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SPECIAL ISSUE

Government subsidies and online branding for agricultural products

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Abstract
Online branding plays an increasingly vital role for agricultural products in agriculture and e-commerce industries alike. To improve the cooperation between farmers and e-retailers, and to increase awareness of agricultural products through online branding, many governments implement series of subsidy policies. We investigate the impact of government subsidies by proposing a three-player game model (consisting of a government, a farmer, and an e-retailer) in supply chains. More specifically, we develop four Stackelberg game scenarios, including a benchmark scenario in which government provides no subsidies, two scenarios in which government subsidizes either farmer or e-retailer without subsidizing the other, and one in which both are subsidized. We find awareness of online branding for agricultural products is positively related to farmers? market sensitivity while e-retailers? cost factor shows a negative relation; optimal awareness emerges when both farmers and retailers are subsidized. In turn, farmers and retailers achieve their best profits when both are subsidized. Furthermore, farmers? profits are higher than e-retailers? in every subsidy scenario. We obtain the most effective parameters for government subsidies using *ex ante* and *ex post* strategies, extending our model by incorporating spillover effects. Most of our conclusions are consistent with intuition and propositions we began with, but it is interesting to note that farmers? best profits appear when farmers receive subsidies and e-retailers do not.

Keywords Agricultural online branding · Supply chain management · Stackelberg game · Government subsidies

1 Introduction

Agricultural brands that represent excellent quality commitment and reduce information asymmetry between farmers and consumers, play a vital role in agricultural industries and fresh food markets all over the world. For example, Washington Apple is a famous apple brand with geographical indication and a production value of more than USD 2 billion per year and exporting about 30% of its product to more than 60 countries [37]. Meanwhile, in recent years, the wines of France?s well-known Bordeaux region show a production value of about EUR 4 billion per year [10]. However, because in agricultural products market quality is critical but hard to define or measure [28], consumers must seek information on brands as a major reference in their purchasing decision. According to a Nielsen survey [6] of more than 30,000 respondents in 61 countries, about 75% of global consumers listed brand origin as a key purchase driver and stated willingness to pay higher prices for branded agricultural products.

With the rapid development of e-commerce in China, e-retailers have begun cooperating with farmers to build agricultural online branding. For instance, Three Squirrels, a leading manufacturer of nut products in China, has cooperated with Alibaba.com and achieved compound growth rates of 110% since its establishment in 2012. Its IPO prospectus shows that online channel sales account for more than 90% of its total sales, of which 70% come from Alibaba.com. Another example is Fengjie Navel Orange, a distinguished navel orange brand in Chongqing, China. Its sales on Alibaba.com in 2018, at more than 10% of overall sales, were 20 times higher than in the first year of cooperation with Alibaba.com. Owing to this cooperation, the brand?s production and value reached 300,000 tons and 2.625 billion RMB in 2018 [3], increasing the income of local farmers, and enhancing the popularity of the Fengjie Navel Orange brand among consumers.

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To promote cooperation between farmers and e-retailers, thus enhancing the competitiveness of regional agricultural brands, governments usually offer agricultural brand subsidy programs for various parties in supply chains. Taking the aforementioned Washington Apple as an example, to increase the products? export rate, the US Department of Agriculture supplied the Washington Apple Commission with USD 8.5 million through the Agricultural Trade Promotion Fund in 2019. Similarly, the People?s Government of Fengjie County of Chongqing Municipality issues support including the use of online policies for the Fengjie Navel Orange brand before every harvest. To increase online sales, e-commerce platforms (such as Alibaba.com) with favorable rates of more than 80% are subsidized by RMB 4.0 per box. Farmers are provided with a subsidy of RMB 50/ton to enhance orders? packaging quality.

With agricultural products, different subsidy policies have different effects on public welfare and supply chain performance. When choosing subsidy policies, the features of agricultural products? online branding should be considered, but the role of online branding has not been measured. Moreover, subsidies? recipients may conflict as budgets for subsidies may be limited [31]. Considering the above industrial policies and governments? management strategies through practical operations, we focus on the following questions in this paper. (1) How do different government subsidy strategies affect the awareness of agricultural products? online branding? (2) How do government subsidies affect the profits of e-retailers and farmers who are responsible for awareness of agricultural products? online branding? (3) Which subsidy strategy should government adopt? What are the best subsidy formats and parameters, considering various strategies?

To address these questions, we built a three-player supply chain structure to show through Stackelberg game models the impact of government subsidies on online branding for agricultural products and the entire supply chain. From the perspective of government subsidy targets, we describe a non-subsidized scenario as a benchmark (denoted as N). Another three modes included subsidizing only the farmer (represented as F), subsidizing only the e-retailer (represented as R), and subsidizing both the farmer and the e-retailer (represented as FR). To obtain management insights and address the study questions, we resolved Stackelberg games and analyzed the impact of government subsidies by comparing the results.

First, government subsidies provided for both the farmer and the e-retailer are always favorable for awareness of agricultural products? online branding, as in the FR scenario. When subsidies are offered to both farmers and e-retailers, both are encouraged to cooperate intimately and offer a high awareness of online branding. By subsidizing the farmer and the e-retailer, government subsidy strategies are beneficial because they induce more consumers to embrace agricultural products. In the FR scenario, a government?s subsidy format compensates a farmer?s per-unit cost and stimulates consumers? demand, encouraging awareness of agricultural products in the marketplace. Although increases in customers? demand result in a higher cost coefficient for the e-retailer, the subsidies provided by the government compensate for the cost.

Second, unlike the other three scenarios, the FR scenario optimizes profits for the farmer and the e-retailer. That is, in the process of establishing the awareness of agricultural online-brand products, the profits of both parties are closely related to their costs and to customers? sensitivity to brand awareness. Governments offering subsidy quotas to both farmers and e-retailers effectively increase awareness of agricultural online-branded products? consumption and strengthen both parties? willingness to cooperate. Although consumers? online acceptance of agricultural products is better, e-retailers need to increase investments, redouble efforts, and continue cooperating with farmers to better meet consumer demand and maximize long-term benefits. As a result, increased profits of intensify this cooperation, and profits rise with consumption but the costs to e-retailers become heavier than before. This also explains an intriguing finding in all the scenarios we designed, whereby farmers? profits are always greater than e-retailers?. We therefore see the best profits for both farmer and e-retailer in the FR scenario.

Third, government is often restricted by limited budgets, and they face two decision-making strategies (i.e., *ex ante* and *ex post* strategies). Although both forms of strategy can exert the incentive purpose of government subsidies, our analysis using the Stackelberg game model is based on this consideration. Many agricultural products require farmers and the e-retailers to make their own preparations before each harvest. Naturally, government needs to grant subsidies in advance. For agricultural products similar to the Fengjie Navel Orange, *ex ante* strategy for government decision making on subsidy programs is a method for assessing and stimulating the needs of local agricultural markets [32], and it can vary by region [29].

In practice, however, government needs to work with the availability of known budgets. As mentioned in [14], subsidy planning is usually based on assessments of the extent to which current projects can meet actual needs. As a result, governments may turn to *ex post* strategies like those for subsidies of Bordeaux wines. These agricultural subsidies require government assessments of actual needs products? penetration of the market before distributing control of the subsidies.

Furthermore, incorporating spillover effects into our study, we obtained and compared important reference values in the different subsidy scenarios. After adding the spillover effects, most of the earlier results were still robust. Interestingly, the best profits for farmers were no longer in the FR scenario, but significantly improved in the F scenario.

This paper is composed as follows. We briefly review the associated literature in Sect. 2. In Sect. 3, we establish the basic framework of the subsidy model. In Sect. 4, we describe a non-subsidized baseline scenario and three distinct government subsidies scenarios. In Sect. 5, we analyze the optimal subsidy scenario and government's stragety between *ex ante* strategy and *ex post* strategy. Section 6 takes the spillover effect into consideration and obtains the optimal format of government subsidies. Section 7 summarizes the conclusions of this paper.

2 Literature review

Our paper mainly involves three streams of literature in operational management and economics, including agricultural products? online branding, cooperation on agricultural supply chain, and government policies for subsidizing agricultural brands? development.

Early in our research we focused on empirical studies in agricultural products? online branding. [35] assumed agricultural products and e-commerce may have potential relationships, taking the cherry industry as an example for research on the relationship between the industry?s reputation and sales via online branding at auction. [9] explained the impact of labels in the marketplace and the characteristics of brands. Similar to the [33] study, theirs showed consumers prefer to purchase eco-labeled products. [16] compared two modes of purchase: online and in-store. They pointed out that not all products are suitable for in-store pickup, and consumers sometimes favor online purchases. [27] focused research on orange juice as a representative agricultural product. They identified supply-chain design conditions for online-branded agricultural products? sales in a food-stressed environment, conditions enabling more sustainable sales. Compared with earlier studies, [27] and [27] presented case studies discussing the development of online sales for agricultural products, and our study is also based on actual consideration of better sales for agricultural products. Different from earlier research, we first used game theory to model a three-party Stackelberg game and explore the impact of government as a party in the supply chain. We further aimed to portray the awareness of agricultural online-branded products and investigate its impact on supply-chain performance.

The operational literature on government subsidies in different contexts is also growing.As shown in [12], proper government subsidies can significantly motivate companies to improve their efficiency. In this stream of research, a few recent studies focus on government subsidies for agriculture. [2] investigate the impact of government subsidies and taxes on sustainability practices, showing zero-spending government subsidies would reduce social welfare. For government to decide on the best subsidies, [13] propose an iterative process. With the aim of understanding the impact of government subsidies on corporate R&D investment behavior, [38] analyze the impact of government subsidies on China?s renewable energy industry. For brick-and-mortar policy, the *New York Times* offers a report on the rural household tax rebate program [34]. Developing our paper in this context, we chose to consider four different scenarios in our model, thus making it as realistic as possible. None of the research mentioned above incorporated awareness of agricultural online-brand products. However, because it is important for the famer to enhance awareness of agricultural products, we chose to explore four different subsidies scenarios, obtaining the optimal format for government subsidies and the best awareness of agricultural online-branded products.

Our work is also related to the cooperative online branding of agricultural products. In this stream of research, [36] uses Indian manufacturing companies as an example to study farmers? organizations as a link between producers and retailers where producers sell farmers? products to help farmers improve their position in the value chain. [15] investigate examples of Switzerland?s elimination of milk quotas, studying collaboration between farmers? organizations and cooperatives to help farmers consolidate distribution of their products. [26] XX compare cost and marketing performance in Turkey?s cooperatives and commission agents, indicating agricultural products? trading performance under both cooperation modes is often better than traditional approaches. As another way of looking at supply-chain cooperation and stakeholders, [18] employ endogenous switching profit models to estimate the impact of cooperative members on sales channels of farmers? choice, also indicating cooperatives? critical role in promoting agricultural products. [1] set up a model for the hybrid case of a direct-selling cooperative capable of benefiting farmers and cooperative alike. Models based on supply-chain members? cooperation thus explore cooperatives? impact on farmers? improved outcomes and the consolidation of brands, but the literature focuses on impacts on farmers or on the entire supply chain. Attention on government funding actions for agricultural brands calls for [36] to investigate where government should provide financial support to promote the positive impact of agricultural products. However, the focus remains limited to supply-chain cooperation as it builds brands. Traditionally, e-retailers only make profits by selling agricultural products to earn the price difference. In our paper we considered a cooperation whereby the retailer pays marketing costs to expand product awareness, thus increasing demand. We further explored the best efforts to increase demand as required by both retailers and farmers.

3 The model

We considered a three-player model for supply chains. A farmer, an e-retailer and a government take part where the government provides subsidies (to the farmer and/or the e-retailer) to encourage cooperation for the promotion and awareness of agricultural online-branded products. The structure of this supply chain is illustrated in Fig. 1.

Implementing government subsidy strategies calls for consideration of two strategies (*ex ante* and *ex post*). The first subsidy strategy for government decisions is an *ex ante* strategy adopted by government before the agricultural ripening season. Adopting this strategy, the government acts as the leader in a Stackelberg game. We combined four different scenarios for analysis and exploration. In these scenarios, the government sets the subsidies? modes and standards for the farmer and/or the e-retailer. The e-retailer, taking advantage of direct market information, decides retail price based on awareness of agricultural products? online brands. The farmer determines wholesale price based on production costs and his efforts to satisfy the standards established by the e-retailer for online branding. For the rest of the study, we use the synonym "he" to represent the farmer, "she" to represent the e-retailer.

Due to the limitations of an actual budget, however, in practice government may implement an *ex post* strategy whereby the government is no longer in the leading role. It distributes limited subsidies, according to budget, for the farmer and the e-retailer. In this form of distribution, often after a harvest, the government uses *ex post* strategy to intensify awareness of agricultural products? online branding and cooperation between farmer and e-retailer. In addition to considering the allocation of subsidies according to the corresponding standards of the farmer and the e-retailer, the government needs to compare the theoretical share of subsidies and the amount of subsidies that can be paid according to the actual budget.

The demand for the agriculture products with online-brand is $D = 1 - p + \theta e$, where p is the retail price of agricultural online-brand products, and e represents awareness of agricultural products? online branding as it increases demand. The coefficient θ ($\theta \geq 0$) measures marginal consumer demand with respect to awareness of products. Because this awareness lowers information asymmetry and reduces searching costs for consumers, they have higher willingness to pay for products with higher awareness, and this leads to greater demand. The linear demand function shows that lower price and higher brand awareness lead to higher demand for a product, and this is consistent with the agricultural product market in practice. Such a linear demand model is also common in the literature on agriculture operations management (such as [4, 5, 17, 22, 40]).

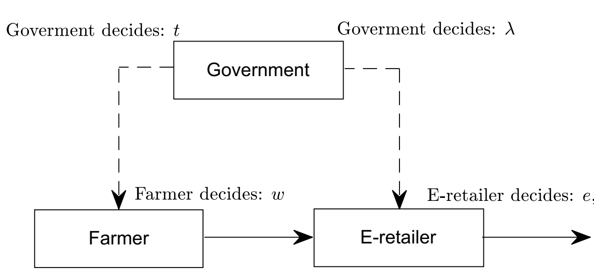


Fig. 1 Supply chain structure

Like the description supplied by [19], our model distinguished between superior and inferior quality in agricultural products as they determine awareness of agricultural products? online branding. To improve awareness, the farmer needs to put in greater effort than usual for product quality. This effort includes choosing good varieties, working harder, spending more time on caring for crops, and so forth, in proportion to the production. Such effort influences pre-unit production cost. In China for example, Gannan navel oranges, as one geographical indication?s agricultural products, face a series of brand standards (including national and local standards as well as and industry standards). These standards require the farmer to choose excellent seedlings, to weed regularly, to supply timely pest control, and so forth. These efforts lead to an extra volume-dependent variable cost which can be modeled as $c = c_0 + \beta e$, where c_0 represents base cost without brand-building efforts, normalized to zero, β is the variable coefficient measuring increases in per-unit costs with brand-building efforts. This approach in linear cost model has also been adopted by other scholars such as [24, 25] and [30].

The farmer needs to decide the wholesale price according to a product?s quality along with the farmer?s output and effort. Furthermore, if government decides to subsidize the farmer, it usually subsidizes the farmer for each unit of output. Therefore, the farmer?s profit is

$$\pi_f = (w - \beta e)D + tD, \tag{1}$$

where the $t \geq 0$ is the variable coefficient related to the subsides standards.

Like the farmer, the e-retailer is required to put in more effort than usual to promote awareness of online-branded agricultural products. These activities include setting standards, marketing the products online, constructing cold chain facilities, and so forth. For example, Fengjie navel oranges in China, another geographical indication?s agricultural products, have since the beginning of online sales seen Alibaba improving industry standards, integrating its marketing, and building local cold chain facilities. These efforts on the part of the e-retailer lead to extra variable costs which usually influence the total cost and can be modeled as $\frac{1}{2}ke^2$. This approach of quadratic cost modeling is also adopted in such literature as [20, 41, 42] and [39].

Thee-retailer determines the retail price of an agricultural product based on the e-retailer?s own efforts and on market demand. To encourage e-retailers to foster online branding, expand brands? sales, and strengthen cold chain construction, government can choose whether to subsidize e-retailers, it usually providing a share of subsidies for the e-retailer?s effort costs. Therefore, the e-retailer's profit is

$$\pi_r = (p - w)D - \frac{1}{2}ke^2 + \frac{1}{2}\lambda ke^2, \tag{2}$$

where the constant $\lambda \geq 0$ is the coefficient of government subsidy share according to the e-retailer?s efforts.

Because the total government subsidies are equal to the sum of subsidies provided for the farmer and the e-retailer, $\phi = tD + \frac{1}{2}\lambda ke^2$. As generally defined in the studies of [7] and [31], consumer surplus shows the area of the demand curve below a given price, which can be expressed as $D^2/2$. Like previous studies have expressed [20, 23, 31], incorporating subsidies, firms? profits, and consumer surplus, a government?s objective function can be expressed as follows:

$$\pi_g = \pi_f + \pi_r + D^2/2 - \phi. \tag{3}$$

The notations used here are listed in Table 1.

4 Government strategy analysis

In this section, we observe the equilibrium solutions for each player under different decision scenarios according to modes of subsidy. As a benchmark, we use subscript N to describe the scenario in which government subsidizes neither farmer nor e-retailer. Based on this benchmark scenario, we analyzed three different decision scenarios. First, using the abbreviation F for farmer, we considered the government might only subsidize the farmer. Second, we used the abbreviation R for retailer for a scenario where the government might subsidize only the e-retailer. In the third scenario, FR denotes government subsidies for both farmer and e-retailer. For the rest of the study, we use the pronouns he him and his for the farmer, and she her and hers for the e-retailer.

4.1 No subsidies for either party

In our benchmark scenario, the government would not provide subsidies for any party in the supply chain. The e-retailer first determines awareness of agricultural products? online branding e based on her marketing strategies. The farmer then determines wholesale prices w, making the corresponding efforts after the e-retailer has decided on brand awareness. Finally, the e-retailer decides the retail price p . This scenario is a benchmark for comparison among the other three subsidy models.

The profit functions for the farmer, the e-retailer and the government are

$$\pi_f = (w - \beta e)D, \tag{4}$$

$$\pi_r = (p - w)D - \frac{1}{2}ke^2, \tag{5}$$

$$\pi_g = \pi_f + \pi_r + D^2/2, \tag{6}$$

respectively.

Using the method of backward induction, we first optimize the Eq. (5) with p and obtain the optimal retail price as $\frac{w+e\theta+1}{2}$. Substituting p^* into Eq. (4) and solving for w in $\frac{d\pi_f}{dw} = 0$ gives the optimal wholesale price, $w^* = \frac{e(\beta+\theta)+1}{2}$. The optimal awareness of the agricultural online-brand e^*

Table 1 List of notations and symbols

Notation	Description
D	Market demand for the product
p	The e-retailer's retail price
α	A constant measure of the spillover effects on the awareness of agricultural online-brand products
e	The awareness of agricultural online-brand products' level
θ	Consumer sensitivity to the awareness of agricultural online-brand products
β	Coefficient measures the increase degree of the farmer's per-unit cost
w	The wholesale price, charged by the farmer
t	Subsidy coefficient for each produced unit of the farmer's efforts
k	Coefficient measures the increase degree of the e-retailer's total cost
λ	Subsidy coefficient for the total cost of the e-retailer's efforts
γ	The proportion of total subsidies provided by the government to the farmer
ϕ	Total subsidy provided by the government

can be obtained as $\frac{\beta-\theta}{(\beta-\theta)^2-8k}$. Finally, we substitute all the optimal solutions p^*, w^*, e^* into Eqs. (4), (5) and (6). Therefore, The optimal profit functions of the government, the e-retailer and the farmer are

$$\pi_f^* = \frac{8k^2}{[8k-(\beta-\theta)^2]^2}, \tag{7}$$

$$\pi_r^* = \frac{k}{2[8k-(\beta-\theta)^2]}, \tag{8}$$

$$\pi_g^* = \frac{k[28k-(\beta-\theta)^2]}{2[8k-(\beta-\theta)^2]^2}, \tag{9}$$

respectively.

4.2 Subsidies for farmer only

In this scenario, the government subsidizes only the farmer with tD, which is based on his production. Meanwhile, the government provides no subsidies for the e-retailer. The government first announces the ratio t to encourage the farmer to put in greater effort on products? quality. Subsequently, the e-retailer decides on awareness of the agricultural products? online branding e. The farmer next determines the wholesale price w according to his subsidies and his efforts to satisfy the requirements of awareness about his products? online branding. Finally, the e-retailer uses all the above information to determine retail price p.

The profit functions of the parties under this scenario are

$$\pi_f = (w-\beta e)D + tD, \tag{10}$$

$$\pi_r = (p-w)D - \frac{1}{2}ke^2, \tag{11}$$

$$\pi_g = \pi_f + \pi_r + D^2/2 - tD, \tag{12}$$

respectively.

Using the inverse derivation method, we first derive the optimal retail price p^* as $\frac{w+e\theta+1}{2}$ by Eq. (11). Second, we take the resulting p^* back into Eq. (10) and obtain the optimal wholesale price w^* as $\frac{e(\beta+\theta)+1-t+1}{2}$. Next, we bring the resulting optimal p^* , w^* back into Eq. (11) and obtain the optimal awareness of agricultural online-brand products e^* as $\frac{(\beta-\theta)(1+t)}{(\beta-\theta)^2-8k}$. After some algebraic operations, the optimal subsidy coefficient t^* can be obtained as $\frac{(\beta-\theta)^2+12k}{4k-3(\beta-\theta)^2}$. Finally, the optimal profit functions of the government, the e-retailer and the farmer are

$$\pi_f^* = \frac{32k^2}{[4k-3(\beta-\theta)^2]^2}, \tag{13}$$

$$\pi_r^* = \frac{2k[8k-(\beta-\theta)^2]}{[4k-3(\beta-\theta)^2]^2}, \tag{14}$$

$$\pi_g^* = \frac{2k}{4k-3(\beta-\theta)^2}, \tag{15}$$

respectively.

4.3 Subsidies for E-retailer only

In this scenario, the government only subsidizes the e-retailer with $\frac{1}{2}\lambda ke^2$, based on e (his efforts). The farmer receive no subsidies. The government first announces the ratio (λ) of subsidies to the e-retailer. Afterwards, the e-retailer determines brand awareness e by comprehensively considering subsidies from the government and her business strategies. However, without subsidies the farmer decides the wholesale price w after the e-retailer has determined brand awareness and requirements. Finally, the e-retailer decides the retail price p.

The profit functions of the farmer, the e-retailer and the government are

$$\pi_f = (w-\beta e)D, \tag{16}$$

$$\pi_r = (p-w)D - \frac{1}{2}ke^2 + \frac{1}{2}\lambda ke^2, \tag{17}$$

$$\pi_g = \pi_f + \pi_r + D^2/2 - \frac{1}{2}\lambda ke^2, \tag{18}$$

respectively.

Similarly, optimizing the Eq. (17) with the optimal retail price p, we first have p^* as $\frac{w+e\theta+1}{2}$. Afterwards, we substitute the solution of the optimal solution p^* into Eq. (16), the optimal price w^* can be derived as $\frac{e(\beta+\theta)+1}{2}$. We bring the resulting optimal solution p^*, w^* back into Eq. (17) and solve the optimal effort level e^* as $\frac{(\beta-\theta)}{(\beta-\theta)^2-8k+8\lambda k}$. Substituting these optimum solutions into the government profit function Eq. (18), we obtain the optimal subsidy coefficient λ^* as $\frac{5}{7}$. Optimizing the profit functions with respect to p^* ,w^*,e^* and λ^*, the optimal profits of the three parties in this scenario can be acquired as

$$\pi_f^* = \frac{32k^2}{[16k-7(\beta-\theta)^2]^2}, \tag{19}$$

$$\pi_r^* = \frac{k}{16k-7(\beta-\theta)^2}, \tag{20}$$

$$\pi_g^* = \frac{7k}{16k - 7(\beta - \theta)^2}, \tag{21}$$

respectively.

4.4 Subsidize both sides

In this scenario, the government respectively subsidies to the farmer with tD and subsidies to the e-retailer with $\frac{1}{2}\lambda ke^2$. The government first declares the subsidy standards to the farmer and the e-retailer. The e-retailer then determines the awareness of agricultural online-brand products' level by considering the subsidies from the government and her own strategies to the market. After the e-retailer's decision on e, the farmer determines wholesale price w according to the awareness of agricultural online-brand products' level. Finally, the e-retailer decides the retail price p based on all the above information. The profit functions of all parties are explained in Eqs. (1)–(3) in Sect. 3.

Computing the partial derivative of Eq. (2) with p, we can obtain the first-order condition (FOC) by equating this derivative to zero, the optimal retail price p^* can be expressed as $\frac{w+e\theta+1}{2}$. We optimize the profit function of the farmer (Eq. 1) and acquire the optimal w^* as $\frac{e(\beta+\theta)-t+1}{2}$. We continue to solve the optimum awareness of agricultural online-brand products' level e^* as $\frac{(\beta-\theta)(1+t)}{(\beta-\theta)^2-8k(1-\lambda)}$. By optimizing the two FOC with $\frac{\partial \pi_g}{\partial t} = 0$ and $\frac{\partial \pi_g}{\partial \lambda} = 0$, we obtain the optimum subsidy coefficient of the farmer t^* as $\frac{3k}{k-(\beta-\theta)^2}$ and the optimum subsidy coefficient of the e-retailer λ^* as $\frac{1}{2}$ respectively. Finally, we obtain the optimal profit functions for each player as

$$\pi_f^* = \frac{2k^2}{[k - (\beta - \theta)^2]^2}, \tag{22}$$

$$\pi_r^* = \frac{k[4k - (\beta - \theta)^2]}{4[k - (\beta - \theta)^2]^2}, \tag{23}$$

$$\pi_g^* = \frac{k}{2[k - (\beta - \theta)^2]}, \tag{24}$$

respectively.

5 Analysis

To simplify the results and facilitate the presentation of insights, we define $S = \theta - \beta$ to represent the *farmer's market sensitivity* ($0 < S < 2\sqrt{2k}$ or $-2\sqrt{2k} < S < 0$ to ensure non-negative solutions of e and meaningful insights). It reflects the farmer's marginal cost of producing cater to the consumer's desire of online-brand agricultural product. On this basis, all of the above solutions in different subsidy scenarios are summarized in Table 2.

Table 2 Equilibrium values of different subsidy modes

Variable	N	F	R	FR
e^*	$\frac{S}{8k-S^2}$	$\frac{2S}{4k-3S^2}$	$\frac{7S}{16k-7S^2}$	$\frac{S}{k-S^2}$
t^*	–	$\frac{S^2+12k}{4k-3S^2}$	–	$\frac{3k}{k-S^2}$
λ^*	–	–	$\frac{5}{7}$	$\frac{1}{2}$
ϕ	0	$\frac{4k(S^2+12k)}{(4k-3S^2)^2}$	$\frac{35kS^2}{2[(16k)^2-(7S)^2]}$	$\frac{k(12k+S^2)}{4(k-S^2)^2}$
π_f^*	$\frac{8k^2}{(8k-S^2)^2}$	$\frac{32k^2}{(4k-3S^2)^2}$	$\frac{32k^2}{(16k-7S^2)^2}$	$\frac{2k^2}{(k-S^2)^2}$
π_r^*	$\frac{k}{2(8k-S^2)}$	$\frac{2k(8k-S^2)}{(4k-3S^2)^2}$	$\frac{k}{16k-7S^2}$	$\frac{k(4k-S^2)}{4(k-S^2)^2}$
π_g^*	$\frac{k(28k-S^2)}{2(8k-S^2)^2}$	$\frac{2k}{4k-3S^2}$	$\frac{7k}{16k-7S^2}$	$\frac{k}{2(k-S^2)}$

where $S = \theta - \beta$

For the sake of explanation, we use subscripts and abbreviations to represent variable values in different scenarios. For example, $e^*(N)$ represents the optimal awareness of agricultural online-brand products' level under the condition of government non-subsidies. Similarly, $\pi_f^*(FR)$ is the farmer's optimal profits under the condition that the government subsidizes both the farmer and the e-retailer scenario, and $\pi_r^*(N)$, $\pi_r^*(F)$, $\pi_r^*(R)$ represent the e-retailer's optimal profits under another three scenarios respectively.

5.1 The impact of government subsidies on online-brand awareness

sWe first examine the impact of government subsidies on the awareness of agricultural online-brand products in different subsidy scenario. Intuitively, the government subsidies encourage supply chain members to improve the awareness of agricultural online-brand products.

Proposition 1 *The awareness of agricultural online-brand products increases with farmer's market sensitivity S and decreases with the e-retailer's cost coefficient k. The government's subsidies always have a positive impact on the awareness of agricultural online-brand products in either case compared with no subsidy. Specifically,* $e^*(FR) > e^*(F) > e^*(R) > e^*(N)$.

Proposition 1 shows that the awareness of agricultural online-brand products is strictly increasing with *farmer's market sensitivity S*. Specifically, greater demand sensitivity and smaller per-unit cost of the farmer lead to higher awareness of agricultural online-brand products. Moreover, bigger investment cost discourages the e-retailer's enthusiasm to promote the awareness of agricultural online-brand products.

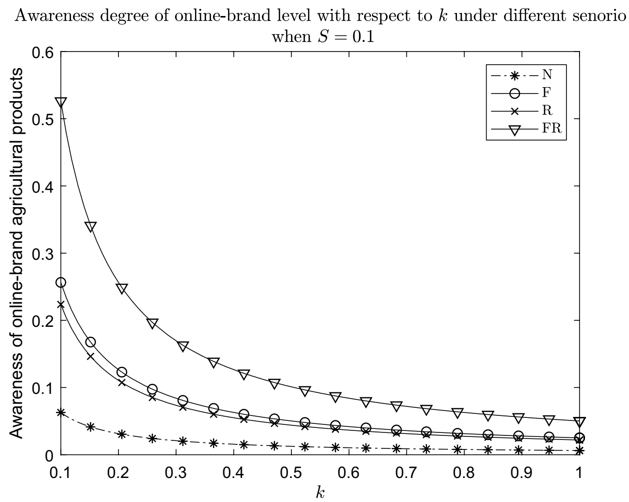


Fig. 2 The awareness of online-brand under different scenario

Consistent with the intuition, the awareness of agricultural online-brand products increases when the government provides subsidies. The awareness of agricultural online-brand products' sequence in different scenarios shows that the government provides subsidies both to the farmer and e-retailer is the best solution. Numerical simulation of this conclusion is show in Fig. 2. 1 provides a more detailed proof of comparing the awareness of agricultural online-brand products in different subsidies scenarios.

5.2 The impact of government subsidies on the profits of the farmer and the e-retailer

It is widely believed that subsidies provided by the government tend to actively increase the profits of the farmer and the e-retailer. We studied the effects of government subsidies on the profits of the farmer and the e-retailer in Propositions 2 and 3, respectively. In Proposition 4, we compare the profits of the farmer and the e-retailer in different subsidies' scenarios.

Proposition 2 *The profits of the farmer increases steadily with the increase of farmer's market sensitivity S. Compared with unsubsidized scenarios, the government subsidies can always have a positive effect on the farmers' profits. The condition can be expressed as* $\pi_f^*(FR) > \pi_f^*(F) > \pi_f^*(R) > \pi_f^*(N)$.

Proposition 2 represents that whether the government provides subsidies, the profits of farmers are strictly proportional to *farmer's market sensitivity S*. Further, the government attempts to increase the farmer's profits when the farmer improves *farmer's market sensitivity S*. As *farmer's market sensitivity S* increases, the farmer gains more profits through the government's subsides and hence produces agricultural products more responsible. As a result, the farmer's profits increase. The order of the farmer's profits under the different subsidies scenarios shows that the government's subsidy to both the farmer and the e-retailer is the best solution. The numerical simulation results of this conclusion are shown in Fig. 3. 1 provides a forceful proof for comparing the profits of the farmer in different subsidies situations.

Proposition 3 *The e-retailer's profits is improved as farmer's market sensitivity S increases, and conversely decrease as the e-retailer's cost factor k increases. In the scenario where the government does not provide subsidies, the e-retailer's profits are the most fragile. The order corresponds to* $\pi_r^*(FR) > \pi_r^*(F) > \pi_r^*(R) > \pi_r^*(N)$.

Proposition 3 shows that the e-retailer's profits are affected by *farmer's market sensitivity S* in positively directions and the e-retailer's cost factor k in opposite directions. The change in the e-retailer's profits depends on the parameters relation. The results reveal that the increase in *farmer's market sensitivity S* tend to actively drive the profits of the e-retailer. Conversely, the greater the e-retailer's cost factor k, the lower the e-retailer's profits. The numerical simulation results of this conclusion are shown in Fig. 4. The sequence of the e-retailer's profits under different subsidies scenarios indicates that the government provides subsidies to both the farmer and the e-retailer is the best subsidy solution. A more detailed proof provided by 1 which is used to compare the profits of e-retailers in different subsidy scenarios.

Proposition 4 *The profits of the farmer is always greater than the profit of the e-retailer, not only in the scenario of the government's non-subsidy, but also in the scenario of*

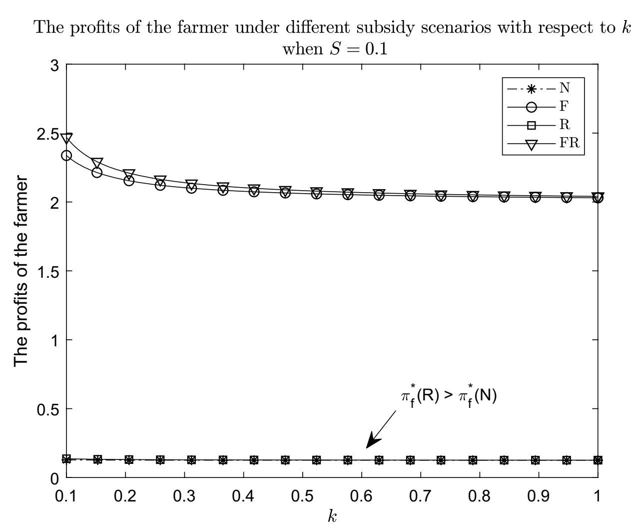


Fig. 3 The profits of the farmer under different scenarios

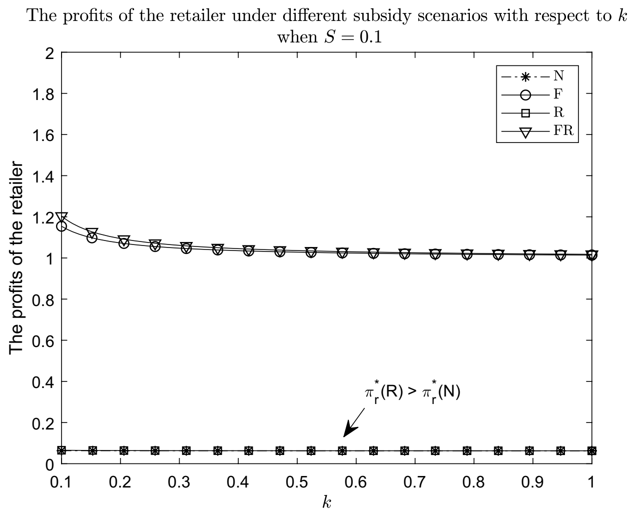


Fig. 4 The profits of the e-retailer under different scenarios

three different government subsidies. Specially, $\pi_f^*(FR) > \pi_r^*(FR)$, $\pi_f^*(F) > \pi_r^*(F)$, $\pi_f^*(R) > \pi_r^*(R)$, $\pi_f^*(N) > \pi_r^*(N)$.

What is interesting in Proposition 4 is that no matter how the government provides subsidies, the farmer's profits always exceed the e-retailer's profits. The government subsidizes to the farmer based on his unit production, and to the e-retailer based on her total investment. In addition, in the process of working with the farmer to build the awareness of agricultural online-brand products, the e-retailer need to pay more efforts than usual. Those efforts include measuring online agricultural product sales standards, online-brand market sales options, and sound cold chain facilities. All of the above information may become part of the reason why the farmer's profits are always better than the e-retailer's profits, no matter how the government provides subsidies. As the government's subsidies increase, the farmer gains more returns through increasing *farmer's market sensitivity S* and hence cooperates with the e-retailer more attentively. As a result, the e-retailer's profits increase. 1 considers the meticulous comparison of the profits of the farmer and the e-retailer in different government subsidies scenarios.

5.3 Government's strategy to subsidize

The government acts as the Stackelberg game leader in the scenarios of F, R and FR. Based on the discussion of Propositions 1–4, we combine the impact of government subsidies on the awareness of agricultural online-brand products with the impact on the member's profit in the supply chain of different scenarios, and then comprehensively consider the best solutions for the government to provide subsidies in Proposition 5.

Proposition 5 *As the Stackelberg leader, the optimal solution to the government is to subsidize both the farmer and the e-retailer. Specifically, subsidizes the farmer and the e-retailer with* $t^*(FR) = \frac{3k}{k-S^2}$, $\lambda^*(FR) = \frac{1}{2}$ *respectively.*

The government adopts *ex ante strategy* before the agricultural mature season, which is accompanied by the government's status as the leader of the Stackelberg game. Taking the illustrious Fengjie Navel Orange as an example, the Fengjie County People's Government of Chongqing issues a series of online support policies for Fengjie Navel Orange before the harvest season to encourage the farmer and the e-retailer to build the high-quality awareness of agricultural online-brand products. Refers to Table 2, when the government adopts the *ex ante strategy* with the optimal subsidy format to the farmer and the e-retailer, the awareness of agricultural online-brand products' optimal value is $e^*(FR) = \frac{S}{k-S^2}$. The total subsidies that the farmer and the e-retailer receive from the government are $\frac{3k^2}{(k-S^2)^2}$ and $\frac{kS^2}{4(k-S^2)^2}$, respectively. Moreover, the optimal profit of the farmer is $\pi_f^*(FR) = \frac{2k^2}{(k-S^2)^2}$, and the e-retailer's optimal profit is $\pi_r^*(FR) = \frac{k(4k-S^2)}{4(k-S^2)^2}$.

6 Extention

We further consider the impact of the spillover effects of the government subsidies. Both [21] and [8] study the spillover effects and related effects of subsidies and benefits in country. The same is true for [11], who study the spillover effects of European regional policies on investment funds in underdeveloped regions. Among them, [21] explore the impact of spillover effects on China's sustained economic growth, and point out that more subsidies to domestic R&D research and purchase of intermediate goods can enhance China's R&D intensity with the spillover effects. In our model, the so-called spillover effects include not only the expected impact of the government subsidies on the development of supply chain member activities, but also the additional impact on people or society outside the supply chain. For example, in the scenario where the government provides subsidies to both the farmer and the e-retailer, the awareness of agricultural online-brand products as well as the profits of the farmer and the e-retailer are all reach the optimal level (like stated in Propositions 1–5). With the effective promotion of the awareness of agricultural online-brand products, the district of this agricultural product is popular among the consumer groups. Further, these effects make more consumers tend to travel to the agricultural products district for consumption, which increase the sales of regional agricultural products, raise regional consumption levels, and develop regional economic. Specifically, the increase in travel fares of the agricultural district, hotel accommodation revenue and food prices, etc., reflects the actual impact of spillover effects on the district. The above series of spillover effects provide an effective reflection of the considerable regional economic growth trend in the agricultural district.

By adding the spillover effect to the positive impact of building the awareness of agricultural online-brand products, driven by the work of [20], the government's total profit function is rewritten from the original Eq. (3),

$$\pi_g = \alpha e - \phi + \pi_f + \pi_r + D^2/2, \tag{25}$$

among them, the first item corresponds to the external spillover benefit brought by the efforts to build the awareness of agricultural online-brand products and $\alpha > 0$ is a constant measure of the spillover effects on the awareness of agricultural online-brand products. After considering the spillover effects of government subsidies into the model we constructed, we obtain the results in Table 3 by the calculations in Sect. 3 and the considerations of various subsidy scenarios in Sect. 4.

Given the external spillover effects of expected results, the analysis and comparison of different subsidy schemes is intractable. In order to directly investigate the impact of government subsidies on fostering the awareness of agricultural online-brand products, and the impact of subsidies on the profits of the farmer and the e-retailer, we further numerically compare all the four different subsidy scenarios.

We first discuss the impact of the spillover effect of the game model on the awareness of agricultural online-brand products. In line with Proposition 5, our conclusions are still robust. As the parameter values remain constant and take into the spillover effects, the awareness of agricultural online-brand products is still at the optimal level in the FR scenario where the farmer and the e-retailer all receive the government's subsidies. Similar to our Proposition 1, the spillover effects to the awareness of agricultural online-brand products are more significant when the government only subsidize the farmer rather than only subsidize the e-retailer. Compared with the other three scenarios, the awareness of agricultural online-brand products in non-subsidy scenarios is not significant. Figure 5 clearly shows the results.

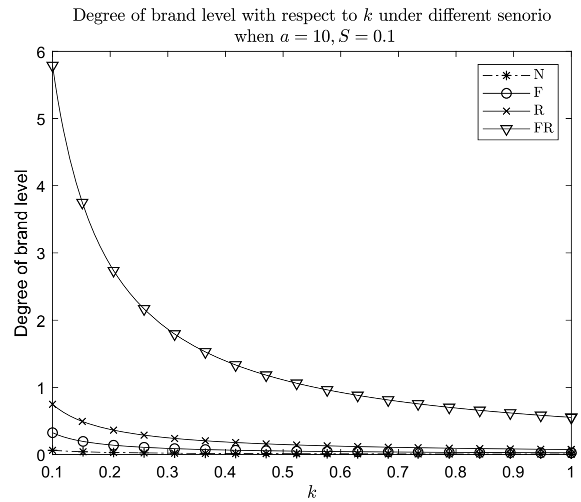


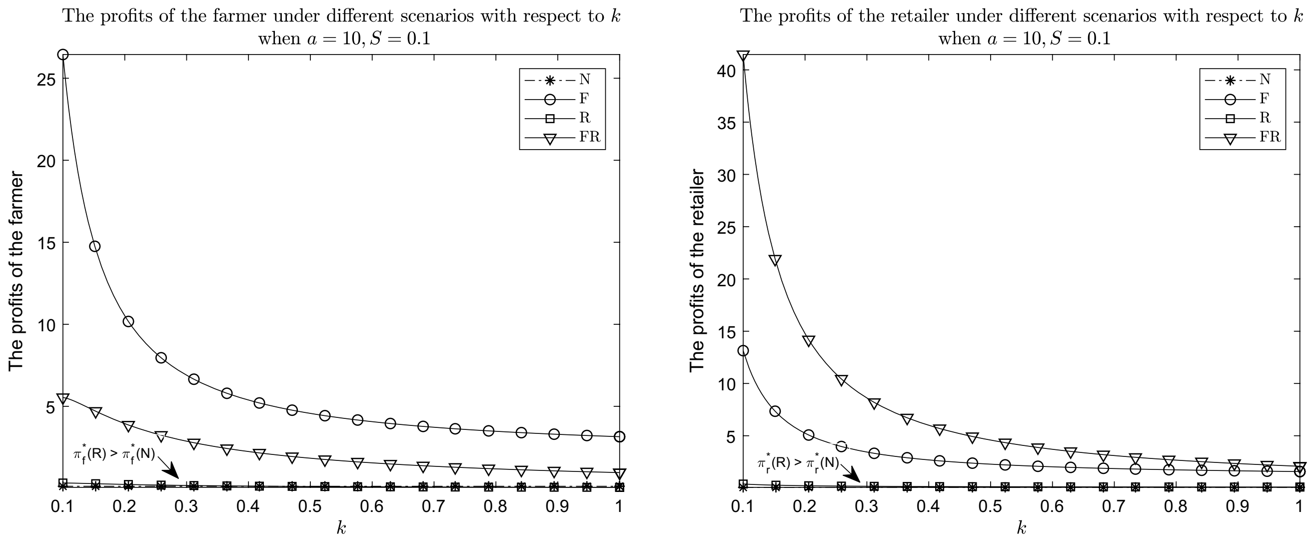
Fig. 5 The awareness of agricultural online-brand products under different scenarios

It's interesting that as we keep other variable parameter remains constant and take into the spillover effects, the farmer's profits are more significant in the scenario of the government only subsidies the farmer than in other subsidies' scenarios. When the government subsidizes both the farmer and the e-retailer, the profits of the farmer are less than the profits of the scenario that the government only subsidizes the farmer. The two order adjustment of the farmer's profits are the most obvious difference from the one mentioned in Proposition 2. What follows is that the farmer obtains more profits in the scenario of the government only subsidizing the e-retailer than he obtains in the scenario of the government providing no subsidies. Therefore, we sufficiently demonstrates that after the considering of the spillover effects and comparing the farmer's profits, the subsidy format that the government subsidizes farmers and e-retailers still

Table 3 Equilibrium values of different subsidy modes with spillover effects

Variable	N	F	R	FR
e^*	$\frac{S}{16k-S^2}$	$\frac{\alpha S^2+4kS}{6kS^2-16k^2}$	$\frac{16\alpha-7S}{7(32k-S^2)}$	$\frac{\alpha-S}{2k-S^2}$
t^*	–	$\frac{\alpha S^3+2kS^2+16k(\alpha S+3k)}{16k^2-6kS^2}$	–	$\frac{6k-3\alpha S}{2k-S^2}$
λ^*	–	–	$\frac{16\alpha k-\alpha S^2-5kS}{16\alpha k-7S}$	$\frac{4\alpha k-\alpha S^2-2kS}{4\alpha k-4kS}$
π_f^*	$\frac{32k^2}{(16k-S^2)^2}$	$\frac{8(4k+\alpha S)^2}{(8k-3S^2)^2}$	$\frac{32(2k-\alpha S^2)}{(32k-7S^2)^2}$	$\frac{2(2k-\alpha S^2)}{(2k-S^2)^2}$
π_r^*	$\frac{k}{16k-S^2}$	$\frac{(4k-\alpha S)^2(16k-S^2)}{4k(8k-3S^2)^2}$	$\frac{\alpha S-2K}{7S^2-32k}$	$\frac{S^2(3\alpha^2-2k)+\alpha S(S^2-14k)+16k}{4(2k-S^2)^2}$
π_g^*	$\frac{\alpha S^3-kS^2-16\alpha kS+56k^2}{(16k-S^2)^2}$	$\frac{(4k-\alpha S)^2}{4k(8k-3S^2)^2}$	$\frac{7(k-\alpha S)+8\alpha^2}{32k-7S^2}$	$\frac{\alpha^2+2k-2\alpha S}{4k-2S^2}$

where $S = \theta - \beta$



(a) farmer's profit

(b) e-retailer's profit

Fig. 6 Extension values with respect to k under different scenarios

dominates the other three subsidies formats, as illustrated in Fig. 6a.

Finally, we find that the profits of the e-retailer are always the highest level when the government subsidizes the e-retailer and the farmer. When the government only subsidizes the farmer, the e-retailer's profits are more obvious, compared with the e-retailer's profits when the government only subsidizes the e-retailer. However, the e-retailer's profit is the lowest level when the government does not implement any subsidy. This consideration of the e-retailer's profits order after adding the spillover effects is consistent with Proposition 3, and can also reference to Fig. 6b.

7 Conclusion

We thus modeled a supply chain consisting of a farmer, an e-retailer, and a government. To promote awareness of agricultural products? online branding, the government may offer subsidies to both or either of the other members in the supply chain. Investigating the impact of different government subsidy strategies, we modeled a three-player Stackelberg game and characterized four different scenarios concerning subsidies in the context of *ex ante* strategy. Considering the implementation of government subsidies in practice, we also examined the government?s *ex post* strategy. Comparing the best solutions under different strategies, we obtained management insights as discussed in the rest of this section.

First, awareness of agricultural products? online branding is negatively affected by the large effort costs to the farmer and e-retailer. Awareness can be most improved if the government supplies subsidies for both the e-retailer and the farmer. Consistent with our intuition, the high investment cost of enhancing awareness for agricultural products may reduce an e-retailer?s incentive to increase effort, yet consumer preference for branded products stimulates the farmer and the e-retailer to raise awareness of their products. Furthermore, only when both farmer and e-retailer are subsidized can the maximum awareness be achieved for agricultural products online. This suggests the e-retailer plays a significant role in promoting the awareness of online-branded agricultural products; it also suggests an insight for government?that subsidizing e-retailers is as important as subsidizing farmers.

Second, either the farmer or the e-retailer obtains greater profits under the circumstance that both are subsidized by the government. Interestingly, the farmer?s profit in this condition is higher than in the scenario where only the farmer is subsidized, and this encourages the farmer strengthen cooperation with the e-retailer. Meanwhile, if the government subsidizes the only e-retailer, the retailer?s profit is lower than under the condition that the government only subsidizes the farmer.

We also expanded our investigation to consider the impact of spillover effects. By inferring from the different subsidy scenarios, we found that a win-win solution can also exist in a model that includes spillover considerations. We see an interesting exception when considering the spillover effects, whereby the farmer prefers to receive government subsidies alone and thus maximize profits. But from the point of view that the main goal of government subsidies is to raise awareness of agricultural products? online branding, subsidizing both the farmer and the e-retailer is still the best subsidy format.

Those above conclusions provide a practical reference for the government to cultivate high-quality agricultural products brands, manage online-brand agricultural products, and adopt corresponding subsidy policies.

There are many potential study directions for expanding on this research. First, our modeling has studied the linear relationship between cost to the farmer and unit output, while the investment of the e-retailer shows a quadratic relationship. Therefore, investigation can be extended to other models based on our study. Second, in contrast to our model, future work may consider the fact that, in practice, multiple farmers often cooperate with a e-retailer. Third, because farmers need to consider weather constraints and take multi-effect protections to ensure the quality of agricultural products sold online, our work may provide support for a productive study direction.

Appendix A. Proof of proposition 1

First we compare the values of $e^*(FR)$ and $e^*(F)$ by division method, that is, we analyze whether the following value is larger than 1 or smaller than 1

$$\frac{e^*(FR)}{e^*(F)} = \frac{4k-3S^2}{2k-2S^2}, \tag{A.1}$$

where S represents/is the farmer's market sensitivity. Here, for ensuring non-negative solutions and meaningful insights for e, we set $0 < S < 2\sqrt{2}k$ or $-2\sqrt{2}k < S < 0$. And k $(0 < k < 1)$ is a coefficient to measure the extent of total cost increase. From the above conditions, we can derive $\frac{4k-3S^2}{2k-2S^2} > 1$, i.e. $e^*(FR) > e^*(F)$.

Similarly, we compare $e^*(F)$ with $e^*(R)$. Noting that

$$\frac{e^*(F)}{e^*(R)} = \frac{32k-14S^2}{28k-21S^2}, \tag{A.2}$$

we can directly claim that the ratio of $\frac{32k-14S^2}{28k-21S^2}$ is bigger than 1, that is, $e^*(F) > e^*(R)$.

Through first two steps, we know that $e^*(R)$ is the smallest value. Thus we just compare the values of $e^*(R)$ and $e^*(N)$. Note

$$\frac{e^*(R)}{e^*(N)} = \frac{56k-S^2}{16k-S^2}. \tag{A.3}$$

It follows from the ranges of S and k and Eq. (A.3) that $e^*(R) > e^*(N)$.

After comparing the status of the popularity of agricultural product brands under three different subsidy methods and no-government subsidies, i.e., Eqs. (A.1)–(A.3), can obtain the order of the awareness of agricultural online-brand products in Proposition 1. According to the sequence, it can be clearly proved that the government subsidy can efficaciously promote the awareness of agricultural online-brand products.

Appendix B. Proof of proposition 2

Similar to the proof in Proposition 1, we employ the division method to compare the profits of the farmer in different situations. Consider

$$\frac{\pi_f^*(FR)}{\pi_f^*(R)} = \frac{(16k-7S^2)^2}{16(k-S^2)^2}, \tag{B.1}$$

in which $0 < S < 2\sqrt{2}k$ or $-2\sqrt{2}k < S < 0$, and $0 < k < 1$. According to conditions satisfied by S and k, we can declare that $\frac{(16k-7S^2)^2}{16(k-S^2)^2} > 1$, which implies $\pi_f^*(FR) > \pi_f^*(R)$.

Then, we continue to compare the profits of the farmer in the two cases where the government only subsidizes the farmer and the government only subsidizes the e-retailer respectively. Note

$$\frac{\pi_f^*(F)}{\pi_f^*(R)} = \frac{(16k-7S^2)^2}{(4k-3S^2)^2}, \tag{B.2}$$

which implies that $\pi_f^*(F) > \pi_f^*(R)$ by using the conditions $0 < S < 2\sqrt{2}k$ or $-2\sqrt{2}k < S < 0$ and $0 < k < 1$.

Following from the results in Eqs. (B.1) and (B.2), we now discuss whether $\pi_f^*(FR)$ or the inverse is right. Considering

$$\frac{\pi_f^*(FR)}{\pi_f^*(F)} = \frac{(4k-3S^2)^2}{16(k-S^2)^2}, \tag{B.3}$$

and the ranges of S and k, $\frac{(4k-3S^2)^2}{16(k-S^2)^2} > 1$ obviously holds, which is equal to $\pi_f^*(FR) > \pi_f^*(F)$.

Finally, we analyze the difference in the farmer's profits between two situations: one is the government only subsidizes the e-retailer, the other is the government providing no subsidies. Set

$$\frac{\pi_f^*(R)}{\pi_f^*(N)} = \frac{4(8k-S^2)^2}{(16k-7S^2)^2}. \tag{B.4}$$

Then we derive $\frac{4(8k-S^2)^2}{(16k-7S^2)^2} > 1$ if S and k fall in the ranges mentioned above.

We discussed the profits of the farmer in those scenario that three different types of subsidies and no subsidy shown in Eqs. (B.1)–(B.4), which can clearly determine the changes in the profit of the farmer depending on the method the government subsidies. This order is consistent with that listed in Proposition 2.

Appendix C. Proof of proposition 3

First, we discuss the profits of the e-retailer in two situations where the subsidy object contains the e-retailer, i.e. the value of the following division

$$\frac{\pi_r^*(FR)}{\pi_r^*(R)} = \frac{(4k - S^2)(16k - 7S^2)}{4(k - S^2)^2}, \tag{C,1}$$

will be analyzed under the assumption that $0 < S < 2\sqrt{2}k$ or $-2\sqrt{2}k < S < 0$ and $0 < k < 1$. From Eq. (C,1), the denominator of this fraction is obviously more than the numerator, which is $\pi_r^*(FR) > \pi_r^*(R)$.

Next, we compare the dominant $\pi_r^*(FR)$ in Eq. (C,1) with the e-retailer's profit under the scenario of only the farmer being subsidized. Note that

$$\frac{\pi_r^*(FR)}{\pi_r^*(F)} = \frac{(4k - S^2)(4k - 3S^2)^2}{(8k - S^2)[8(k - S^2)^2]}. \tag{C,2}$$

By comparing the coefficient values in front of each parameter, the value of the denominator is slightly larger than the numerator. That is the e-retailer's profit is greater in the context of subsidizing both e-retailers and farmers than in the scenario of subsidized the farmer only. The meaning of symbolic expression is that $\pi_r^*(FR) > \pi_r^*(F)$.

According to the comparison results of Eqs. (C,1) and (C,2), we immediately realize that the smaller values $\pi_r^*(F)$ and $\pi_r^*(R)$ should be discussed, i.e. discuss whether the following fraction

$$\frac{\pi_r^*(F)}{\pi_r^*(R)} = \frac{(16k - 2S^2)(16k - 7S^2)}{(4k - 3S^2)^2}, \tag{C,3}$$

is larger than 1 or smaller than 1. By derivation, we know $\pi_r^*(F) > \pi_r^*(R)$. The profits that the e-retailer receive in the scenario where the government only subsidizes the farmer are greater than those when the government subsidizes the e-retailer only.

Finally, we compare the profits of the e-retailer in the two scenarios where the government only subsidizes the e-retailer and the government does not provide any subsidies. Set

$$\frac{\pi_r^*(R)}{\pi_r^*(N)} = \frac{16k - 2S^2}{16k - 7S^2}. \tag{C,4}$$

For Eq. (C,4), the numerator is heavier, as a result $\pi_r^*(R) > \pi_r^*(N)$.

Appendix D. Proof of proposition 4

According to the order in Propositions 1–3, we first compare the farmer's profits with the e-retailer's profits, under the government subsidies for both the e-retailer and the farmer scenario. Consider

$$\frac{\pi_f^*(FR)}{\pi_r^*(FR)} = \frac{8k}{4k - S^2}, \tag{D.1}$$

Owing to $k \in [0, 1]$, $0 < S < 2\sqrt{2}k$ or $-2\sqrt{2}k < S < 0$, obviously the numerator of this fraction in (D.1) is larger than the denominator, i.e., $\pi_f^*(FR) > \pi_r^*(FR)$.

Then, we analyze the farmer's profits with the e-retailer's profit, under the scenario of only the farmer being subsidized. Noting

$$\frac{\pi_f^*(F)}{\pi_r^*(F)} = \frac{16k}{8k - S^2}, \tag{D.2}$$

similarly, the coefficient before the k in the numerator is greater than the coefficient of the denominator, and the denominator is additionally subtracted a value which is greater than zero, so the value of formula D.2 is obviously greater than 1, which can be expressed as $\pi_f^*(F) > \pi_r^*(F)$.

We compare the farmer's profit with the e-retailer's profit in the following under the government only subsidizing the e-retailer scenario. Set

$$\frac{\pi_f^*(R)}{\pi_r^*(R)} = \frac{32k}{16k - 7S^2}, \tag{D.3}$$

Here, $k \in [0, 1]$, and $0 < S < 2\sqrt{2}k$ or $-2\sqrt{2}k < S < 0$. We can derive that $0 < S < 4\sqrt{(\frac{k}{7})}$ or $-4\sqrt{(\frac{k}{7})} < S < 0$ under the assumption of $16k - 7S^2 > 0$. Thus we obtain that $32k > 16k - 7S^2$. Consequently, $\pi_f^*(R) > \pi_r^*(R)$.

Finally, we compare the farmer's profit with the e-retailer's profit under the non-subsidies scenario. Considering,

$$\frac{\pi_f^*(N)}{\pi_r^*(N)} = \frac{16k}{8k - S^2}, \tag{D.4}$$

obviously the value of the above fraction is greater than 1, which means $\pi_f^*(N) > \pi_r^*(N)$.

Appendix E. Proof of proposition 5

First, in the scenario of the government adopting *ex post strategy* and subsidizing both the farmer and the e-retailer, we can respectively obtain their profits according to the aforementioned works as follows,

$$\pi_f(ep) = \frac{8k^2}{(8k - S^2)^2} + \gamma\phi_{ep}, \tag{E.1}$$

$$\pi_r(ep) = \frac{k}{2(8k - S^2)} + (1 - \gamma)\phi_{ep}, \tag{E.2}$$

where γ indicates that the government considers the proportion of the limited subsidy granted to the farmer after the *ex post strategy*, and the remaining (i.e., $1 - \gamma$) is given to the e-retailer.

Second, we recognize that the government judges distribution according to the awareness of agricultural online-brand products' establishment by the farmer and the e-retailer, and subsidizes them with *ex post strategy*. Hence, the object of maximizing benefits is to jointly optimize both $\pi_f(ep)$ and $\pi_r(ep)$ in the case of *ex post strategy*.

Finally, we derive the optimal subsidy allocation γ^*_{ep} in the case of the government adopting *ex post strategy*. Considering

$$\pi_f(ep) * \pi_r(ep) = \frac{[k + (1 - \gamma)\phi_{ep}](8k^2 + \gamma\phi_{ep})}{(2S^2 - 16k)[(8k - S^2)^2]}. \tag{E.3}$$

Let $\frac{d\pi_f(ep)*\pi_r(ep)}{d\gamma} = 0$ which gives the optimal proportion allocated to the farmer. Therefore, $\gamma^*_{ep} = \frac{1}{2} + \frac{8k^2+kS^2}{2\phi_{ep}(8k-S^2)^2}$. Hence, the corresponding proportion of the subsidy allocated to the e-retailer is $1 - \gamma^*_{ep} = \frac{1}{2} - \frac{8k^2+kS^2}{2\phi_{ep}(8k-S^2)^2}$.

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