_E} \left\{ -2\alpha_1(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2M^{2\alpha_1 - 1} + \alpha_1(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]M^{\alpha_1 - 1} \right\}.
\end{aligned} \tag{A.7}$$

When $d^2\pi(p)/d^2M = 0$,

$$\begin{aligned}
& -2\alpha_1(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2M^{2\alpha_1 - 1} + \alpha_1(\alpha_1 + 1) \\
& \cdot [(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]M^{\alpha_1 - 1} = 0, \\
2(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2M^{2\alpha_1 - 1} &= (\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]M^{\alpha_1 - 1}, \\
\frac{M^{2\alpha_1 - 1}}{M^{\alpha_1 - 1}} &= \frac{(\alpha_1 + 1)[(1 - \theta)D_0 + \alpha_2(C_d + C_p)]}{2(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0}, \tag{A.8} \\
M^{\alpha_1} &= \frac{(\alpha_1 + 1)[(1 - \theta)D_0 + \alpha_2(C_d + C_p)]}{2(2\alpha_1 + 1)(1 - \theta)\alpha_2}, \\
M &= e^{\ln\{(\alpha_1 + 1)[(1 - \theta)D_0 + \alpha_2(C_d + C_p)]\}/\alpha_1 - \ln[2(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0]/\alpha_1}.
\end{aligned}$$

We can find that when $M > e^{\ln\{(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]\}/\alpha_1 - \ln[2(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2]/\alpha_1}$, $\pi(p)$ is a convex function. When $0 < M < e^{\ln\{(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]\}/\alpha_1 - \ln[2(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2]/\alpha_1}$, $\pi(p)$ is a concave function.

When $0 < M < M_1$, $d\pi(p)/dM > 0$ and $0 < e^{\ln\{(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]\}/\alpha_1 - \ln[2(2\alpha_1 + 1)(1 - \theta)\alpha_2\alpha_0^2]/\alpha_1} < M_1$.

We can find that

$$\begin{aligned}
\max \pi(M = e^{\ln\{(\alpha_1 + 1)(D_0 + \alpha_2(C_d + C_p))\}/\alpha_1 - \ln[2(2\alpha_1 + 1)\alpha_0\alpha_2]/\alpha_1}) \\
< \max \pi(M = M_1). \tag{A.9}
\end{aligned}$$

Then, we have

$$\max \pi(M = 0) = 0 < \max \pi(M = M_1). \tag{A.10}$$

We can easily find that when $M > 0$, the maximum profit level is $\max \pi(M = M_1)$. The optimal quality exists and is unique; that is, $M^* = M_1$. The corresponding M_k^* and p^* are shown as follows:

$$\begin{aligned}
M_k^* &= M_1 + M_E = e^{\ln\left\{(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)]/\alpha_1 + \sqrt{(\alpha_1 + 1)^2[(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2\alpha_1^2\alpha_2(C_d + C_p)D_0}\right\}/\alpha_1 - \ln[2(2\alpha_1 + 1)(1 - \theta)\alpha_0^2\alpha_2]/\alpha_1} \\
&+ M_E, \\
p^* &= \frac{(\alpha_1 + 1)[(1 - \theta)\alpha_0D_0 + \alpha_0\alpha_2(C_d + C_p)] + \sqrt{(\alpha_1 + 1)^2[(1 - \theta)\alpha_0D_0 - \alpha_0\alpha_2(C_d + C_p)]^2 + 4(1 - \theta)\alpha_0^2\alpha_1^2\alpha_2(C_d + C_p)D_0}}{2(2\alpha_1 + 1)(1 - \theta)\alpha_0\alpha_2}. \tag{A.11}
\end{aligned}$$

Thus, we can find the unique optimal community group purchase price for this problem. \square

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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