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Research Article

Dynamic Strategies on Firm Production and Platform Advertisement in Crowdfunding considering Investor's Perception

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Taking investor's perception into account, the optimal decisions about the product quality and platform advertisement are investigated in a dynamic model in the context of crowdfunding. Researches in the literature, however, usually set investor's perception as a fixed value and rarely consider the important phenomenon that the online information has some influences on investor's perception. Considering the effects of information about product quality and platform advertisement on the investor's perception, a dynamic decision model is proposed. Firstly, investment desire and reference price of the investor are introduced in two dynamic settings to describe investor's perception. Then, the optimal decisions about the product quality and platform advertisement are formulated under two circumstances: the sponsor and the platform make decisions independently and they cooperate as a system. Finally, the influences of reference price and cost-sharing ratio on the optimal results are compared and the data simulation experiment verifies the necessity of the study. Some new insights can be drawn for the operations management of the firm in crowdfunding as follows: (i) it is more profitable for the firm to cooperate with the platform when investors pay more attention to their reference price; (ii) it is optimal for the firm to share a larger proportion of platform cost when the profit-sharing ratio is low.

1. Introduction

As an effective way of financing, crowdfunding has rapid development in the investment market. Crowdfunding is a general term that refers to the activities of raising funds from common investors through the Internet. In one of the most popular crowdfunding websites, Kickstarter.com, more than 3.5 million people have participated in 108,437 creative projects, and over 2.47 billion dollars has been pledged from the date Kickstarter.com founded till now. More than 115 numbers of crowdfunding platforms have been built and over 1 billion yuan has been raised at the end of 2014 in China [1]. Therefore, how to produce and operate effectively is becoming an increasingly prominent problem for crowdfunding firms with the popularity of crowdfunding activities.

There are four types of crowdfunding projects depending on what the investors can receive from the project, including donation-based, reward-based, lending, and equity crowdfunding [2–4]. In reward-based crowdfunding, the sponsor publishes the product's material and function information on the platform to introduce the products in detail. The information provides accurate product quality, and the cases that the sponsor provides faulty information to mislead readers are not considered in the present study. After accessing to the information, investors will form a certain valuation about the product quality and they will compare the price of the product with their reference price when they make purchase decisions. If the published online information can not attract investors effectively, the investment will be failing.

Investor's perception frequently appears in the field of financial investment. When investors consider whether to participate in a crowdfunding project or not, the process of making decisions is similar to making purchase decisions in financial market. Therefore, it is reasonable to apply investor's perception to analyze investor's behavior in the context

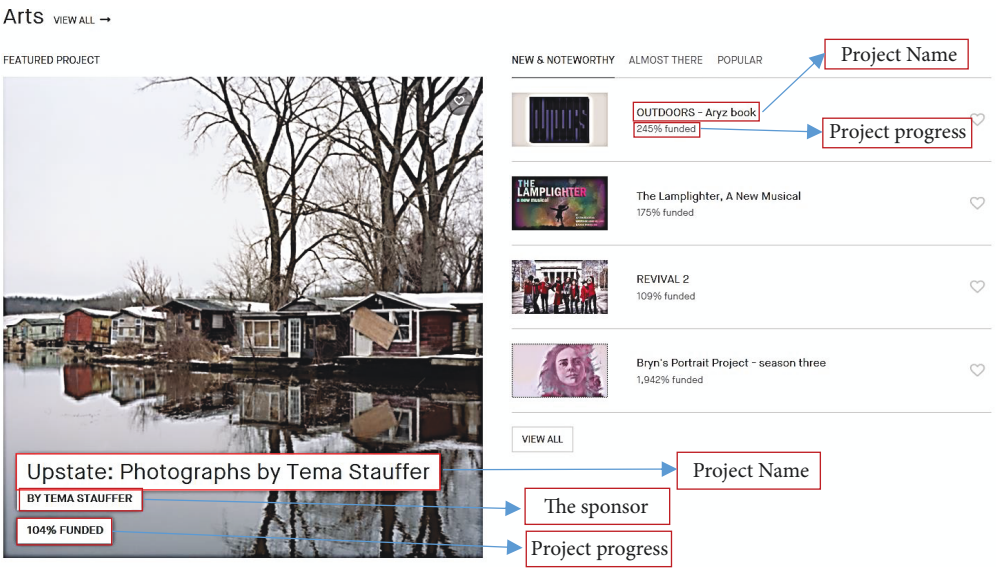

Figure 1: One webpage on Kickstarter.com.

of crowdfunding. Researches in the literature usually set investor's perception as a fixed value, and they rarely consider the important phenomenon that the online information will cause some influences on investor's perception.

As the most important way of information dissemination, personal networks and entrepreneur's social network have significant effects on crowdfunding performance [5]. Bi [1] illustrated that the signals of product quality and electronic word of mouth have caused great influences on funder's investment decisions by solving ELM model. Undoubtedly, the information about the product quality is the most important factor that affects investors to buy the product or not. Figure 1 illustrates that the advertisements of the project on platform can also cause some influences on the product valuations of the investors.

Figure 1 is one webpage of art projects on Kickstarter.com. There are five art projects in the picture. It is obvious that the project on the left side, Upstate: Photographs by Teama Stauffer, can attract us mostly when we click on this webpage since it takes more space than the other four projects.

As shown in Figure 1, the location and space of the project advertisement will cause some important influences on investor's perception. Platforms of crowdfunding such as Kickstarter.com decide the location and space of the project introductions in a whole webpage. Further, platforms provide the services of matching fund raisers with investors and they also provide some investment style to fund raisers. Therefore, it is reasonable to suppose the advertisement on the platform as a risk factor that can cause some influences on investor's perception.

Considering the effects of online information on investor's perception, investor's perception applied in the present study is that the investors will continuously change their own valuations about the product based on the information they got. In detail, the investment desire and reference price of the investor are introduced in two dynamic settings to describe investor's perception.

Therefore, taking investor's perception into account the problems of product design are illustrated in the present study. Product design refers to firms which make suitable designs about product quality, price, marketing strategy, etc. Product design has been proved to be an efficient tool for the firms to produce their product, and the advisable product design shown was an effective way for the actual firms to maintain a long-term competitive advantages [6]. When dynamic investor's perception is taken into consideration, we want to analyze the following four questions:

(1)How do the online information of the product quality and platform advertisement affect investor's investment decisions?

(2)What is the optimal decisions of product quality for the sponsor in crowdfunding?

(3)What is the optimal decisions of platform advertisement in crowdfunding?

(4)How do the cost-sharing ratio, profit-sharing ratio, and reference price affect the optimal decisions?

To solve the above questions, we propose and analyze a dynamic model in which the sponsor designs the product quality to cater investor's preference, and the platform formulates the strategies about project advertisement to optimize their own profit based on the changeable investor's perception. Firstly, the information about product quality and platform advertisement is identified as the two risk factors that affect investor's perception. Then, investment desire and reference price are used to illustrate investor's perception in detail which are described in two dynamic equations. Finally, the optimal decisions about the product quality and platform advertisement are formulated under two circumstances: the sponsor and the platform make decisions independently and they cooperate as a system.

The rest of the paper is organized as follows. Literature reviews are presented in Section 2. In Section 3, investor's perception is introduced into the dynamic product quality design model and the optimal results are given in two circumstances, respectively. Based on the model, the influences of investor's perception on the optimal results are analyzed, and some profitable strategies for the sponsor are given. In Section 4, some sensitive analyses for parameters are given and the simulation is described in Section 5. Section 6 describes some concluding remarks of the present study.

2. Literature Reviews

It is difficult for many innovative companies to get financial support by traditional financing methods since small innovative companies have no power to make public offerings. Crowdfunding provides a solution for the small innovative companies to raise the initial startup capital on the Internet [7, 8]. It is found that Internet financing was a good way to solve the traditional financing difficulties of small companies effectively [9].

The preliminary literatures of crowdfunding focus on the following two aspects. First, some studies have discussed the definition and the business model of the crowdfunding. Crowdfunding was defined as a concept that invites individuals to invest in various section [10]. The concept of crowdfunding originates from the idea of the crowdsourcing which can be seen as the wisdom of a crowd, while the difference in the crowdfunding focuses on the financial perspective of crowdsourcing [11, 12]. For the business model, there are three participators involved in crowdfunding: Internet platforms, fund raisers, and investors. Internet platforms provide the services of matching fund raisers with investors and provide some investment style to fund raisers [13, 14]. As shown in the research of Lukkarinen [15], the driving force of crowdfunding can be summarized as two aspects. One is the characteristics of the project such as the early fund raised by media networks and the value of minimum investment. The other includes the total target, the project's duration, and the provision of financial information.

Second, some studies have investigated which factors affect the crowdfunding mostly. The period of fund raising and the amount of goal were identified as the directive factors related to a project [3, 16–19]. Many researches revealed that an appropriate fund raising goal and an appropriate geographical location of a crowdfunding project have caused some valid influences on the success of crowdfunding [1, 3, 5, 18, 19]. It was found that the amount of the target is negative to the success of the project while the projects that attract the interest of investors are more likely to have a higher success rate of a crowdfunding [16, 18]. Some researches claimed frequent updates, and a high level of communication through updates and the information about the investors type also caused great influence on the success of crowdfunding [20, 21].

There are few researches focusing on the production and operation problem of the firms in crowdfunding when the investor's product valuation is changing over time. The preliminary researches have focused on analyzing the effects of the information on investor's perception in financial market, and accordingly some studies have explored the effects of the investor's perception on the investment decisions. It was found that the low risk of fund and the liquidity of fund scheme have a great impact on investor's perception for investing in the mutual fund [22]. Joshi and Patel [23] found that the adverse investor's perception has prevented the information being reflected into the prices of stock. Investors may form their own valuations about the product according to their previous purchase experience and the information they mastered in the market. How to produce the products with a reasonable product quality to attract investors to participate in a crowdfunding is our focus. Hu [24] studied the optimal product pricing strategy in a reward-based crowdfunding, and the product line was proved to be more optimal than providing a single product. Based on the study of Hu, Chen [25] proposed the optimal pricing strategy for the sponsor when facing strategic and myopic consumers in a crowdfunding of green product.

Based on the above studies, we give the dynamic model to describe how to design the product quality when investor's perception is taken into account in the next following sections.

3. The Basic Model

The decision system considered in the present study consists of a sponsor and a platform. The sponsor raises funds through the crowdfunding on the platform and provides some rewards to the platform when the raised funds reach the amount of target. Different from the real sales, investors understand the product based on the online information they perceived from the platform. In crowdfunding, sponsor designs the product quality to cater investor's preference, and platform makes decisions about the advertisement of the project. Therefore, investor's perception is considered as the function of the product quality and the platform advertisement in the present study. For understanding easily, the description of parameters is illustrated in Table 1.

Since the information updates continuously, investor's perception changes over time. In detail, investment desire and reference price are introduced to describe investor's perception. First, the changing of the investment desire follows the Nerlove-Arrow framework [26]:

$$\begin{aligned} \dot{g}(t) &= \theta_1 q + \theta_2 e - \delta g, \\ g(0) &= g_0, \end{aligned} \tag{1}$$

where $g(t)$ is the accumulated investment desire over time t and $g(0) > 0$ is the initial investment desire. θ_1 and θ_2 are positive constants that reflect both the product quality and platform advertisement which have an positive effects on the investment desire, and δ is the diminishing rate of investment desire.

Then, product quality and platform advertisement can also affect investor's reference price. The reference price is formed after investors get the information about the product attributes. The changeable reference price in the present study is supposed to be affected by product quality,

Table 1: Parameters description.

Symbol	Explanation	Variable type
q	The quality of product	Decision variable
e	The advertisement of platform	Decision variable
V_t	Investor's product valuations (V_t=H, L)	–
g	Investment desire	–
r	Reference price	–
d	The demand of product	–
Π_s	The profit of the sponsor	–
Π_p	The profit of the platform	–
J_s	The present value of sponsor's profit	Decision goal
J_p	The present value of platform's profit	Decision goal
ε	The ratio of the profit-sharing	–
ϕ	The ratio of the cost-sharing	Decision variable
k	The probability of success	–
$m, \theta_1, \theta_2, \delta, \mu_1, \mu_2, \lambda_1, \lambda_2, \alpha, \beta$	Parameters	–

platform advertisement, and product price. The following equation is introduced to illustrate the changeable procession of reference price:

$$\begin{aligned} \dot{r}(t) &= \beta(p - r) + \mu_1 q + \mu_2 e, \\ r(0) &= r_0, \end{aligned} \tag{2}$$

where $r(0) = r_0$ is the initial reference price and β, μ_1, μ_2 are all constants. The item $\beta(p - r)$ means the price influence; a higher β implies that the investors have short memory of the product. The two items $\mu_1 q$ and $\mu_2 e$ represent the influences of the product quality and the platform advertisement on the reference price. Higher product quality and platform advertisement can enhance the consumer's valuations on the product, so $\mu_1 > 0$ and $\mu_2 > 0$ are supposed.

Further, investors are divided into short and long sightedness which means that investors have less or deep impression on the product purchase experience in the past. Based on the research of *Hu* [24], combining the consumer's type, i.e., short or long sightedness, we give the following equation to illustrate the different investor's product evaluations:

$$V_t = \begin{cases} H & \text{with probability } \alpha(1 - \beta), \\ L & \text{with probability } \alpha\beta, \end{cases} \tag{3}$$

where $H > L > 0$ represents the product valuations of the investor.

The price of product is determined by the sponsor at the beginning of the crowdfunding, and then the platform advertises the product online. This paper focuses on choosing the optimal product quality and platform advertisement when investor's perception is taken into account. The price of product p is assumed as a fixed value when the model is solved, and the different results caused by the changes of price will be discussed based on the research of *Hu* [24]. *Hu* provided several price strategies for the product crowdfunding; accordingly the optimal product quality and platform advertisement are analyzed in the present study based on his research.

Generally, the reference price, the product quality, and the platform advertisement are assumed to have positive effects on the sale. Thus, the demand $d(t)$ of the product in a crowdfunding is supposed to satisfy the following equation:

$$d(t) = m(r - p) + g + \lambda_1 q + \lambda_2 e, \tag{4}$$

where m, λ_1, and λ_2 are all positive constants. The item $m(r - p)$ represents the influence of reference price on demand. The influence on the demand is positive when $r > p$ and the influence is negative otherwise. A high m implies that the investors are more sensitive to the gap between the reference price and the real price. The other two items $\lambda_1 q$ and $\lambda_2 e$ indicate that both the product quality and the platform advertisement have positive influences on the demand.

Similar to the previous research of Jørgensen [27], the cost is in the form of quadratic function. The product cost of the sponsor is $Cs = (1/2)q^2$, and the cost of the platform is $Cp = (1/2)e^2$. Platforms can get some rewards when the raised funds reach the goal amount while there are no rewards provided to the platform if the crowdfunding fails. Therefore, it is advisable for the sponsor to share a part of the platform's cost to encourage the platform to make their efforts to improve the crowdfunding. $\phi \in (0, 1)$ is the cost-sharing ratio that means the sponsor is willing to undertake the platform's advertisement cost, then the profit of the sponsor is

$$\Pi_s = kp(1 - \varepsilon)d - \frac{1}{2}q^2 - \frac{1}{2}\phi e^2, \tag{5}$$

where $k \in (0, 1)$ is the probability that the raised funds reach the goal amount which is often called the successful probability of a crowdfunding. $\varepsilon \in (0, 1)$ is called the ratio of profit sharing. So the profit of the platform is

$$\Pi_p = kp\varepsilon d - \frac{1}{2}(1 - \phi)e^2, \tag{6}$$

where the item $k\varepsilon pd$ ($\varepsilon \in (0, 1)$) is the reward of the platform when the crowdfunding raised the goal amount of funds.

The goals of the sponsor and the platform are to maximize the present value of their profit, respectively,

$$\max_{d(t)} \quad J_s = \int_0^{+\infty} \exp(-\rho t)\left[kp(1-\varepsilon)d(t) - \frac{1}{2}q^2 - \frac{1}{2}\phi e^2\right]dt, \tag{7}$$

and

$$\max_{d(t)} \quad J_p = \int_0^{+\infty} \exp(-\rho t)\left[kp\varepsilon d(t) - \frac{1}{2}(1-\phi)e^2\right]dt, \tag{8}$$

where ρ is the discount rate.

In the next sections, the optimal product quality and platform advertisement are calculated in two different scenarios. One scenario is that the sponsor and the platform make decisions independently, and the other is that the sponsor and the platform are coordinate as a system to make decisions.

3.1. The Optimal Decisions in Separation. Separation means that the sponsor and the platform make decisions independently; the sponsor offers a cost-sharing ratio ϕ firstly to the platform. Then the sponsor decides their product quality and the platform decides their advertisement to maximize their profit. It is reasonable to suppose that the sponsor and the platform make decisions simultaneously since the demand changes over time, and the cost-sharing ratio ϕ is assumed as a fixed value when we calculate the values of decisions about the product quality and platform advertisement. The profit of the two firms will be calculated after we obtain the optimal equilibrium value of decisions, and then the optimal cost-sharing ratio ϕ that maximizes the sponsor's profit is calculated.

To maximize the profit of the sponsor and the platform, the function of Hamiltonian for the sponsor and the platform are given as the follows, respectively,

$$\begin{aligned} H_s = {} & kp(1-\varepsilon)[m(r-p) + g + \lambda_1 q + \lambda_2 e] - \frac{1}{2}q^2 \\ & - \frac{1}{2}\phi e^2 + \gamma_{1s}(\beta(p-r) + \mu_1 q + \mu_2 e) \\ & + \gamma_{2s}(\theta_1 q + \theta_2 e - \delta g), \end{aligned} \tag{9}$$

and

$$\begin{aligned} H_p = {} & kp\varepsilon[m(r-p) + g + \lambda_1 q + \lambda_2 e] - \frac{1}{2}(1-\phi)e^2 \\ & + \gamma_{1p}(\beta(p-r) + \mu_1 q + \mu_2 e) \\ & + \gamma_{2p}(\theta_1 q + \theta_2 e - \delta g), \end{aligned} \tag{10}$$

where $\gamma_{1s}, \gamma_{2s}(\gamma_{1p}, \gamma_{2p})$ represent the costate variables.

Calculating the two Hamiltonian functions, the equilibrium product quality and platform advertisement are given in the following Theorem 1.

Theorem 1. *The equilibrium product quality is*

$$\overline{q} = kp(1-\varepsilon)\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right), \tag{11}$$

and the equilibrium platform advertisement is

$$\overline{e} = \frac{kp\varepsilon}{1-\phi}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{12}$$

Therefore the reference price and accumulated investment desire can also be given as follows:

$$\begin{aligned} r(t) &= A_1 e^{-\beta t} + r_n, \\ g(t) &= A_2 e^{-\delta t} + g_n, \end{aligned} \tag{13}$$

where $A_1 = r_0 - r_n$, $r_n = p + (\mu_1\overline{q} + \mu_2\overline{e})/\beta$, $A_2 = g_0 - g_n$, and $g_n = (\theta_1\overline{q} + \theta_2\overline{e})/\delta$.

The proof of each theorem is illustrated in Appendixes, and some conclusions can be addressed from Theorem 1 as follows:

(i) There are three parts of equilibrium product quality level in (11): the first part $kp\lambda_1$ represents the product quality influences on the product demand which is the short-term influence on product sales. The second part $kp\theta_1/(\rho+\delta)$ expresses the long-term effect that means the product quality has the positive influence in accumulate investment desire. The third part $kpm\mu_1/(\rho+\beta)$ expresses the fact that the product quality has the effect on the reference price with $\mu_1 \neq 0$. The structure of (12) is the same as (11), so we do not repeat it here. Since the product quality and platform advertisement have positive effect on the reference price, i.e., $\mu_1 > 0$ and $\mu_2 > 0$, the sponsor will provide a higher quality product and the platform will put more advertisement in adverting when they take the effect of reference price into consideration. The higher m means the consumers are more sensitive to the reference price; therefore the decision makers should pay more attention to this impact.

(ii) The reference price and investment desire in (13) will get their steady states r_n and g_n when $t \longrightarrow +\infty$. The steady states, i.e., $r_n = p + (\mu_1\overline{q} + \mu_2\overline{e})/\beta$ and $g_n = (\theta_1\overline{q} + \theta_2\overline{e})/\delta$, are mainly influenced by the product price p, the product quality $\overline{q}$, and the platform advertisement $\overline{e}$. It is shown that the reference price and the investment desire are increasing when the product quality and platform advertisement are taken into account. In addition, investors will have a large reference price when the value of β is small. Analyzing g_n similarly, the investment desire is positively correlated with the product quality and the platform advertisement.

Based on the above results, the profits of the sponsor and platform are calculated as follows:

$$\begin{aligned} J_s = {} & kp(1-\varepsilon)\left(\frac{D_1 m}{\rho+\beta} + \frac{D_2}{\rho+\delta} + \frac{m(r_n-p)}{\rho} + \frac{g_n}{\rho}\right. \\ & \left. + \frac{\lambda_1\overline{q}}{\rho} + \frac{\lambda_2\overline{e}}{\rho}\right) - \frac{\overline{q}^2}{2\rho} - \frac{\phi\overline{e}^2}{2\rho}, \end{aligned} \tag{14}$$

and

$$J_p = kp\varepsilon\left(\frac{D_1 m}{\rho+\beta} + \frac{D_2}{\rho+\delta} + \frac{m(r_n - p)}{\rho} + \frac{g_n}{\rho} + \frac{\lambda_1\overline{q}}{p} + \frac{\lambda_2\overline{e}}{\rho}\right) - \frac{(1-\phi)\overline{e}^2}{2\rho}. \tag{15}$$

Since sponsors make the decisions about the product price strategy at the beginning of the crowdfunding, they will decided the optimal value of product quality and platform advertisement for any specific price strategy. The optimal results in margin (H) and volume (L) price strategy are analyzed, respectively, based on the research of *Hu* [24]. Therefore, there will be two groups, i.e., $(\overline{q}, \overline{e}, H), (\overline{q}, \overline{e}, L)$, to choose different situations. In the following Theorem 2, the optimal product quality and platform advertisement are given in detail in different price strategy.

Theorem 2. *(i) When*

$$B_2 = (1-\varepsilon)^2 A_1 + \frac{m\mu_2 A_2\varepsilon(1-\varepsilon) + \lambda_2\beta A_2\varepsilon(1-\varepsilon)}{\rho\beta(1-\phi)} + \frac{\theta_1 A_1(1-\varepsilon)^2(1-\phi) + \theta_1 A_2\varepsilon}{\rho\delta(1-\phi)} + \frac{2\lambda_1 A_1(1-\varepsilon)^2 - A_1^2(1-\varepsilon)^2}{2\rho} - \frac{A_2^2\varepsilon^2}{(1-\phi)^2} > 0, \tag{16}$$

we obtain the following two conclusions:

(a) $0 < H/l < 1/\alpha^2(1-\beta)^2$*; the optimal values of product quality and platform advertisement are*

$$\overline{q} = (1-\varepsilon)L\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right), \tag{17}$$

and

$$\overline{e} = \frac{\varepsilon L}{1-\phi}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{18}$$

(b) $H/l > 1/\alpha^2(1-\beta)^2$*; the optimal values of product quality and platform advertisement are*

$$\overline{q} = (1-\varepsilon)H\alpha^2(1-\beta)^2\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right), \tag{19}$$

and

$$\overline{e} = \frac{\varepsilon H\alpha^2(1-\beta)^2}{1-\phi}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{20}$$

(ii) When

$$B_2 = (1-\varepsilon)^2 A_1 + \frac{m\mu_2 A_2\varepsilon(1-\varepsilon) + \lambda_2\beta A_2\varepsilon(1-\varepsilon)}{\rho\beta(1-\phi)} + \frac{\theta_1 A_1(1-\varepsilon)^2(1-\phi) + \theta_1 A_2\varepsilon}{\rho\delta(1-\phi)} + \frac{2\lambda_1 A_1(1-\varepsilon)^2 - A_1^2(1-\varepsilon)^2}{2\rho} - \frac{A_2^2\varepsilon^2}{(1-\phi)^2} < 0, \tag{21}$$

the optimal values of product quality and platform advertisement are

$$\overline{q} = \frac{(\varepsilon-1)B_1}{2B_2}\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right), \tag{22}$$

and

$$\overline{e} = \frac{\varepsilon(\varepsilon-1)B_1}{2B_2(1-\phi)}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{23}$$

Note that the equilibrium value of product quality and platform advertisement will be higher if the sponsor takes the margin price strategy compared to the volume price strategy. It is also clear that both two equilibriums are the increasing function of the consumer's evaluation (L or H). When the evaluation of consumer is higher the sponsor should improve their product quality level and similarly the platform should pay more advertisement to advertise the product. And there are no differences of the sponsor profit in the two price strategies when $H/l = 1/\alpha^2(1-\beta)^2$.

3.2. The Optimal Decisions in Coordination. In this section, the sponsor and the platform cooperate as a system to make decisions about product quality and platform advertisement. We calculate the optimal decision of the system to maximize the present value of it. Taking (5) and (6) in to account, the Hamiltonian function for the system is given as follows:

$$H = pk[m(r-p) + g + \lambda_1 q + \lambda_2 e] - \frac{1}{2}q^2 - \frac{1}{2}e^2 + \gamma_1(\beta(p-r) + \mu_1 q + \mu_2 e) + \gamma_2(\theta_1 q + \theta_2 e - \delta g), \tag{24}$$

where γ_1, γ_2 represent the costate variables of the system problem associating the reference price and investment desire with the decisions. Similar to the process of Theorem 1, the equilibrium of the system is shown as follows:

$$\check{q} = kp\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right), \tag{25}$$

and

$$\check{e} = kp\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{26}$$

It is clearly shown that the product quality is improved due to the cooperation. In Theorem 3, the optimal cost-sharing ratio is given and the advertisement of platform in two situations is compared.

Theorem 3. *The optimal cost-sharing ratio* ϕ *is*

$$\phi = \begin{cases} \dfrac{2-3\varepsilon}{2-\varepsilon} & \text{if } \varepsilon \le \dfrac{2}{3}, \\ 0 & \text{else.} \end{cases} \tag{27}$$

Taking (27) into (20), we get

$$\overline{e} = kp\frac{\varepsilon(2-\varepsilon)}{2\varepsilon}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right), \tag{28}$$

and

$$\check{e} - \overline{e} = \frac{kp\varepsilon}{2}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right) > 0. \quad (29)$$

For the cooperation system, the reference price and investment desire are also steady similar to the situation of separation as follows:

$$r(t) = E_1 e^{-\beta t} + r_c,$$
$$g(t) = E_2 e^{-\delta t} + g_c, \quad (30)$$

where $E_1 = r_0 - r_c$, $r_c = p + (\mu_1\check{q} + \mu_2\check{e})/\beta$, $E_2 = g_0 - g_c$, and $g_c = (\theta_1\check{q}+\theta_2\check{e})/\delta$. The steady states of the reference price and investment desire are r_c and g_c.

From the above results, we can find that both the steady reference price and steady investment desire are higher compared to Theorem 2 since both the product quality and platform advertisement are improved in cooperation system. Substituting (30) into (7), we get the present value of the profit for cooperation system as follows:

$$\check{J} = kp\left(\frac{E_1 m}{\rho+\beta} + \frac{E_2}{\rho+\delta} + \frac{m(r_c - p)}{\rho} + \frac{g_c}{\rho} + \frac{\lambda_1\check{q}}{p} + \frac{\lambda_2\check{e}}{\rho}\right) - \frac{\check{q}^2}{2\rho} - \frac{\check{e}^2}{2\rho}. \quad (31)$$

In the next section we will discuss the changes of the results in our model when relevant parameters are in different values. Analyzing these changes does not only build the robustness of our results but also deepen our understanding of this problem.

4. Parameters Sensitivity Analysis

In this section, we analyze the relations between the relevant parameters and the values of profit, product quality, and platform advertisement. Firstly, the impact of parameter m on the present value of profit is illustrated in Figures 2 and 3. The parameter m is seen as an item that reflects the degree of the reference price effects on the investor's behavior. There are two firms: the sponsor and the platform in the research, so it is worthwhile to analyze the influence of parameter m on the profit of them because the effects of m may be different.

As shown in Figure 2, J_s, J_p, and J represent the profit of the sponsor, the profit of the platform, and the total profit when the sponsor and the platform chose to cooperate, respectively. The present value of the sponsor's profit will decrease if the investors pay more attention to reference price while the platform's profit is an increasing function of parameter m when they make decisions independently. It is clear that the profits of the two firms are increased when they cooperate as a system, and the cooperation profit is an increasing function of the parameter m. Note that parameter m denotes the degree of the reference price effects on the investor's behavior; the fact implied in Figure 2 shows that the larger the effect of the reference price, the more profit the two items can get when they cooperate as a system.

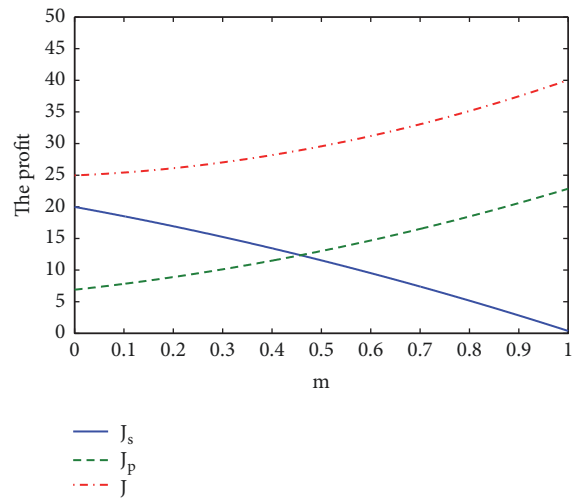

Figure 2: Profit changes.

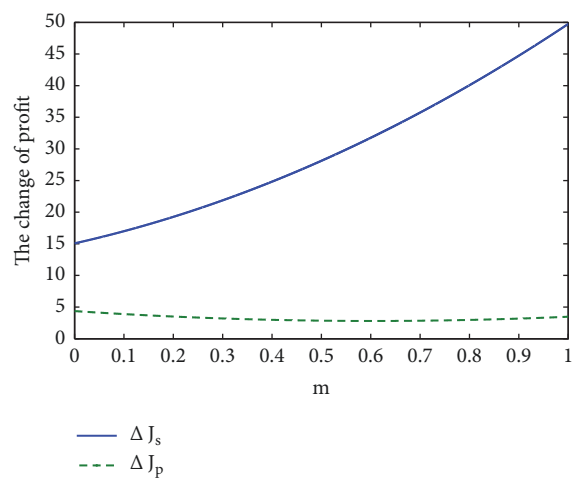

Figure 3: Differences of profit in two situations.

From Figure 3, we can find that cooperation is more profitable for the sponsor than the platform and the differences of the two profits are both the increasing function of parameter m. Therefore, the sponsor should choose to cooperate with the platform when the investors pay more attention to their reference price. And the differences of platform's profit are not obvious in two ways, which means that it has a little difference for platform in two cases.

Comparing Figure 2 with Figure 3, it is found that cooperation with platform not only promotes the profit of sponsor but also can help the sponsor to keep a growing trend of the profit when investors pay more attention to their reference price.

Then, the impact of parameters ε, ϕ on the values of product quality and platform advertisement are illustrated in Figures 4 and 5.

As shown in Figures 4 and 5, it is clear that the platform will increase their advertisement to improve crowdfunding project with the profit-sharing ratio increasing. And this trend is more obvious when the value of cost-sharing ratio is

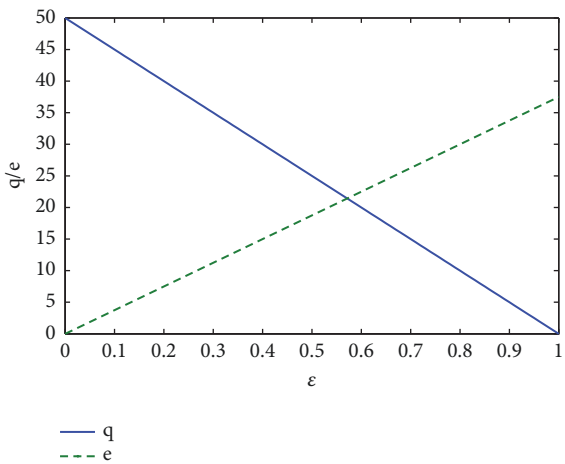

Figure 4: The changes of product quality (platform advertisement).

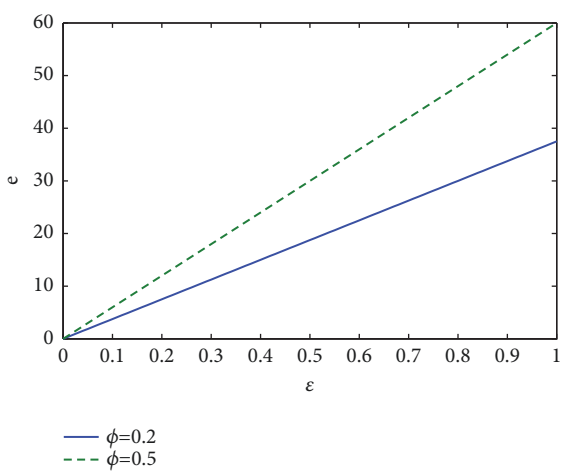

Figure 5: The changes of platform advertisement in two situations.

Table 2: Impacts of ε, ϕ on the optimal results.

parameters		J_s	J_p	e	q
(ε, ϕ)	(0.03, 0.10)	871.6	906.3	1	48.5
	(0.03, 0.20)	2951.5	903.6	1.125	48.5
	(0.10, 0.20)	3955.5	781.1	3.75	45
	(0.20, 0.30)	8017.5	583.1	8.6	40

higher. It is also clear that the advertisement of platform has a complementary effect with product quality. In Table 2, the impact of ε, ϕ on the optimal results is illustrated in detail.

As shown in Table 2, the present value of the sponsor's profit is an increasing function of ε and ϕ, and the trend is more obvious if both the two ratios increase simultaneously. And the advertisement of platform will also increase if the sponsor shares more cost or profit with them. The above results illustrate that sponsor sharing the cost of the platform can not only promote the development of crowdfunding but also improve its own profit.

5. Simulation

To demonstrate some external validity for our theoretical model, an empirical study about the impact of product quality and platform advertisement on the success of a crowdfunding project is conducted. Data for our study is derived from publicly available information on the Kickstarter.com website (https://www.kickstarter.com/). Kickstarter has grown into one of the best-known and oldest crowdfunding platforms in the world since its inception in April 2009. We write a computer program by using the language of Python to get the information on all projects posted on the platform. Over six months, the information for 1400 projects from Kickstarter.com has been collected. The projects for charity are removed because charity crowdfunding projects are donation-based crowdfunding. And some data for inaccuracies and incomplete information are also removed. After that, the data for analysis purposes included 835 crowdfunding projects in the categories art, design, and technology.

Data about a given project includes the money which have been raised, the number of comments, and the introduction of the project. The introduction of the product includes the number of introduction pictures, the number of videos, and the number of description words. In the present study, the description and introduction of the project are defined as the factors that relate to the quality of the product. And the number of comments is seen as an external influence.

The correlation analysis of the variables is first performed, and results of which are shown in Table 3. It is can be seen from the table that correlations between the dependent variable and all independent variables are positive. Therefore, the assumptions that the information about the product quality and platform advertisement will cause some influences on the success of crowdfunding were supported. In Table 4, some results of a regression analysis are illustrated in detail. We choose the signal of introduction picture count to represent the signal of product quality, and the signal of comments count is seen as the signal of external influences. As can be seen from the table, the introduction picture count explains 44.6% of the raised money and the comment count explains 43.5% of the raised money. The F value is 42.462, and the values of VIF (<10) for each variable all indicate that there is no multicollinearity in the model. The results of the numerical experiment support the theory and model analyzed in the present study and provide some external validity for our theoretical model.

6. Conclusion

Product design allows firms to improve their profit and market competitiveness in crowdfunding market. However, the successful crowdfunding is always hampered by lack of guidance on how to design the product quality to attract investors' preference. To solve this dilemma, we describe two items: investment desire and reference price to represent investor's perception that can cause some effects on the success of crowdfunding.

A necessary consideration that investor's investment desire and reference price have a significant effect on investor

Table 3: Correlations of variables.

	1	2	3	4	5
(1) Raised money ($)	1				
(2) No. of comment	0.6624	1			
(3) Introduction picture count	0.3943	0.4637	1		
(4) Introduction video count	0.3621	0.3889	0.3556	1	
(5) Introduction word count	0.6571	0.4960	0.5173	0.3741	1

Table 4: Results of regression analysis.

Variable		Total sample	
		β	VIF
Dependent variable	Raised money ($)		
Signals of platforms advertisement	No. of comment	0.435	1.32
Signals of product quality	Introduction picture count	0.446	1.319
	F	42.462	
Summary of the model specified	R^2	0.69	
	ΔR^2	0.687	

behavior is shown in our paper. Further, the product quality and platform advertisement which are supposed have some effects on investor's investment desire and reference price. This supposition is different from the previous literature that they assumed that there are only two types of investors: high evaluation and low evaluation investors. Accordingly, a dynamic model about the product quality is investigated by taking the investor's perception into account.

In this paper, the optimal product quality and platform advertisement are calculated in two situations: separation and cooperation, respectively. The results offer some new insights that will be useful to firms to research the product quality decisions in crowdfunding considering investor's perception. First, firms should pay more attention to the potential behavior of investors influenced by online information when they make decisions about the product quality. Then, it is an optimal strategy for firms to cooperate with platform when investors pay more attention to their reference price. Finally, sharing the cost of the platform can not only promote the development of crowdfunding but also improve the profit of firms.

Appendix

A. Proof of Theorem 1

In model, the necessary conditions for equilibrium of the sponsor profit are given by

$$\frac{\partial H_s}{\partial q} = 0, \tag{A.1}$$

$$\frac{\partial H_s}{\partial \gamma_{1s}} = \dot{r}(t), \tag{A.2}$$

$$\frac{\partial H_s}{\partial \gamma_{2s}} = \dot{g}(t), \tag{A.3}$$

$$\dot{\gamma_{1s}} = \rho\gamma_{1s} - \frac{\partial H_s}{\partial r}, \tag{A.4}$$

$$\dot{\gamma_{2s}} = \rho\gamma_{2s} - \frac{\partial H_s}{\partial g}. \tag{A.5}$$

From (A.1), we get

$$q = kp\lambda_1 + \mu_1\gamma_{1s} + \theta_1\gamma_{2s}. \tag{A.6}$$

Combining (A.4), (A.5), and (A.6), we can get

$$\dot{q} = (\rho+\beta)\mu_1\gamma_{1s} + (\rho+\delta)\theta_1\gamma_{1s} - kpm\mu_1 - kp\theta_1. \tag{A.7}$$

Substituting $\mu_1\gamma_{1s}$ into (A.7) by (A.6), we get

$$\begin{aligned}\dot{q} = {} & (\rho+\beta)q + (\delta-\beta)\theta_1\gamma_{2s} - (\rho+\beta)kp\lambda_1 \\ & - kpm\mu_1 - kp\theta_1.\end{aligned} \tag{A.8}$$

Similarly, combining (A.6), (A.8), we get the differential of (A.8) as follows:

$$\begin{aligned}\ddot{q} = {} & (2\rho+\beta+\delta)\dot{q} - (\rho+\delta)(\rho+\beta)q \\ & + (\rho+\delta)(\rho+\beta)kp\lambda_1 + (\rho+\delta)kpm\mu_1 \\ & + (\rho+\beta)kp\theta_1.\end{aligned} \tag{A.9}$$

Calculating (A.9), we get

$$q(t) = D_1 e^{(\rho+\delta)t} + D_2 e^{(\rho+\beta)t} + \overline{q}, \tag{A.10}$$

where $\overline{q} = kp(\lambda_1 + \theta_1/(\rho+\delta) + m\mu_1/(\rho+\beta))$ and D_1, D_2 are parameters to be determined. The value of q will be infinite when $t \longrightarrow \infty$ which will obey our rules, so we have $D_1 = D_2 = 0$. Therefore, the equilibrium value of $q(t)$ can expressed as follows:

$$\overline{q} = kp\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right). \tag{A.11}$$

Similarly, the equilibrium platform advertisement can be got as follows:

$$\overline{e} = \frac{\varepsilon k p}{1-\phi}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{A.12}$$

Taking (A.11), (A.12) into, we get

$$\frac{\partial g(t)}{\partial t} = \theta_1\overline{q} + \theta_2\overline{e} - \delta g, \tag{A.13}$$

and

$$\frac{\partial r(t)}{\partial t} = \beta(p-r) + \mu_1\overline{q} + \mu_2\overline{e}. \tag{A.14}$$

Solving the differential equations (A.13), (A.14), the general solutions can be got

$$\begin{aligned} r(t) &= E_1 e^{-\beta t} + r_n, \\ g(t) &= E_2 e^{-\delta t} + g_n, \end{aligned} \tag{A.15}$$

where $E_1 = r_0 - r_n$, $r_n = p + (\mu_1\overline{q} + \mu_2\overline{e})/\beta$, $E_2 = g_0 - g_n$, and $g_n = (\theta_1\overline{q} + \theta_2\overline{e})/\delta$.

B. Proof of Theorem 2

Based on the research of Hu, with a volume strategy, the sponsor sets the price $p = L$ which is the lower limit of consumer valuation. Since the price is the lower limits of consumer valuation, we suppose that all consumers will take part in the crowdfunding and the success rete $k = 1$. With the margin strategy, the sponsor sets the price $p = H$, the high-type consumers will buy the product, and the low-type consumer will decline. The success rate in margin strategy is $k = \alpha^2(1-\beta)^2$. Sponsor will make decisions about the product price, so we compare the profit of the sponsor in different price strategy to maximize sponsor's profit as follows. From (7), we can get the fact that the profit of the sponsor is

$$\begin{aligned} J_s = kp(1-\varepsilon)\Bigg(&\frac{D_1 m}{\rho+\beta} + \frac{D_2}{\rho+\delta} + \frac{m(r_n-p)}{\rho} + \frac{g_n}{\rho} \\ &+ \frac{\lambda_1\overline{q}}{\rho} + \frac{\lambda_2\overline{e}}{\rho}\Bigg) - \frac{\overline{q}^2}{2\rho} - \frac{\phi\overline{e}^2}{2\rho}. \end{aligned} \tag{B.1}$$

Taking (25) and (26) in to (B.1), we can get

$$\begin{aligned} J_s = kp(1-\varepsilon)B_1 + (kp)^2\Bigg(&(1-\varepsilon)^2 A_1 \\ &+ \frac{m\mu_2 A_2\varepsilon(1-\varepsilon) + \lambda_2\beta A_2\varepsilon(1-\varepsilon)}{\rho\beta(1-\phi)} \\ &+ \frac{\theta_1 A_1(1-\varepsilon)^2(1-\phi) + \theta_1 A_2\varepsilon}{\rho\delta(1-\phi)} \\ &+ \frac{2\lambda_1 A_1(1-\varepsilon)^2 - A_1^2(1-\varepsilon)^2}{2\rho} - \frac{A_2^2\varepsilon^2}{(1-\phi)^2}\Bigg), \end{aligned} \tag{B.2}$$

where $A_1 = \lambda_1 + \theta_1/(\rho+\delta) + m\mu_1/(\rho+\beta) > 0$, $A_2 = \lambda_2 + \theta_2/(\rho+\delta) + m\mu_2/(\rho+\beta) > 0$, and $B_1 = D_1 m/(\rho+\beta) + D_2/(\rho+\delta) > 0$.

(i) When the coefficient of the quadratic term is positive,

$$\begin{aligned} &(1-\varepsilon)^2 A_1 + \frac{m\mu_2 A_2\varepsilon(1-\varepsilon) + \lambda_2\beta A_2\varepsilon(1-\varepsilon)}{\rho\beta(1-\phi)} \\ &\quad + \frac{\theta_1 A_1(1-\varepsilon)^2(1-\phi) + \theta_1 A_2\varepsilon}{\rho\delta(1-\phi)} \\ &\quad + \frac{2\lambda_1 A_1(1-\varepsilon)^2 - A_1^2(1-\varepsilon)^2}{2\rho} - \frac{A_2^2\varepsilon^2}{(1-\phi)^2} \\ &> 0. \end{aligned} \tag{B.3}$$

The value of inequity (B.3) is positive which means that the function of (B.2) is the monotonically increasing function of the item kp when $kp > 0$, so the following can be got easily:

(a) When $0 < H/l < 1/\alpha^2(1-\beta)^2$, we get $L > H\alpha^2(1-\beta)^2$, so the volume strategy is better than margin strategy for the sponsor and the price is $p = L$. Taking $p = L$, $k = 1$ into (19) and (20), we can get

$$\overline{q} = (1-\varepsilon)L\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right), \tag{B.4}$$

and

$$\overline{e} = \frac{\varepsilon L}{1-\phi}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{B.5}$$

(b) When $H/l > 1/\alpha^2(1-\beta)^2$, we get $L < H\alpha^2(1-\beta)^2$, and the margin strategy is better than the volume strategy. Similarly, the optimal values of product quality and platform advertisement are

$$\overline{q} = (1-\varepsilon)H\alpha^2(1-\beta)^2\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right), \tag{B.6}$$

and

$$\overline{e} = \frac{\varepsilon H\alpha^2(1-\beta)^2}{1-\phi}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{B.7}$$

(ii) When the coefficient of the quadratic term is negative, that is,

$$\begin{aligned} B_2 = &(1-\varepsilon)^2 A_1 \\ &+ \frac{m\mu_2 A_2\varepsilon(1-\varepsilon) + \lambda_2\beta A_2\varepsilon(1-\varepsilon)}{\rho\beta(1-\phi)} \\ &+ \frac{\theta_1 A_1(1-\varepsilon)^2(1-\phi) + \theta_1 A_2\varepsilon}{\rho\delta(1-\phi)} \\ &+ \frac{2\lambda_1 A_1(1-\varepsilon)^2 - A_1^2(1-\varepsilon)^2}{2\rho} - \frac{A_2^2\varepsilon^2}{(1-\phi)^2} \\ &< 0, \end{aligned} \tag{B.8}$$

the optimal price is constant:

$$kp = \frac{(\varepsilon-1)B_1}{2B_2}, \tag{B.9}$$

where $B_1 = D_1 m/(\rho+\beta) + D_2/(\rho+\delta) > 0$. Taking (B.4) into (11) and (12), we get

$$\overline{q} = \frac{(\varepsilon-1)B_1}{2B_2}\left(\lambda_1 + \frac{\theta_1}{\rho+\delta} + \frac{m\mu_1}{\rho+\beta}\right), \tag{B.10}$$

and

$$\overline{e} = \frac{\varepsilon(\varepsilon-1)B_1}{2B_2(1-\phi)}\left(\lambda_2 + \frac{\theta_2}{\rho+\delta} + \frac{m\mu_2}{\rho+\beta}\right). \tag{B.11}$$

C. Proof of Theorem 3

Since the sponsor decides the optimal ϕ to get the present value of his profit, by the first-order optimal condition

$$\frac{dJ_s}{d\phi} = 0 \tag{C.1}$$

we get

$$\phi = \frac{2-3\varepsilon}{2-\varepsilon}, \tag{C.2}$$

and combining $\phi \in [0,1]$, we get

$$\phi = \begin{cases} \dfrac{2-3\varepsilon}{2-\varepsilon} & if\ \varepsilon \le \dfrac{2}{3}, \\ 0 & else. \end{cases} \tag{C.3}$$

Data Availability

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

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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