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IMPACTS OF E-COMMERCE PLATFORM AND CONSUMERS' SUPPORTING PREFERENCES FOR POOR AREAS IN A SUPPLY CHAIN

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Abstract. In this paper, we consider a poverty alleviation (PA) agricultural product supply chain with an e-commerce platform, a farmer in poor areas, and a farmer in other general areas, where the platform with corporate social responsibility and consumers both have supporting preferences for poor areas. We investigate the optimal strategies by further considering logistics cost difference between the poor areas and other areas. The results indicate that the platform and consumers' supporting preferences are both beneficial to improve the poor farmer's profit, while they may decrease the sales quantity and the price of general agricultural products. In addition, the high logistics cost of poor areas has negative impacts on the sales of PA agricultural products and the poor farmer's profit. By virtue of some numerical analysis, we further discover that the platform's profit improves with its supporting preference only when consumers' supporting preference is relatively large, or when the platform and consumers' supporting preferences are both relatively small. In addition, the consumer surplus always improves with supporting preference.

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1. Introduction

Poverty is a global challenge faced by many countries, especially those in Sub-Saharan African, South Asia and other regions. Eliminating poverty is the primary goal of the United Nations in 2030 Agenda for Sustainable Development. According to the World Bank, the global extreme poverty rate, which is measured by the number of people living on less than \$1.9 per day, was steadily declining from 40% in the 1990s to 8.5% in 2019. In particular, as of 2020, China has eliminated absolute poverty, which is measured as living on less than 2300 yuan (CNY) per year. However, COVID-19, climate change, wars and other factors have put a lot of challenges to the poverty cutting procedure. It is estimated that the global extreme poverty rate rises to 9.4% and 9.1% in 2020 and 2021 respectively. Moreover, those factors have brought uncertainty in our real life and supply chain management (see, *e.g.*, [5, 20, 21]).

Underdeveloped agricultural industry, and agricultural products with thin profits and difficulty to sell, are two main reasons for an area's poverty or returning to poverty [39]. On one hand, the local market in poor areas

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usually have a small capacity and insufficient demand. On the other hand, poor areas are usually far from big cities, and are lack of transportation and logistics infrastructure, which have significant negative impacts on the sale of agricultural products.

As digital technologies develop, there has been a rapid development of e-commerce of agricultural products[1]. Recently, some e-commerce giants with corporate social responsibility implement various measures to support the selling of agricultural products from poverty-stricken areas (we also call poverty alleviation agricultural products or PA agricultural products thereafter), such as providing e-selling channels and opening special sale area for PA agricultural products. The e-commerce platform can also acquire ethical value for fighting poverty [29]. For example, Jingdong (JD. com) launched special pavilions for agricultural products of poor and rural areas in 2021, such as China Specialty·Luochuan Pavilion and China Specialty·Enshi Pavilion, and provided logistics support for them. Taobao (Taobao.com) launched "Local goods and fresh food" channel covering agricultural products from 832 counties just out of poverty in China. Pinduoduo (Pinduoduo.com) set up the pavilion for high quality agricultural products of Gansu Province in 2019 and per capita income of farmers increased by 380 Chinese yuan (CNY)[2].

Ethical consumers also have preference for supporting poor areas and they acquire ethical value when helping poverty-stricken areas [6,11]. Therefore, consumers are willing to pay a price premium for PA agricultural products, compared to agricultural products of other general areas (we call general agricultural products thereafter) [6,11]. It is reported that the value of PA agricultural products purchased or sold by other regions in China has reached 11.16 trillion CNY in 2022[3].

However, impoverished areas still face logistics challenges during the process of online selling. Impoverished areas are usually remote and mountainous regions. For example, the four southern Xinjiang regions represented by Aksu Prefecture, China, are confronted with long transportation distance and multiple transition, which brings huge logistics costs. Furthermore, due to the lack of pre-cooling infrastructures in poor and rural areas, those areas have the First Mile problem, which exaggerates logistics costs. Actually, the local purchase price of green walnuts of Longnan City, Gansu Province, China is 4 CNY per kilogram, while the shipping cost reaches 15 CNY per kilogram [39].

Based on the above background, we aim to find answers to the following questions: (1) Considering that e-commerce platforms with corporate social responsibility and consumers both present supporting preferences for poor areas and relatively higher logistics costs of poor areas, what would be the impacts on poor farmers' welfare? (2) How do e-commerce platforms and consumers' supporting preferences for poor areas affect the selling of agricultural products from other general areas and farmers' profits? (3) What are the impacts of e-commerce platforms and consumers' support for poor areas on profits of platforms and the consumer surplus?

To address the above inquires, we consider a supply chain with a farmer from poor areas, a farmer from general areas and an e-commerce platform, where the e-commerce platform with corporate social responsibility have supporting preference for poor areas and is concerned about the poor farmer's profit. Consumers also have supporting preference for poor areas and are willing to pay more for PA agricultural products. The characteristics of poor areas, such as high logistics costs, are also taken into consideration. We use a Stackelberg game model to investigate optimal strategies of the supply chain.

The rest of the paper is organized as follows. In Section 2, we review relevant literature and summarize innovation points of the paper. Then we present the assumptions and formulate the problem in Section 3. In Section 4, we derive the optimal strategies of the supply chain. Then, we discuss and analyze the optimal strategies and propose some managerial implications in Section 5. In Section 6, we conclude the paper and give some future research topics. All the proofs are given in the Appendix A.

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[1] https://www.gov.cn/lianbo/fabu/202307/content_6893264.htm.

[2] http://www.farmer.com.cn/2020/09/29/99860156.html.

[3] https://nrra.gov.cn/2022/12/29/ARTIPuGBfWEg9RSv9QTWWPbM221229.shtml.

2. Literature review and motivations

In this section, we review related literature from three aspects: poverty alleviation (PA) agricultural product supply chain management, corporate social responsibility, and competitive supply chain management.

2.1. Poverty alleviation agricultural product supply chain management

The topics of poverty alleviation (PA) and poverty alleviation agricultural product supply chain management have gained more and more interest recently. Most researchers consider that enterprises support the selling of agricultural products of poor areas and examine poverty alleviation performance considering consumers' poverty alleviation preference and enterprises' poverty alleviation effort. Xie *et al.* [32] examine the performance of three poverty alleviation schemes (contract only, contract with compensation, and capacity training) in a supply chain including a pre-poor enterprise and a group of poor farmers. Blockchain technology can help to improve the transparency of supply chains and it has been considered by many researchers (see, *e.g.*, [2–4]). In particular, Yu *et al.* [33] investigate the poor farmer's production strategies and the retailer's strategies of pricing and poverty alleviation effort with and without the blockchain technology adoption in a two-level supply chain. Feng and Guo [8] and Feng *et al.* [9] consider consumers' supporting preference in a supply chain consisting of a poor farmer, a general farmer and a retailer, and they investigate the pricing strategies of agricultural products and the profits of supply chain members.

Some researchers focus on e-commerce platforms' support for e-selling of agricultural products of poor areas. Zhang and Luo [35] consider an agricultural product supply chain including a poor farmer and an e-commerce platform to study optimal production strategies of the farmer, and pricing and poverty alleviation effort strategies of the platform under agency selling and reselling modes. Sun and Peng [29] further consider the e-commerce platform's supporting preference for the poor farmer and compare poverty alleviation performance of two modes. Zhang *et al.* [37] consider two poverty alleviation schemes of e-commerce platforms: interest subsidy and *Fupinguan* investment which can expand market demand. They investigate the optimal strategies for a supply chain including a poor farmer, a general farmer and an e-commerce platform, and analyze the effects of two schemes on the profits of the farmers and the platform, and the consumer surplus.

The design of poverty alleviation policies are further explored. Zhou and Che [39] study optimal strategies for a supply chain with a poor farmer, a general farmer and a logistics enterprise under the logistics cost subsidy and cold chain logistics investment subsidy. Farmers' profits and social welfare under two subsidies are compared. Kang *et al.* [13] investigate the coordination mechanism for a two-level agricultural product supply chain considering government subsidies and the farmer's fairness concern.

However, very few literature consider logistics costs with regard to online selling of agricultural products of poor areas. To the authors' best knowledge, Sun and Peng [29], Zhou and Che [39] are the only two papers on this topic. However, Sun and Peng [29] do not consider market competition between PA and general agricultural products, and Zhou and Che [39] do not consider enterprises' supporting preference for poor farmers. It is meaningful to explore poverty alleviation performance in competitive market environment with enterprises and consumers' supporting preferences for poor areas, and logistics costs difference between poor areas and general areas.

2.2. Corporate social responsibility

Current literature consider corporate social responsibility (CSR) in supply chains mainly from two aspects: corporate social responsibility investment and enterprises' concern about the welfare of other supply chain members. Many researchers investigate optimal strategies of corporate social responsibility investment [10, 19, 33, 35, 37] and incentive mechanisms for such investment [12, 26], considering that corporate social responsibility investment can improve market demand.

Ma *et al.* [18] propose that corporations with social responsibility are concerned about the welfare of other stakeholders, such as upstream and downstream corporations, consumers or the whole society, and take them into decision-making objectives. Accordingly, some researchers investigate optimal strategies and coordination mechanisms for supply chains considering corporations' concern about the consumer surplus [14, 17]. Other researchers consider enterprises' concern about profits of upstream or downstream enterprises, which also refers to altruistic preference. Fan *et al.* [7] investigate optimal pricing strategies for a two-level supply chain, considering the retailer's altruistic preference for the manufacturer. Rong and Xu [24] study the impacts of the manufacturer's altruistic preference for the retailer on the greenness level and price of products. Sun and Peng [29] consider the e-commerce platform's concern about the profit of the upstream poor farmer and consumers' supporting preference for agricultural products of poor areas to study the farmer's production strategies and the platform's pricing strategies. Wu *et al.* [31] analyze the impacts of the retailer's altruistic preferences for competitive manufacturers on pricing strategies and profits of supply chain members. Liu *et al.* [16] consider a two-level logistics service supply chain and study impacts of altruistic preferences of both upstream and downstream parties on their utilities.

In this paper, we consider that e-commerce platforms with corporate social responsibility is concerned about upstream farmers' profits and have supporting preference for them, which is similar to altruistic preference. To our best knowledge, very few papers consider enterprises and consumers' altruistic preferences simultaneously other than Sun and Peng [29]. The comprehensive effects of enterprises and consumers' altruistic preferences in competitive environment need to be investigated further.

2.3. Competitive supply chain management

With increasing market competition, competitive supply chain management has received more and more attention. Some researchers consider the competition between downstream firms and investigate optimal strategies for the supply chain [27, 38]. Zheng *et al.* [38] consider a supply chain including a supplier and competitive manufacturers, and they analyze the coordination mechanism for the supply chain with the supplier's concession of benefits for manufacturers.

Some researchers focus on the competition between upstream firms [8, 9, 37]. Nematollahi *et al.* [22] consider consumers' different preferences for organic agricultural products and general agricultural products to investigate production and pricing strategies of agricultural products in a supply chain with an organic farmer, a general farmer and a retailer. Wu *et al.* [31] consider a supply chain consisting of competitive manufacturers and a retailer, and analyze the influence of the retailer's altruistic preferences for both manufacturers on pricing strategies and profits of supply chain members. Lin *et al.* [15] and Saha *et al.* [25] investigate pricing and carbon reduction strategies of the supply chain with two manufacturers and a retailer, considering price and greenness level competition between manufacturers. Zhang *et al.* [36] further consider the price, greenness level and quality level competition between manufacturers, and investigate the optimal strategies of pricing, carbon reduction and quality investment of the supply chain.

Among all the literature mentioned above, only Wu *et al.* [31] study the effects of altruistic preference in a competitive supply chain, and they assume that the retailer presents altruistic preferences for both manufacturers, and the manufacturers have symmetric costs. To our best knowledge, the impacts of enterprises and consumers' different altruistic preferences for heterogeneous upstream parties, which are with asymmetric costs, on profits of supply chain members and the consumer surplus have not been investigated yet.

2.4. Motivations and highlights

From above literature review, we can see that poverty alleviation supply chain management has become a very hot research topic, and many research works have been done related to this topic. However, one thing that was missing in the existing literature is the comprehensive effects of enterprise and consumers' supporting preferences on poverty alleviation performance in a competitive environment. Further, the characteristics of agricultural products of poor areas, such as high logistics cost, are often not taken into account. Aiming at filling the gaps, we investigate the optimal strategies of an agricultural product supply chain consisting of a poor farmer, a general farmer and an e-commerce platform, in which the e-commerce platform and consumers

Table 1. Comparison with related existing literature.

Papers	PA supply chain	Logistics cost	CSR		Consumers' preference	Competition
			CSR investment	Altruistic preference		
Xie *et al.* [32]	√					
Feng and Guo [8]	√				√	√
Feng *et al.* [9]	√				√	√
Sun and Peng [29]	√	√		√	√	
Zhang and Luo [35]	√		√		√	
Zhang *et al.* [37]	√		√		√	√
Zhou and Che [39]	√	√				√
Fan *et al.* [7]				√		
Wu *et al.* [31]				√		√
This Paper	√	√		√	√	√

both have supporting preferences for the poor farmer, and logistics costs difference between poor areas and general areas are considered.

We summarize the key differences between this paper and the existing literature in Table 1. In particular, this paper is different from the existing literature at three aspects. (1) We consider the e-commerce platform with corporate social responsibility and consumers both have supporting preferences for the poor farmer, and we analyze the impacts of such preferences on poverty alleviation performance in a competitive environment. (2) We consider the high logistics cost of poor areas, and investigate the effects of logistics costs difference between poor areas and general areas on poverty alleviation performance. (3) We analyze the influence of the e-commerce platform and consumers' supporting preferences for the poor farmer on the selling of general agricultural products, profits of the general farmer and the e-commerce platform, and the consumer surplus.

3. Problem formulations

In this section, we formulate the problem as a Stackelberg game model, and present some critical assumptions. We consider an agricultural product supply chain consisting of a farmer from poor areas (the poor farmer) and a farmer from general areas (the general farmer) and an e-commerce platform. In the supply chain, the poor farmer sells agricultural products both in the local market of poor areas and through the e-commerce platform to consumers in the national market (Fig. 1). The e-commerce platform with corporate social responsibility and consumers both present supporting preferences for the poor farmer, which means that the e-commerce platform is concerned about the poor farmer's welfare and consumers are willing to pay a price premium for agricultural products produced by the poor farmer (poverty alleviation (PA) agricultural products). Moreover, the expensive logistics cost associated with e-selling of PA agricultural products and logistics costs difference between PA agricultural products and general agricultural products are considered.

We build a Stackelberg game model to examine the optimal selling quantity strategies of two farmers and the optimal pricing strategies of the e-commerce platform based on above considerations. Typically, farmers have less bargaining power than the e-commerce platform [23, 28]. Therefore, we consider that the e-commerce platform is the leader and two farmers are followers in the Stackelberg game model. The decision sequence is as follows. First, the e-commerce platform decides the purchase prices of both PA and general agricultural products. Then, two farmers decide their selling quantities of agricultural products simultaneously. On this basis, we analyze the effects of the e-commerce platform and consumers' supporting preferences for poor areas on the optimal strategies and profits of the farmers and the e-commerce platform, and the consumer surplus. The notations and meaning for variables and parameters are given in Table 2.

In addition, we make the following assumptions.

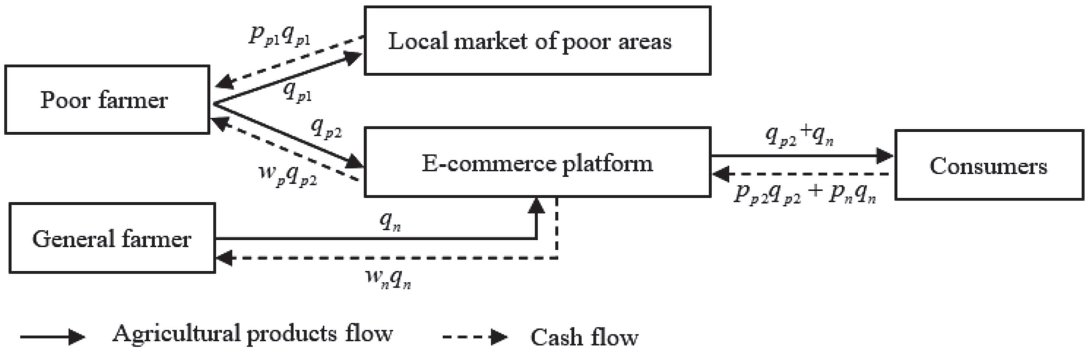


Figure 1. Agricultural product supply chain system.

Table 2. Model notations.

Notations	Meaning
fp, fn, e	Subscripts, representing the poor farmer, the general farmer and the e-commerce platform;
p_{p_1}, p_{p_2}, p_n	The local market price and e-selling price of PA agricultural products, e-selling price of general agricultural products;
γ	The supporting preference coefficient of the e-commerce platform;
θ	The supporting preference coefficient of consumers;
c_p, c_n	The production effort cost coefficients of the poor farmer and the general farmer;
c_{tp}, c_{tn}	Unit logistics costs of PA and general agricultural products;
c_t	The logistics effort cost coefficient for e-selling of PA agricultural products;
q_0	The basic quantity of agricultural products for e-selling in poor areas;
π_{fp}, π_{fn}	Profits of the poor farmer and the general farmer;
π_e, U_e	Profit and utility of the e-commerce platform;
CS	The consumer surplus;
q_{p_1}, q_{p_2}	Selling quantities of PA agricultural products in the local market and through the e-commerce platform, the poor farmer's decision variables;
q_n	Selling quantity of general agricultural products through the e-commerce platform, the general farmer's decision variable;
w_p, w_n	Purchase prices of PA and general agricultural products, the e-commerce platform's decision variables.

Assumption 1. *The inverse demand function in the local market of poor areas is given by*

$$p_{p_1} = a_1 - b_1 q_{p_1}. \tag{1}$$

Since both the poor farmer and the general farmer sell agricultural products through the e-commerce platform to consumers in the national market, the inverse demand function of general agricultural products is given by

$$p_n = a_2 - b_2(q_{p_2} + q_n). \tag{2}$$

In addition, consumers have supporting preference for poor areas and are willing to pay a price premium for PA agricultural products [6, 11]. We make the following assumption.

Assumption 2. *Assume that the relative poverty line regulated by the government is g, the average income of farmers in poor areas is π_0, and the poverty level of farmers is $\Delta\pi = g - \pi_0$. We further assume that consumers'* *supporting preference coefficient is θ and the inverse demand function of PA agricultural products in the national market is given by*

$$p_{p_2} = a_2 - b_2(q_{p_2} + q_n) + \theta\Delta\pi. \tag{3}$$

The national market has a far greater capacity than the local market of poor areas, and the sensitivity of price to quantity in the national market is smaller than that in the local market of poor areas. Therefore, we assume that $a_2 \gg a_1, b_2 < b_1$.

Agricultural production has the characteristic of scale diseconomy [23,28], and we make the following assumption.

Assumption 3. *Production cost functions of the poor farmer and the general farmer are given by*

$$C_P(q_{p_1} + q_{p_2}) = c_p(q_{p_1} + q_{p_2})^2, \quad C_P(q_n) = c_n q_n^2. \tag{4}$$

Compared to farmers of general areas, farmers of poor areas have weakness in production technology and learning [30]. Therefore, we assume that $c_p > c_n$.

In our model, we consider that e-commerce platforms purchase agricultural products from farmers, which is so called the reselling mode. Under this mode, e-commerce platforms usually bear the logistics costs during the process of online selling [1]. We denote unit logistics costs of general agricultural products and PA agricultural products by c_{tn} and c_{tp} respectively. Since poor areas are usually remote and e-selling of PA agricultural products have a long transportation distance and multiple transition, we assume that $c_{tp} > c_{tn}$. Furthermore, due to lack of logistics infrastructures (such as pre-cooling infrastructures in places of origin and the First Mile transportation infrastructures), the logistics for e-selling of PA agricultural products have scale diseconomy [34]. Therefore, we have the following assumption.

Assumption 4. *The logistics costs for e-selling of PA agricultural products and general agricultural products are given by*

$$C_t(q_{p_2}) = c_{tp}q_{p_2} + c_t(q_{p_2} - q_0)^2, \quad C_t(q_n) = c_{tn}q_n, \tag{5}$$

where q_0 represents the basic quantity of agricultural products for e-selling in poor areas and we assume that q_0 is relatively small [34].

E-commerce platforms with corporate social responsibility present supporting preference for poor areas, which means they are concerned about poor farmers' welfare and can acquire positive value from alleviating poverty [29]. We make the following assumption.

Assumption 5. *The e-commerce platform's supporting preference coefficient for poor areas is γ and $\gamma \in [0, 1]$. In addition, the utility function of the e-commerce platform is given by*

$$U_e = \pi_e + \gamma(\pi_{fp} - g). \tag{6}$$

4. Optimal strategies of agricultural product supply chain

In this section, we derive the optimal strategies of the agricultural product supply chain while we consider the e-commerce platform and consumers' supporting preferences for PA products.

The profit functions of the poor farmer and the general farmer can be expressed as

$$\pi_{fp} = (a_1 - b_1q_{p_1})q_{p_1} + w_pq_{p_2} - c_p(q_{p_1} + q_{p_2})^2, \tag{7}$$
$$\pi_{fn} = w_nq_n - c_nq_n^2. \tag{8}$$

The profit function of the e-commerce platform can be formulated as

$$\begin{aligned}\pi_e &= (p_{p_2} - w_p)q_{p_2} + (p_n - w_n)q_n - [c_{tp}q_{p_2} + c_t(q_{p_2} - q_0)^2] - c_{tn}q_n \\ &= [a_2 - b_2(q_{p_2} + q_n) + \theta\Delta\pi - w_p]q_{p_2} + [a_2 - b_2(q_{p_2} + q_n) - w_n]q_n \\ &\quad - [c_{tp}q_{p_2} + c_t(q_{p_2} - q_0)^2] - c_{tn}q_n,\end{aligned} \tag{9}$$

and the utility function of the e-commerce platform with supporting preference is given by

$$U_e = \pi_e + \gamma(\pi_{fp} - g). \tag{10}$$

The Stackelberg game model for the agricultural product supply chain is

$$\max_{w_p, w_n} U_e, \quad \text{s.t.} \quad \begin{cases} \max\limits_{q_{p_1}, q_{p_2}} \pi_{fp}, \\ \max\limits_{q_n} \pi_{fn}. \end{cases} \tag{11}$$

The game model is solved *via* the backward induction method and we have the following proposition.

Proposition 1. *With the e-commerce platform and consumers' support for poor areas, the optimal selling quantities strategies of farmers and pricing strategies of the e-commerce platform are*

$$\begin{cases} w_p^* = \dfrac{c_p a_1}{b_1 + c_p} + \dfrac{b_1 c_p\{(b_1 + c_p)[(b_2 + 2c_n)M_1 - b_2 M_2] - (b_2 + 2c_n)c_p a_1\}}{(b_1 + c_p)A}, \\ w_n^* = \dfrac{c_n\{[(b_1 + c_p)(b_2 + c_t) + b_1(2 - \gamma)c_p]M_2 - (b_1 + c_p)b_2 M_1 + b_2 c_p a_1\}}{A}, \\ q_{p_2}^* = \dfrac{(b_1 + c_p)[(b_2 + 2c_n)M_1 - b_2 M_2] - (b_2 + 2c_n)c_p a_1}{2A}, \\ q_{p_1}^* = \dfrac{a_1}{2(b_1 + c_p)} - \dfrac{c_p}{b_1 + c_p} q_{p_2}^*, \\ q_n^* = \dfrac{[(b_1 + c_p)(b_2 + c_t) + b_1(2 - \gamma)c_p]M_2 - (b_1 + c_p)b_2 M_1 + b_2 c_p a_1}{2A}, \end{cases} \tag{12}$$

where M_1, M_2 and A are given by

$$\begin{cases} M_1 = a_2 - c_{tp} + \theta\Delta\pi + 2c_t q_0, \quad M_2 = a_2 - c_{tn}, \\ A = (b_1 + c_p)[(b_2 + 2c_n)(b_2 + c_t) - b_2^2] + b_1(b_2 + 2c_n)(2 - \gamma)c_p. \end{cases} \tag{13}$$

The proof of Proposition 1 is given in Appendix A.1.

Accordingly, we can acquire profits of two farmers and the e-commerce platform, and the consumer surplus.

$$\begin{cases} \pi_{fp}^* = \dfrac{b_1 c_p\{(b_1 + c_p)[(b_2 + 2c_n)M_1 - b_2 M_2] - (b_2 + 2c_n)c_p a_1\}^2}{4(b_1 + c_p)A^2} + \dfrac{a_1^2}{4(b_1 + c_p)}, \\ \pi_{fn}^* = \dfrac{c_n\{[(b_1 + c_p)(b_2 + c_t) + b_1(2 - \gamma)c_p]M_2 - (b_1 + c_p)b_2 M_1 + b_2 c_p a_1\}^2}{4A^2}, \\ \pi_e^* = \dfrac{[A - \gamma b_1 c_p(b_2 + 2c_n)]\{(b_1 + c_p)[(b_2 + 2c_n)M_1 - b_2 M_2] - (b_2 + 2c_n)c_p a_1\}^2}{4(b_1 + c_p)(b_2 + 2c_n)A^2} \\ \qquad + \dfrac{M_2^2}{4(b_2 + 2c_n)} - c_t q_0^2, \\ \mathrm{CS}^* = \dfrac{b_2\{2c_n[(b_1 + c)M_1 - c_p a_1] + [(b_1 + c_p)c_t + b_1(2 - \gamma)c_p]M_2\}^2}{8A^2}. \end{cases} \tag{14}$$

Here we consider a benchmark scenario where the e-commerce platform and consumers have no supporting preferences for poor areas as a contrast, which means $\gamma = 0$, $\theta = 0$. We use the superscript N to denote this benchmark scenario and we get Corollary 1 as follows.

Corollary 1. *Without the e-commerce platform and consumers' support for poor areas, optimal selling quantities strategies of farmers and pricing strategies of the e-commerce platform are*

$$\begin{cases} w_p^{N^*} = \dfrac{c_p a_1}{b_1 + c_p} + \dfrac{b_1 c_p\{(b_1 + c_p)[(b_2 + 2c_n)\overline{M}_1 - b_2 M_2] - (b_2 + 2c_n)c_p a_1\}}{(b_1 + c_p)\overline{A}}, \\ w_n^{N^*} = \dfrac{c_n\{[(b_1 + c_p)(b_2 + c_t) + b_1(2 - \gamma)c_p]M_2 - (b_1 + c_p)b_2\overline{M}_1 + b_2 c_p a_1\}}{\overline{A}}, \\ q_{p_2}^{N^*} = \dfrac{(b_1 + c_p)[(b_2 + 2c_n)\overline{M}_1 - b_2 M_2] - (b_2 + 2c_n)c_p a_1}{2\overline{A}}, \\ q_{p_1}^{N^*} = \dfrac{a_1}{2(b_1 + c_p)} - \dfrac{c_p}{b_1 + c_p} q_{p_2}^{N^*}, \\ q_n^{N^*} = \dfrac{[(b_1 + c_p)(b_2 + c_t) + b_1(2 - \gamma)c_p]M_2 - (b_1 + c_p)b_2\overline{M}_1 + b_2 c_p a_1}{2\overline{A}}, \end{cases} \tag{15}$$

where $\overline{M}_1$ and $\overline{A}$ are given by

$$\overline{M}_1 = a_2 - c_{tp} + 2c_t q_0,\ \overline{A} = (b_1 + c_p)[(b_2 + 2c_n)(b_2 + c_t) - b_2^2] + 2b_1 c_p(b_2 + 2c_n). \tag{16}$$

From the above corollary, the optimal profits of two farmers and the e-commerce platform, and the consumer surplus under the benchmark scenario are as follows.

$$\begin{cases} \pi_{fp}^{N^*} = \dfrac{b_1 c_p\{(b_1 + c_p)[(b_2 + 2c_n)\overline{M}_1 - b_2 M_2] - (b_2 + 2c_n)ca_1\}^2}{4(b_1 + c_p)\overline{A}^2} + \dfrac{a_1^2}{4(b_1 + c_p)}, \\ \pi_{fn}^{N^*} = \dfrac{c_n\{[(b_1 + c_p)(b_2 + c_t) + 2b_1 c_p]M_2 - (b_1 + c_p)b_2\overline{M}_1 + b_2 c_p a_1\}^2}{4\overline{A}^2}, \\ \pi_e^{N^*} = \dfrac{\{(b_1 + c_p)[(b_2 + 2c_n)\overline{M}_1 - b_2 M_2] - (b_2 + 2c_n)ca_1\}^2}{4(b_1 + c_p)(b_2 + 2c_n)\overline{A}} + \dfrac{M_2^2}{4(b_2 + 2c_n)} - c_t q_0^2, \\ \mathrm{CS}^{N^*} = \dfrac{b_2\{2c_n[(b_1 + c_p)\overline{M}_1 - ca_1] + [(b_1 + c_p)c_t + 2b_1 c_p]M_2\}^2}{8\overline{A}^2}. \end{cases} \tag{17}$$

5. Discussion and numerical illustrations

In this section, we analyze and discuss the optimal strategies of the agricultural product supply chain, profits of supply chain members, and the consumer surplus, and we present some numerical results for illustration purpose. First, we analyze how the e-commerce platform's supporting preference for poor areas (in terms of γ), consumers' supporting preference for poor areas (in terms of θ), and the logistics cost of PA agricultural products (in terms of c_{tp}) affect the optimal strategies and supply chain members' profits, and the consumer surplus respectively. Then, we discuss comprehensive effects of the e-commerce platform's and consumers' support for poor areas on the selling of agricultural products, profits of farmers and the e-commerce platform, and the consumer surplus, by comparing optimal strategies and profits with and without the e-commerce platform and consumers' supporting preferences. Meanwhile, we use a numerical example to illustrate some interesting results.

Wushi County, Aksu Prefecture, Xinjiang is a national poverty-stricken county of China. Driven by policies like e-commerce poverty alleviation, some e-commerce platforms, such as JD.com and Taobao.com, actively helped to expand online sale channels of local high quality agricultural products, such as apples and red jujubes. Benefited from e-commerce, the sales of agricultural products and farmers' income have effectively improved. We select the sales of apples of Wushi County as an example and choose the values of parameters based on the data in 2022. Based on the freight prices of YTO Express, an express delivery enterprise in China, we set the logistics costs of agricultural products as $c_{tp} = 3000$ (CNY/Ton) and $c_{tn} = 1500$ (CNY/Ton). In addition, we set the production effort cost coefficients of farmers as $c_p = 20$ and $c_n = 15$. The e-selling price of apples of Wushi County is about 7500 (CNY/Ton) and their price in local areas is about 1800 (CNY/Ton). The e-selling price of apples of other general areas is about 7000 (CNY/Ton). Therefore, we assume that $a_1 = 2000$, $b_1 = 30$, $a_2 = 8000$, $b_2 = 10$, $\theta = 0.2$, $\Delta\pi = 2000$. When the e-selling quantity of apples of Wushi County is 40 Tons, the e-selling price is about 7500 (CNY/Ton). When the local selling quantity of apples of Wushi County is 7 Tons, the price in local areas is about 1800 (CNY/Ton). Moreover, we set $\gamma = 0.5$, $q_0 = 3$, $c_t = 15$ in the numerical analysis.

5.1. Sensitivity analysis

5.1.1. Impacts of the e-commerce platform and consumers' supporting preferences

Regarding the impacts of the e-commerce platform and consumers' supporting preferences for poor areas, we have the following two propositions.

Proposition 2.

$$(1)\ \frac{\mathrm{d}q^*_{p_1}}{\mathrm{d}\gamma} < 0,\ \frac{\mathrm{d}q^*_{p_2}}{\mathrm{d}\gamma} > 0,\ \frac{\mathrm{d}q^*_{n}}{\mathrm{d}\gamma} < 0,\ \frac{(\mathrm{d}q^*_{p_2} + q^*_n)}{\mathrm{d}\gamma} > 0; \quad (2)\ \frac{\mathrm{d}w^*_{p}}{\mathrm{d}\gamma} > 0,\ \frac{w^*_{n}}{\mathrm{d}\gamma} < 0;$$
$$(3)\ \frac{\mathrm{d}p^*_{p_1}}{\mathrm{d}\gamma} > 0,\ \frac{\mathrm{d}p^*_{p_2}}{\mathrm{d}\gamma} < 0,\ \frac{\mathrm{d}p^*_{n}}{\mathrm{d}\gamma} < 0; \quad (4)\ \frac{\mathrm{d}\pi^*_{fp}}{\mathrm{d}\gamma} > 0,\ \frac{\mathrm{d}\pi^*_{fn}}{\mathrm{d}\gamma} < 0,\ \frac{\mathrm{d}\pi^*_{e}}{\mathrm{d}\gamma} < 0,\ \frac{\mathrm{d\,CS}^*}{\mathrm{d}\gamma} > 0.$$

Proposition 3.

$$(1)\ \frac{\mathrm{d}q^*_{p_1}}{\mathrm{d}\theta} < 0,\ \frac{\mathrm{d}q^*_{p_2}}{\mathrm{d}\theta} > 0,\ \frac{\mathrm{d}q^*_{n}}{\mathrm{d}\theta} < 0,\ \frac{(\mathrm{d}q^*_{p_2} + q^*_n)}{\mathrm{d}\theta} > 0; \quad (2)\ \frac{\mathrm{d}w^*_{p}}{\mathrm{d}\theta} > 0,\ \frac{w^*_{n}}{\mathrm{d}\theta} < 0;$$
$$(3)\ \frac{\mathrm{d}p^*_{p_1}}{\mathrm{d}\theta} > 0,\ \frac{\mathrm{d}p^*_{p_2}}{\mathrm{d}\theta} > 0,\ \frac{\mathrm{d}p^*_{n}}{\mathrm{d}\theta} < 0; \quad (4)\ \frac{\mathrm{d}\pi^*_{fp}}{\mathrm{d}\theta} > 0,\ \frac{\mathrm{d}\pi^*_{fn}}{\mathrm{d}\theta} < 0,\ \frac{\mathrm{d}\pi^*_{e}}{\mathrm{d}\theta} > 0,\ \frac{\mathrm{dCS}^*}{\mathrm{d}\theta} > 0.$$

The proofs of Propositions 2 and 3 are given in Appendices A.2 and A.3.

According to Propositions 2 and 3, the impacts of the e-commerce platform and consumers' supporting preferences on purchase prices and selling quantities of agricultural products are similar. As the e-commerce platform's supporting preference for poor areas (or consumers' supporting preference for poor areas) increases, the purchase price for PA agricultural products by the e-commerce platform increases while that of general agricultural products decreases. Thus, e-selling quantity of PA agricultural products expands while that of general agricultural products shrinks, and the selling quantity of PA agricultural products in the local market of poor areas also decreases. Further, Figures 2 and 3 indicate that the increment of e-selling quantity of PA agricultural products is larger than the reduction of that of general agricultural products. As a result, the total selling quantities in the e-commerce platform increase.

Furthermore, the impacts of the e-commerce platform and consumers' supporting preferences on the e-selling prices of agricultural products are different. On one hand, as the e-commerce platform's supporting preference (or consumers' supporting preference) increases, the price in the local market of poor areas increases due to decreased selling quantity, while the e-selling price of general agricultural products decreases due to the increased total selling quantities in the e-commerce platform. On the other hand, with regard to the e-selling price of PA agricultural products, the e-commerce platform's supporting preference cause the price to decrease, due to the increased total e-selling quantities, while consumers' supporting preference increases the price due to the positive and dominant effect of such preference. The results are reflected in Figures 4 and 5.

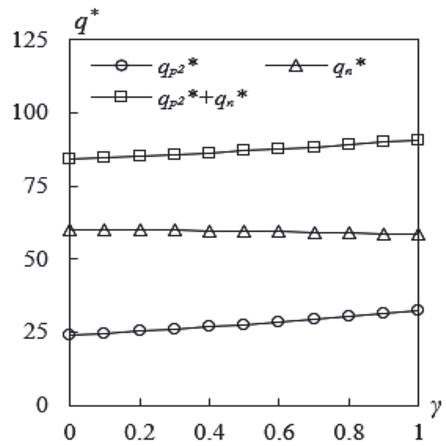


FIGURE 2. Impacts of e-commerce platform's supporting preference on e-selling quantities.

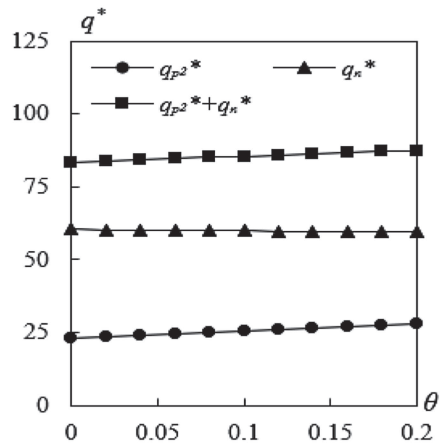


FIGURE 3. Impacts of consumers' supporting preference on e-selling quantities.

As to supply chain members' profits, as the e-commerce platform's supporting preference (consumers' supporting preference) increases, the profit of the poor farmer improves while that of the general farmer decreases. The e-commerce platform's profit improves with respect to consumers' supporting preference, but the profit decreases as its own supporting preference increases. For consumers, the consumer surplus always increases as the e-commerce platform's supporting preference or consumers' supporting preference increases due to the increased total e-selling quantities.

From the above results and discussions, we can obtain some managerial implications. First, to promote poverty alleviation performance and improve poor farmers' income, e-commerce platforms can actively undertake social responsibility and increase their supporting preference for poor areas. As examples, Jingdong (JD.com), Taobao (Taobao.com), and Pinduoduo (Pinduoduo.com) have launched special sale channels for agricultural products from poor and rural areas. Second, the government should strengthen consumers' awareness of supporting poor areas by advertisement, publicity, and/or provide subsidies as incentives for e-commerce platforms. One such

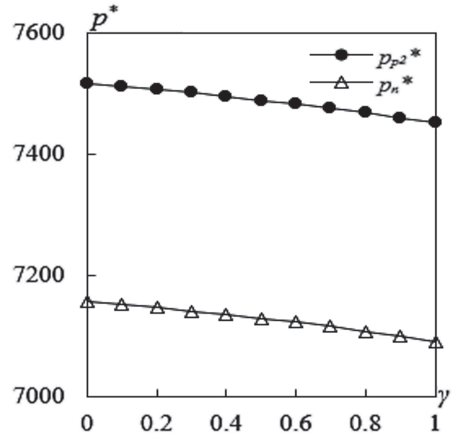


FIGURE 4. Impacts of e-commerce platform's supporting preference on e-selling prices.

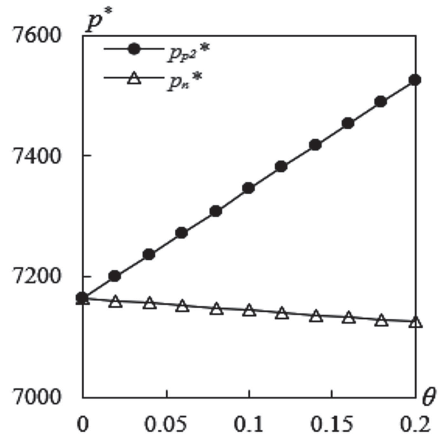


FIGURE 5. Impacts of consumers' supporting preference on e-selling prices.

example is that, Lu'an City, Anhui Province, China subsidizes e-commerce enterprises when they purchase local agricultural products[4].

5.1.2. Impacts of logistics cost of poor areas

Compared to agricultural products from other areas, agricultural products from poor and rural areas usually have higher logistic costs when they are sold through e-commerce platforms. We have the follow results regarding the impacts of logistics cost of poor areas.

Proposition 4.

$$(1)\ \frac{\mathrm{d}q_{p_1}^*}{\mathrm{d}c_{tp}} > 0,\ \frac{\mathrm{d}q_{p_2}^*}{\mathrm{d}c_{tp}} < 0,\ \frac{\mathrm{d}q_n^*}{\mathrm{d}c_{tp}} > 0,\ \frac{(\mathrm{d}q_{p_2}^* + q_n^*)}{\mathrm{d}c_{tp}} < 0; \quad (2)\ \frac{\mathrm{d}w_p^*}{\mathrm{d}c_{tp}} < 0,\ \frac{w_n^*}{\mathrm{d}c_{tp}} > 0;$$

$$(3)\ \frac{\mathrm{d}p_{p_1}^*}{\mathrm{d}c_{tp}} < 0,\ \frac{\mathrm{d}p_{p_2}^*}{\mathrm{d}c_{tp}} > 0,\ \frac{\mathrm{d}p_n^*}{\mathrm{d}c_{tp}} > 0; \quad (4)\ \frac{\mathrm{d}\pi_{fp}^*}{\mathrm{d}c_{tp}} < 0,\ \frac{\mathrm{d}\pi_{fn}^*}{\mathrm{d}c_{tp}} > 0,\ \frac{\mathrm{d}\pi_e^*}{\mathrm{d}c_{tp}} < 0,\ \frac{\mathrm{d}\,\mathrm{CS}^*}{\mathrm{d}c_{tp}} < 0.$$

[4] https://www.ja.gov.cn/zxzx/ztzl/tpgj/tszs/25178291.html.

From Proposition 4, we can see that, as the logistics cost of poor areas increases, the e-commerce platform will decrease the purchase price of PA agricultural products and increase that of general agricultural products in order to make up the increasing logistics cost. As a result, the e-selling quantity of PA agricultural products decreases while that of general agricultural products increases. In addition, the decrease of e-selling quantity of PA agricultural products is more than the increase of that of general agricultural products and total selling quantities in the e-commerce platform decrease. Consequently, the e-selling prices of PA agricultural products and general agricultural products both rise. Furthermore, Proposition 4 also indicates that higher logistics cost would hurt the e-selling of PA agricultural products, and thus the profits of the poor farmer and the e-commerce platform, as well as the consumer surplus, will all decrease.

The managerial insight is that, the government should pay more attention to the logistics expense problems during the e-selling of agricultural products of poor areas. The government can take actions to help reduce logistics costs, such as providing subsidies or encouraging the investment in logistics infrastructures. For example, Zhuxi County, Hubei Province, China provides a subsidy of 0.7 CNY for each parcel of agricultural products sold online[5]. Another example is that, Hunan Province subsidizes cold chain logistics projects up to 20% of the total investment[6].

5.2. Comparative analysis

The following thresholds (θ_1 and θ_2) of θ will be used in the subsequent discussion.

$$\begin{cases} \theta_1 = \dfrac{b_1 c_p^2\{(b_1+c_p)[(b_2+2c_n)\overline{M}_1 - b_2 M_2] - (b_2+2c_n)c_p a_1\}}{\overline{A}\Delta\pi[\overline{A} - b_1 c_p(b_2+2c_n) - b_2 c_p(b_1+c_p)]}, \\ \theta_2 = \left[\sqrt{1+\dfrac{b_1^2 c_p^2 (b_2+2c_n)^2}{\overline{A}[\overline{A} - 2b_1 c_p(b_2+2c_n)]}} - 1\right] \dfrac{\{(b_1+c_p)[(b_2+2c_n)\overline{M_1} - b_2 M_2] - (b_2+2c_n)c_p a_1\}}{(b_1+c_p)(b_2+2c_n)\Delta\pi}. \end{cases} \tag{18}$$

It is easy to prove that $\theta_1 < \theta_2$. We define $\theta < \theta_1$ as consumers' supporting preference being *very small*, $\theta < \theta_2$ as consumers' supporting preference being *relatively small*, $\theta \geq \theta_2$ as consumers' supporting preference being *relatively large*. In particular, for the numerical example we consider here, we have $\theta_1 = 0.04$, $\theta_2 = 0.09$.

By comparing the selling quantities and prices of agricultural products, the profits of farmers and the e-commerce platform, and the consumer surplus with and without the e-commerce platform and consumers' supporting preferences, we can get Propositions 5 and 6.

Proposition 5.

$$(1)\quad q_{p_1}^* < q_{p_1}^{N^*},\ q_{p_2}^* > q_{p_2}^{N^*},\ q_n^* < q_n^{N^*},\ q_{p_2}^* + q_n^* > q_{p_2}^{N^*} + q_n^{N^*};$$

$$(2)\quad p_{p_1}^* > p_{p_1}^{N^*},\ p_n^* < p_n^{N^*},\ \begin{cases} p_{p_2}^* > p_{p_2}^{N^*}, & \theta \geq \theta_1, \text{ and } \theta < \theta_1, \gamma < \gamma_1 \\ p_{p_2}^* \leq p_{p_2}^{N^*}, & \theta < \theta_1, \gamma \geq \gamma_1 \end{cases}$$

where γ_1 *is given by*

$$\gamma_1 = 1 - \frac{\theta_1 - \theta}{\theta_1[2b_1 c_p^2\{(b_1+c_p)[(b_2+2c_n)\overline{M_1} - b_2 M_2] - (b_2+2c_n)c_p a_1\} + b_1 c_p(b_2+2c_n)\overline{A}\theta\Delta\pi]}. \tag{19}$$

The proof of Proposition 5 is given in Appendix A.4.

From Propositions 2, 3 and 5, we can easily get the following conclusions. Compared to the benchmark scenario without the e-commerce platform and consumers' supporting preferences, the e-selling quantity of

[5] http://www.zhuxi.gov.cn/xxgkxi/zc/gfxwj/zfwj/202109/t20210901_3367017.shtml.
[6] https://www.hunan.gov.cn/hnszf/xxgk/wjk/szfbgt//202004/t20200409_11875094.html.

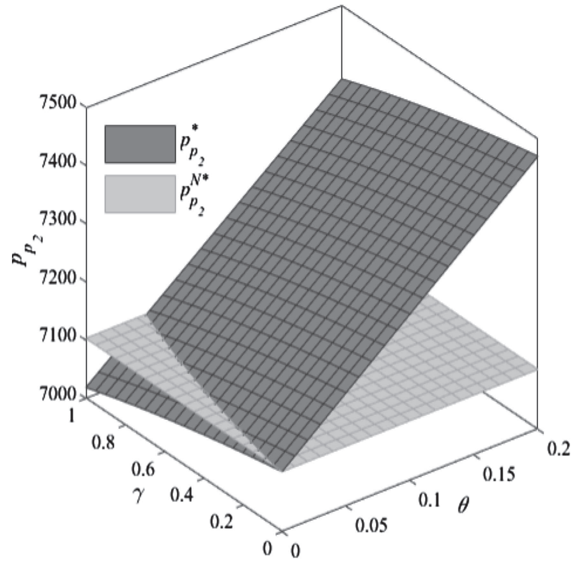


FIGURE 6. Comparison of e-selling prices of PA agricultural products with and without e-commerce platform and consumers' supporting preferences.

PA agricultural products increases, while that of general agricultural products and selling quantity of agricultural products in the local market of poor areas both decrease with the e-commerce platform and consumers' supporting preferences. Consequently, the total e-selling quantities in the e-commerce platform increase.

As to the e-selling prices, the e-selling price of general agricultural products decreases. For PA agricultural products, when consumers' supporting preference is not very small ($\theta \geq \theta_1$), the e-selling price increases. When consumers' supporting preference is very small ($\theta < \theta_1$), the e-selling price of the PA products also increases if the e-commerce platform's supporting preference is smaller than a critical value ($\gamma < \gamma_1$), and the price decreases otherwise. Figure 6 illustrates the results. As we can see from Proposition 5 and Figure 6, the increase of the e-selling price of PA agricultural products due to consumers' supporting preference usually exceeds the reduction of price due to the e-commerce platform's supporting preference. Thus, the e-selling price of PA agricultural products usually increases.

Proposition 6.

$$(1)\quad \pi^*_{fp} > \pi^{N^*}_{fp},\ \pi^*_{fn} < \pi^{N^*}_{fn};$$

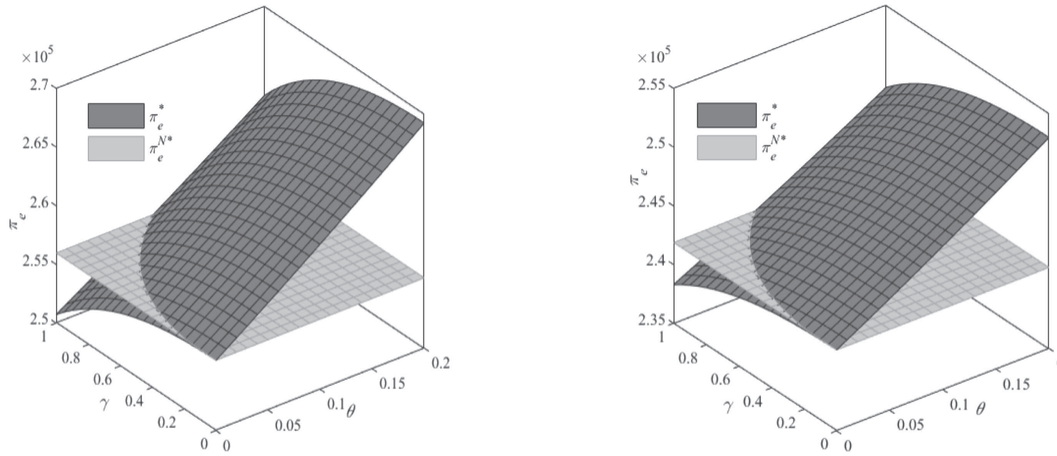
$$(2)\quad \begin{cases} \pi^*_e > \pi^{N^*}_e, & \theta \geq \theta_2,\ \text{and}\ \theta < \theta_2, \gamma < \gamma_2 \\ \pi^*_e \leq \pi^{N^*}_e, & \theta < \theta_2, \gamma \geq \gamma_2 \end{cases},\ \mathrm{CS}^* > \mathrm{CS}^{N^*},$$

where γ_2 is given by

$$\gamma_2 = \frac{\overline{A}\sqrt{Z^2 - \overline{Z}^2}\left[Z - \sqrt{Z^2 - \overline{Z}^2}\right]}{b_1 c(b_2 + 2c)\overline{Z}^2}, \tag{20}$$

with Z and $\overline{Z}$ given by

$$\begin{cases} Z = (b_1 + c_p)[(b_2 + 2c_n)M_1 - b_2 M_2] - (b_2 + 2c_n)c_p a_1, \\ \overline{Z} = (b_1 + c_p)[(b_2 + 2c_n)\overline{M_1} - b_2 M_2] - (b_2 + 2c_n)c_p a_1. \end{cases} \tag{21}$$



(a) (b)

FIGURE 7. Comparison of profits of the e-commerce platform with and without e-commerce platform and consumers' supporting preferences. (a) $c_{tp} = 3000$. (b) $c_{tp} = 3500$.

The proof of Proposition 6 is given in Appendix A.5.

Proposition 6 indicates that, compared to the benchmark scenario without the e-commerce platform and consumers' supporting preferences, the profit of the poor farmer improves while that of the general farmer decreases with respect to the e-commerce platform and consumers' supporting preferences. For consumers, the consumer surplus also improves, benefiting from increased total selling quantities of agricultural products in the e-commerce platform. In particular, the variance of the e-commerce platform's profit depends on the platform and consumers' supporting preferences. Specifically, when consumers' supporting preference is relatively large ($\theta \geq \theta_2$), the platform's profit improves. When consumers' supporting preference is relatively small ($\theta < \theta_2$), the platform's profit also improves if its own supporting preference is smaller than a critical value ($\gamma < \gamma_2$), while the profit decreases otherwise. The numerical results illustrated in Figure 7 are consistent with the above conclusion. Furthermore, as we can see from Figure 7, the larger consumers' supporting preference and the lower logistics cost of poor areas, the more profit improvement of the platform.

Figure 8 further illustrates the combined effects of the e-commerce platform and consumers' supporting preferences on the profit of the e-commerce platform. In Figure 8, the e-commerce platform's profit improves after supporting poor areas (with positive supporting preference) in Region (I) (the shaded area in Fig. 8), which is characterized by $\{(\mathrm{I})|\pi_e^* > \pi_e^{N^*}\}$. In Region (II) (the unshaded area in Fig. 8), which refers to $\{(\mathrm{II})|\pi_e^* < \pi_e^{N^*}\}$, the e-commerce platform's profit hurts after supporting poor areas. In addition, the larger consumers' supporting preference and logistics cost of poor areas, the more likely the e-commerce platform's profit will improve after supporting poor areas, which means Region (I) will expand as θ and c_{tp} increase.

We present some managerial implications from two aspects. First, encouraging consumers to support poor areas and to purchase PA agricultural products is essential to realize a triple win situation among poor area farmers, e-commerce platforms and consumers. One such example is that, in June 2022, Xinhua Net, CCTV and China Net of Assistance by Consumption launched "Assisting farmers and alleviating poverty by consumption" to help sell agricultural products from poor areas[7]. Another example is that, in April 2022, Guangzhou branch of China Agricultural Bank provided a subsidy of 4 million CNY budget for consumption of agricultural products

[7] http://www.cfgw.net.cn/xb/content/2022-06/13/content_25012257.html.

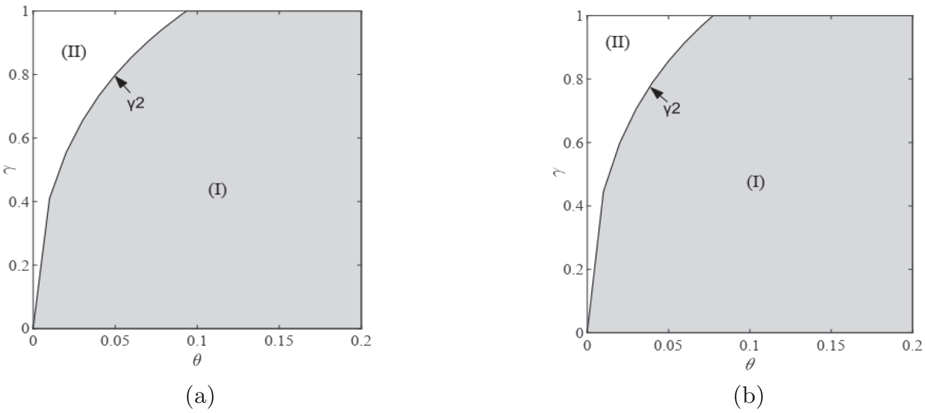


FIGURE 8. The impacts of supporting poor areas on the e-commerce platform's profit. (a) $c_{tp} = 3000$. (b) $c_{tp} = 3500$.

from poor areas[8]. Second, the government should take actions to help reduce logistics costs of agricultural products of poor and rural areas to better alleviate poverty.

6. Conclusions

In this paper, we investigate the optimal selling quantity strategies of farmers and the optimal pricing strategies of the e-commerce platform in an agricultural product supply chain consisting of a poor farmer, a general farmer and an e-commerce platform, considering the e-commerce platform and consumers' supporting preferences for poor areas and logistics costs difference between poor areas and general areas. We further analyze the comprehensive effects of the e-commerce platform and consumers' supporting preferences on the sales of agricultural products, profits of supply chain members and the consumer surplus. We derive some interesting results which are listed as follows.

(1) The e-commerce platform and consumers' supporting preferences are both beneficial to improve the poor farmer's profit but they may decrease the e-selling quantity and price of general agricultural products. As the e-commerce platform's supporting preference or consumers' supporting preference increases, the e-selling quantity of PA agricultural products and the total selling quantities in the platform both increase. However, the e-selling price of PA agricultural products performs differently. In particular, the PA product's price decreases with respect to the e-commerce platform's supporting preference, but it increases with respect to consumers' supporting preference due to a more positive effect of such preference. The e-commerce platform and consumers' supporting preferences also have various impacts on the e-commerce platform's profit. In particular, the e-commerce platform's profit improves as consumers' supporting preference increases while the profit decreases as its own supporting preference increases.
(2) The larger the logistics cost of poor areas, the higher the e-selling prices of both PA agricultural products and general agricultural products. However, the e-commerce platform may lower the purchase price of PA agricultural products. In that way, the e-selling quantity of PA agricultural products reduces, and the profits of the poor farmer and the e-commerce platform both decrease.
(3) Compared to the benchmark scenario without the e-commerce platform and consumers' supporting preferences for poor areas, the consumer surplus always improves after supporting poor areas. However, the e-commerce platform's profit improves after supporting poor areas only when consumers' supporting pref-

[8] https://www.nrra.gov.cn/art/2022/5/10/art_42_195114.html.

erence is relatively large, or when consumers' supporting preference and its own supporting preference are both relatively small.

Those results can provide some useful managerial implications. First, the CSR (corporate social responsibility) implementation of e-commerce platforms, such as supporting the e-selling of agricultural products from poor areas, is an effective way to improve the profits of poor area farmers, and the poverty alleviation performance. Second, consumers' supporting preference for poor areas is also essential for poverty alleviation, and it contributes to a triple win situation for poor farmers, e-commerce platforms and consumers under certain conditions. Therefore, the government should encourage e-commerce platforms to undertake social responsibility, and promote consumers' preference for poverty alleviation by various means, such as providing subsidy or reward. Meanwhile, the government and e-commerce platforms should pay attention to the logistics problems of poor areas, and they should take actions to solve the problems.

Some extensions can be done based on the results presented in this paper. We reveal the impacts of the e-commerce platform and consumers' supporting preferences for poor areas on the sales of agricultural products, profits of poor farmers and other stakeholders, and the consumer surplus. However, we do not consider the quality of PA agricultural products and consumers' quality preference. The farmers' production decision (both quantity and quality), and the poverty alleviation performance with consumers' supporting preference and quality preference can be subjects for future research. Moreover, information asymmetry problems during e-commerce transaction of agricultural products and the value of blockchain technology for poverty alleviation in competitive environment are also worth further investigation.

Appendix A.

A.1. Proof of Proposition 1

According to (7) and (8), we can acquire that

$$\frac{\partial \pi_{fp}}{\partial q_{p_1}} = a_1 - 2(b_1 + c_p)q_{p_1} - 2c_p q_{p_2},\ \frac{\partial \pi_{fp}}{\partial q_{p_2}} = w_p - 2c_p q_{p_1} - 2c_p q_{p_2},\ \frac{\mathrm{d}\pi_{fn}}{\mathrm{d}q_n} = w_n - 2c_n q_n.$$

The Hessian matrix of $\pi_{fp}(q_{p_1}, q_{p_2})$ is $H_1 = \begin{bmatrix} -2(b_1+c_p) & -2c_p \\ -2c_p & -2c_p \end{bmatrix}$. Since $det(H_1) = 4b_1c_p > 0$, H_1 is negative definite. It is easy to defer that π_{fn} is a concave function of q_n. Set $\frac{\partial \pi_{fp}}{\partial q_{p_1}} = 0$, $\frac{\partial \pi_{fp}}{\partial q_{p_2}} = 0$, $\frac{\mathrm{d}\pi_{fn}}{\mathrm{d}q_n} = 0$, we can solve q_{p_1}, q_{p_2} and q_n. Plug q_{p_1}, q_{p_2} and q_n into (9) and (10), we have

$$\frac{\partial U_e}{\partial w_p} = \frac{\begin{array}{c} c_pc_n\{b_1(b_1+c_p)M_1 + [(b_1+c_p)(b_2+c_t) + b_1(1-\gamma)c_p]a_1\} - (b_1+c_p)\{[(b_1+c_p)(b_2+c_t) \\ +b_1(2-\gamma)c_p]c_nw_p + b_1b_2c_pw_n\} \end{array}}{2b_1^2c_p^2c_n},$$

$$\frac{\partial U_e}{\partial w_n} = \frac{c_pc_n(b_1M_2 + b_2a_1) - (b_1+c_p)b_2c_nw_p - b_1(b_2+2c_n)c_pw_n}{2b_1c_n^2c_p}.$$

The Hessian matrix of $U_e(w_p, w_n)$ is

$$H_2 = \frac{1}{2b_1^2c_p^2c_n^2}\begin{bmatrix} -(b_1+c_p)c_n^2[(b_1+c_p)(b_2+c_t)+b_1(2-\gamma)c_p] & -b_1b_2c_pc_n(b_1+c_p) \\ -(b_1+c_p)b_1b_2c_pc_n & -b_1^2(b_2+2c_n)c_p^2 \end{bmatrix}.$$

Since $\det(H_2) = \frac{(b_1+c_p)A}{4b_1^2c_p^2c_n^2} > 0$, H_2 is negative definite. Set $\frac{\partial U_e}{\partial w_p} = 0$ and $\frac{\partial U_e}{\partial w_n} = 0$, we can solve w_p^* and w_n^*. Plug w_p^* and w_n^* into q_{p_1}, q_{p_2} and q_n, we get Proposition 1.

A.2. Proof of Proposition 2

According to (12) and (14), we can get that

$$\frac{\mathrm{d}w_p^*}{\mathrm{d}\gamma} = \frac{b_1c_p\{(b_2+2c_n)[(b_1+c_p)M_1-c_pa_1]-(b_1+c_p)b_2M_2\}}{(b_1+c_p)\{(b_1+c_p)[(b_2+2c_n)(b_2+c_t)-b_2^2]+b_1(b_2+2c_n)(2-\gamma)c_p\}^2} > 0,$$

$$\frac{\mathrm{d}(q_{p_2}^*+q_n^*)}{\mathrm{d}\gamma} = \frac{b_1c_p^2\{(b_2+2c_n)[(b_1+c_p)M_1-c_pa_1]-(b_1+c_p)b_2M_2\}}{\{(b_1+c_p)[(b_2+2c_n)(b_2+c_t)-b_2^2]+b_1(b_2+2c_n)(2-\gamma)c_p\}^2} > 0,$$

$$\frac{\mathrm{d}\pi_e^*}{\mathrm{d}\gamma} = -\frac{\gamma b_1^2c_p^2\{(b_2+2c_n)[(b_1+c_p)M_1-c_pa_1]-(b_1+c_p)b_2M_2\}^2}{2(b_1+c_p)\{(b_1+c_p)[(b_2+2c_n)(b_2+c_t)-b_2^2]+b_1(b_2+2c_n)(2-\gamma)c_p\}^3} < 0.$$

A.3. Proof of Proposition 3

According to (12), we have

$$\frac{\mathrm{d}p_{p_2}^*}{\mathrm{d}\theta} = \frac{\{(b_1+c_p)[(b_2+2c_n)c_t+b_2c_p]+b_1(b_2+2c_n)(2-\gamma)c_p\}\Delta\pi}{(b_1+c_p)[(b_2+2c_n)(b_2+c_t)-b_2^2]+b_1(b_2+2c_n)(2-\gamma)c_p} > 0.$$

A.4. Proof of Proposition 5

From (12) and (15), we can acquire that

$$p_{p_2}^* - p_{p_2}^{N^*} = \frac{\overline{A}\theta\Delta\pi[\overline{A}-b_2c_p(b_1+c_p)]-[b_1b_2c_p^2\overline{Z}+b_1c_p(b_2+2c_n)\overline{A}\theta\Delta\pi]\gamma}{\{(b_1+c_p)[(b_2+2c_n)(b_2+c_t)-b_2^2]+b_1(b_2+2c_n)(2-\gamma)c_p\}\overline{A}}.$$

Set $h(\gamma) = \overline{A}\theta\Delta\pi[\overline{A}-b_2c_p(b_1+c_p)]-[b_1b_2c_p^2\overline{Z}+b_1c_p(b_2+2c_n)\overline{A}\theta\Delta\pi]\gamma$. It is easy to deduce that $h(0) = \overline{A}\theta\Delta\pi[\overline{A}-b_2c_p(b_1+c_p)] > 0$, $h(1) = \overline{A}\theta\Delta\pi[\overline{A}-b_2c_p(b_1+c_p)-b_1c_p(b_2+2c_n)]-b_1b_2c_p^2\overline{Z}$. Set $\theta=\theta_1$ satisfies $h(1)=0$. When $\theta \geq \theta_1$, $h(1) \geq 0$ and we have $h(\gamma) \geq 0$ for $\gamma \in [0,1]$, which means $p_{p_2}^* \geq p_{p_2}^{N^*}$. When $\theta < \theta_1$, $h(1) < 0$ and there exists $\gamma_1 \in [0,1]$ satisfies $h(\gamma_1) = 0$. If $\gamma < \gamma_1$, $h(\gamma) > 0$ and $p_{p_2}^* > p_{p_2}^{N^*}$; if $\gamma \geq \gamma_1$, $h(\gamma) \leq 0$ and $p_{p_2}^* \leq p_{p_2}^{N^*}$.

A.5. Proof of Proposition 6

From (14) and (17), we can acquire that

$$\pi_e^* - \pi_e^{N^*} = \frac{-[b_1c_p(b_2+2c_n)]^2\gamma^2-2b_1c_p(b_2+2c_n)\overline{A}(Z^2-\overline{Z}^2)\gamma+\overline{A}^2(Z^2-\overline{Z}^2)}{4(b_1+c_p)(b_2+2c_n)\{(b_1+c_p)[(b_2+2c_n)(b_2+c_t)-b_2^2]+b_1(b_2+2c_n)(2-\gamma)c_p\}^2\overline{A}}.$$

Set $F(\gamma) = -[b_1c_p(b_2+2c_n)]^2\gamma^2-2b_1c_p(b_2+2c_n)\overline{A}(Z^2-\overline{Z}^2)\gamma+\overline{A}^2(Z^2-\overline{Z}^2)$. It is easy to deduce that $F(0) = \overline{A}^2(Z^2-\overline{Z}^2) > 0$, $F(1) = [\overline{A}-2b_1c_p(b_2+2c_n)]\overline{A}Z(\theta)^2-\{\overline{A}[\overline{A}-2b_1c_p(b_2+2c_n)]+[b_1c_p(b_2+2c_n)]^2\}\overline{Z}^2$. Set $\theta=\theta_2$ satisfies $F(1)=0$. When $\theta<\theta_2$, $F(1)<0$ and there exists $\gamma_2 \in [0,1]$ satisfies $F(\gamma_2)=0$. If $\gamma<\gamma_2$, $F(\gamma)>0$ and $\pi_e^* > \pi_e^{N^*}$, while if $\gamma \geq \gamma_2$, $F(\gamma) \leq 0$ and $\pi_e^* \leq \pi_e^{N^*}$. When $\theta \geq \theta_2$, $F(1) \geq 0$ and we have $F(\gamma) \geq 0$ for $\gamma \in [0,1]$, which means $\pi_e^* \geq \pi_e^{N^*}$.

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