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Research Article

Selecting Online Channel Mode for Green Products in a Capital-Constrained Platform Supply Chain

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This paper investigates operational decisions and online channel mode selection for green products with an e-commerce supply chain in which the manufacturer is subject to capital constraint. Starting from a Stackelberg game framework where the platform acts as a leader, two different online channel modes applied with an e-commerce supply chain are explored for equilibria, respectively. This paper then extends to a different supply chain with a reversed channel leadership, so as to reveal how the supply chain leaderships affect the equilibriums and supply chain performance. With the analytical studies, several important and interesting insights are derived. For example, but not limited to, the following is found: (a) the equilibrium decisions of the capital-constrained supply chain highly rely on the associated interest rate but are independent of the initial capital level of the financially-constrained manufacturer; (b) the platform and the capital-constrained manufacturer act largely differently when choosing the optimal online channel mode for themselves; (c) a win-win situation benefiting two parties holds when and only when the two members choose the agency mode under certain conditions; (d) the impacts of the supply chain leaderships and online channel modes on the consumer surplus and social welfare are clearly revealed. These results derived in our paper shed lights on industrial practicer on how to effectively make such decision-making in platform economy. The members in an e-commerce supply chain can appropriately determine their decisions such as commission and slotting fee to reach a win-win situation for two parties.

1. Introduction

With the rapid increase in the environmental awareness of the general public, many firms are well devoted to producing green products partly for developing a green economy and improving eco-environment in different industries around the world. These green products include the electric cars produced by American car-maker Tesla, the fluorine-free air conditioner made by Japanese home appliance manufacturer Panasonic, and others [1–4]. In addition to these manufacturing producers, some leading retailers are also engaged in the investment and promotion of green products. For example, one of the giant home appliance retailers in the world, Best Buy, sells ENERGY STAR-certified products to help businesses and consumers save money and protect our climate through superior energy efficiency.

Transforming from producing a regular product to a green one requires a large amount of capital, including product design, product publicity, and technological innovation. Hence, the capital constraint may constitute a major obstacle restricting this transformation of the firms, especially for the small and medium-sized ones, which always suffers from the financial difficulties even during regular operations. To ease the capital shortage, the firms can borrow loans to invest in green innovation, and the most common way is to finance from Bank. For example, by the end of 2021, 15 major banks in China have issued a total of 220.3 billion carbon emission reduction loans, supporting 2,246 projects to assist enterprises in producing low-carbon products [5]. Inevitably, the capital-constrained firms will pay additional costs to raise the capital, such as paying the interest to the lender, which in turn affects its operation and the associated performance. Hence, an interesting issue has arisen here to reveal how the financing affects the firm's selling and greening operation.

Nowadays, especially during the COVID-19 epidemic, online retailing has gradually become a mainstream alternative for the firms to distribute their various products [6, 7]. It is noticed from the industrial practice that the two complementary online channel modes are available for the firms to sell the products with an online marketplace, i.e., one is online agency channel and the other is online reselling channel. In terms of the online agency mode, the firm directly sells the products to the end consumers, paying commission sales to the e-commerce platform as the revenue share. In this case, the firm takes the ownership over the products, and the platform just serves as an online marketplace. By contrast, with the online reselling mode, the seller first wholesales products to the platform, and after that, the platform retails the products to end consumers. Under this circumstance, the platform takes the ownership over products and thus acts as an online reseller. The conventional wisdom suggests that the online agency mode will mitigate the double-marginalization effect and may require a low capital level to cover production. Therefore, the online channel mode will induce a significant impact on the financing decisions. Given different features of the two online channel modes, the two online channel modes will pose a key role in the operation decisions of the members, thereby decreasing or increasing the individual profits with an e-commerce platform supply chain. Herein, an interesting issue has arisen to explore the optimal online channel mode for the individuals with this e-commerce platform supply chain.

As a matter of fact, different individuals may act contradictorily when selecting the online channel modes. Essentially, it is the bargaining power among different individuals that finally determines the online channel mode selection between the individuals. Thus, it is worth investigating how the channel leaderships between the individuals affect the optimal online channel mode selection as well as the individual surplus, such as consumer and social community.

Motivated by the previous industrial practice, this paper develops an e-commerce supply chain consisting one platform and one capital-constrained manufacturer with two different online channel modes, in which the capital-constrained manufacturer chooses bank loan to ease capital shortage. To be specific, the main research questions of this paper are addressed as follows:

(i) How does the financing affect the operation and the individual profits with an e-commerce platform supply chain?

(ii) When should the individual select the online agency mode and when should it select the online reselling mode instead?

(iii) What are the impacts of the channel leadership on the consumer surplus and the social welfare?

The remainder of this paper is organized as follows: Section 2 reviews the most related literature. The problem descriptions are explicitly exhibited in Section 3, followed by which we develop an e-commerce supply chain system with the online agency mode in Section 4 and with the online reselling mode in Section 5, respectively. By comparing the equilibrium profits across two different online channel modes, Section 6 further investigates the optimal online channel mode selections for the manufacturer and the platform, respectively. This paper extends to a supply chain with a different leaderships and discusses the impacts of the consumer surplus and the social welfare on the two different supply chains in Section 7. Section 8 concludes the key findings with the managerial insights and future researches. For clarity, all proofs of the results are collected together in the Appendix.

2. Literature

The literature closely related to this paper is threefold, namely, green supply chain, supply chain finance, and online channel mode selection.

2.1. Green Supply Chain. As the increasing pressure of the environmental protection, the governmental regulation, and the continuous development in green product, green supply chain design and management has gradually become an environmentally sustainable strategy for the supply chain decision-makers and has thus been paid notable attention in academia.

A large number of studies in the green supply chain mainly focus on the green innovation and operational decisions. Chen and Sheu [8] apply a differential game model to demonstrate that a proper design of environment-regulation pricing strategy can boost the extended product responsibility for green supply chain, especially in a highly competitive market. Bhaskaran and Krishnan [9] propose various mechanisms of collaboration between two firms in the development of green products yielding technology uncertainty. Ghosh and Shah [10] examine the green investment in an apparel serial supply chain in which the players cooperate or act individually. Li et al. [11] explore a dual-channel supply chain where the manufacturer produces green products for the environmental conscious and investigate the joint pricing and greening strategies for the chain members in both centralized and decentralized cases. Meng et al. [12] use game theory to analytically explore the pricing policy in a green supply chain of a dual-channel structure, in which consumers' green preference and channel preference are considered. Huang et al. [1] investigate the optimal green and pricing strategies in a capital-constrained supply chain with different governmental green subsidies. Das Roy and Sana [13] examine a multiechelon green supply chain system in which a traditional production process is integrated with a remanufacturing in a single-setup-multidelivery system under setup cost reduction. Liu et al. [14] study how the retailer's fairness concern levels affect the cooperation in a three-stage sustainable supply chain. Sana [15] look into a newsvendor inventory problem where comparisons between green and nongreen marketing are explicitly analyzed including subsidy and tax implementation by the governmental regulation.

2.2. Supply Chain Finance. Capital shortage has always been a most important issue that the firms suffer from during the production and operation process, especially for those small and medium ones. Financing is an effective way for those capital-constrained firms to deal with the capital shortage and thus has drawn much attention in academic studies by scholars.

Chen and Cai [16] look into an extended supply chain model with a supplier, a budget-constrained retailer, a bank, and a 3PL firm, where the retailer has insufficient initial budget and can borrow loans from either a bank or a 3PL firm. Cai et al. [17] investigate the roles of bank and trade credits in a supply chain with a capital-constrained retailer yielding demand uncertainty. Zhang et al. [18] propose a portfolio financing strategy of bank loan financing and retailer credit financing for a closed-loop supply chain consisting of a financially constraint manufacturer and a retailer. Jin et al. [19] develop a proper financing scheme and discuss its efficiency of supplier intermediation in retailer financing in the case of unreliable products. Yan et al. [20] examine a dual-channel supply chain where the retailer and e-commerce platform can freely use the other's sales efforts and the e-commerce platform can provide online finance services to the capital-constrained supplier. Zheng et al. [21] consider a remanufacturing supply chain in which the retailer is capital-constrained and examine the optimal financing decision in terms of the market uncertainty. Sana et al. [22] discuss the operational and financial decisions among the supply chain individuals including one manufacturer and one distributor. Yan et al. [23] introduce supplier finance and supplier investment to a capital-constrained supply chain in which the retailer is subject to a capital constraint and investigate the impacts of retailer's loss aversion on the supply chain financing decisions.

2.3. Online Channel Mode Selection. In recent years, the online selling has been paid notable attention in supply chain management. Extended studied focusing on this research stream mainly includes the following aspects, such as competition and cooperation [6, 24], information disclosure [25–27], return policy [28–30], online reviews [31–33], interactions of online and offline channels [34, 35], and online value-add services [36, 37].

Specifically, this paper contributing to this research stream lies in the optimal online channel modes in an e-commerce platform supply chain. It is well noticed that the two online channel modes, i.e., the agency mode and the reselling mode, are typically adopted by the e-commerce platform to their upstream suppliers. Hence, the most related researching line of this stream in regards to the online channel mode is to identify the optimal online channel mode for the different individuals and reveal the key drivers behind deriving this strategic online channel mode selections. For example, Tian et al. [6] indicate how to select a better online channel mode for an e-commerce platform based on which the two competing suppliers sell the complementary products through the platform. Qin et al. [36] look into the interplay of the logistics service provision and online channel mode and focus on how the logistics service strategy affect the optimal online channel mode selection in a platform supply chain. Zhang and Zhang [38] study the e-tailer information sharing strategy with supplier offline entry in which the e-tailer can choose either online agency channel or online reselling channel. Chen et al. [39] investigate the optimal online channel mode for an e-seller and explore who is better off to offer the return-freight insurance in a platform supply chain. Yu et al. [40] explore a manufacturer's production decisions and a government's choice between cap-and-trade and carbon tax regulation in which the manufacturer sells the product through offline and online channels where the online channel can be the reselling mode or the agency mode. Zhang et al. [41] investigate how to select an optimal online channel mode for a manufacturer in an e-commerce platform supply chain in the presence of a secondary marketplace. Wang et al. [42] consider a multiple echelon supply chain where an upstream supplier can retail its products through an online e-commerce platform and a live streaming sales channel, and the online platform company can choose the reselling channel mode or the agency channel mode.

This paper contributes to the literature from the following aspects: Firstly, this paper focuses on the joint financing and green decisions in a capital-constrained platform supply chain. The aim of this paper is to investigate the mutual impacts of financing and operational decision in this platform supply chain. Secondly, in contrast to the existing studies on the optimal online channel mode selection in an e-commerce supply chain with sufficient capital, the fundamental difference of this paper lies in the fact that this paper explicitly selects the optimal online channel mode for the two parties when the manufacturer is subject to the capital constraint.

For better exhibiting the key differences between this paper and the most related literature, Table 1 thus formulates.

3. Model Formulation

We consider an e-commerce platform supply chain consisting of an e-platform and a capital-constrained manufacturer. It is well noticed from the industrial practice that the platform typically provides two options with their manufacturer to sell products [6, 7, 39], that is, the capital-constrained manufacturer has two choices to sell the green product via the platform's online marketplace; one is the online reselling mode and the other is the online agency mode. In terms of the reselling mode, the manufacturer wholesales the products to the platform at wholesale price (w), and after that, the platform sells them to the end consumers at retail price (p). Under this circumstance, the platform takes the ownership over products and acts as an online reseller. In contrast, with the agency mode, the

Table 1: Positioning of this paper in the literature.

Paper	Green product	Financing	Channel mode	Channel leadership	Consumer surplus	Social welfare
Ghosh and Shah [10]	√			√		
Li et al. [11]	√					
Huang et al. [1]	√				√	√
Zheng et al. [21]		√				
Zhang et al. [18]		√				
Zhang et al. [41]			√			
[43]			√	√		
Zhang et al. [7]			√	√		
Our work	√	√	√	√	√	√

manufacturer directly charges a retail price (p) and sells products to the consumers after paying a sales commission (θ) and a slotting fee (F) to the platform as the revenue share. In this case, the manufacturer takes the ownership over products, and the platform purely serves as an online marketplace.

To encourage green product development, the capital-constrained manufacturer invests in green R&D technology, and the green effort is denoted as e. Product with a higher greenness can improve the environmental benefit(or reduce environmental pollution) but also incurs a higher R&D cost. By following Huang et al. [1], a quadratic R&D cost of green investment is given by

$$C(e) = \frac{ke^2}{2}. \tag{1}$$

On the market side, it is well noticed that consumers are willing to purchase the green products because of their high greenness and lower environmental damages. The greener the product , the more the consumers will pay for it. This paper applies a linear demand function to capture such a phenomenon by following the related literature [1, 44, 45], such as

$$D(p,e) = a - p + \lambda e, \tag{2}$$

where a $(a > 0)$ denotes the market potential, p is the retail price, and λ $(0 < \lambda \leqslant 1)$ measures how much the consumers concern about the environmental awareness.

The capital-constrained manufacturer faces financing obstacles when producing the green products. The marginal cost of a unit product for the manufacturer is cD. To focus on a capital-constrained manufacturer, the initial capital level (K) is not sufficient to maintain the production, incurring that $K < cD + (ke^2/2)$. The capital-constrained manufacturer can choose to borrow the loans from bank with paying a fraction of interest (r). Hence, the financing costs for the manufacturer are $(cD + (ke^2/2) - K)r$.

For eases of exposition and clarity, the notation used in this paper can be found in Table 2.

4. Reselling Mode-Scenario R

With the reselling mode, the manufacturer produces the product with green degree e and wholesales the product to the e-platform at price w, and after that, the platform sells the product to the end consumers at price p. Mathematically, the profits of the manufacturer and the e-platform are, respectively, formulated as follows:

$$\begin{aligned}\pi_M^R(w,e) &= (w-c)D - \frac{ke^2}{2} - r\left(cD + \frac{ke^2}{2} - K\right),\\ \pi_E^R(p) &= (p-w)D.\end{aligned} \tag{3}$$

Applying the backward induction, the equilibrium decisions are achieved in Proposition 1.

Proposition 1. *With the reselling mode, the equilibrium decisions are given by*

$$\begin{aligned}w^{R*} &= \frac{(1+r)\left[ak - 2c\lambda^2 + 3ck(1+r)\right]}{4k(1+r) - 2\lambda^2},\\ e^{R*} &= \frac{\lambda[a - c(1+r)]}{4k(1+r) - 2\lambda^2},\\ p^{R*} &= \frac{\left(3ak + 2ck - c\lambda^2\right)(1+r) + ckr^2 - ck - a\lambda^2}{4k(1+r) - 2\lambda^2},\end{aligned} \tag{4}$$

and the associated equilibrium profit for the manufacturer and the e-platform are

$$\begin{aligned}\pi_M^{R*} &= \frac{k(1+r)[a - c(1+r)]^2}{8\left[2k(1+r) - \lambda^2\right]} + Kr,\\ \pi_E^{R*} &= \frac{k(1+r)[a - c(1+r)]^2}{4\left[2k(1+r) - \lambda^2\right]}.\end{aligned} \tag{5}$$

According to Proposition 1, the resulting demand for the product is $D^{R*} = (k(1+r)[a - c(1+r)])/(4k(1+r) - 2\lambda^2)$, and the following corollary is obtained:

Corollary 1. *With the reselling mode, the impacts of the interest rate on the equilibriums and individual profits are as follows:*

(i) $(\partial e^{R*}/\partial r) < 0$ *and* $(\partial D^{R*}/\partial r) < 0$;

(ii) if $0 \leqslant r < r_1$, *then* $(\partial w^{R*}/\partial r) < 0$ *and if* $r_1 \leqslant r \leqslant 1$, *then* $(\partial w^{R*}/\partial r) > 0$;

(iii) if $0 \leqslant r < r_2$, *then* $(\partial p^{R*}/\partial r) < 0$ *and if* $r_2 \leqslant r \leqslant 1$, *then* $(\partial p^{R*}/\partial r) > 0$;

Table 2: List of notations.

	Parameters
a	The market potential
λ	The consumer's sensitivity to the environmental awareness
D	The resulting demand of the product
k	The cost factor when the manufacturer invests in green technology
c	The marginal cost of a unit product
K	The initial capital of the capital-constrained manufacturer
r	The interest rate set by bank
θ	The commission. With the online agency mode, the capital-constrained manufacturer pays a sales commission (θ) to the E-platform and keeps the remaining fraction $(1-\theta)$ of sales
F	The capital-constrained manufacturer pays the slotting fee (F) to the E-platform with the online agency mode
CS	Consumer surplus
SW	Social welfare
	Decision variables
w	The wholesale price of the product when the capital-constrained manufacturer selects the online reselling mode
p	The retail price of the product with the both reselling and agency modes
e	The green effort of the manufacturer

(iv) $(\partial\pi_M^{R*}/\partial r) < 0$ *and* $(\partial\pi_E^{R*}/\partial r) < 0$.

In the previous corollary, $r_1 = (-3c(2k-\lambda^2) + \sqrt{3}\lambda\sqrt{c(2ak - c\lambda^2)})/(6ck)$ and $r_2 = (-c(2k-\lambda^2) + \lambda\sqrt{c(2ak - c\lambda^2)})/(2ck)$.

It is seen from Corollary 1 that the product's greenness, the resulting market demand, and the individual profits of the manufacturer and the platform decrease with an increase in the interest rate. This phenomenon is naturally understandable that with an increase in the financing rate, the associated financing cost also increases. Therefore, the manufacturer has to reduce investments in the product's greenness by balancing the production amount and the financing cost, which results in a decrease of the resulting demand. Also, it is obvious that an increase in the interest rate signifies that bank extracts more profits from the entire supply chain. Consequently, the two individuals will obtain less profits with a higher interest rate set by bank.

Corollary 1 also indicates how the interest rate affects the wholesale and retail prices, which is largely relied on the specific interest rate. To be specific, an increase in the interest rate first decreases the wholesale and retail prices and then increases the wholesale and retail prices. On the one hand, when the interest rate is relatively small as $0 \leqslant r < r_1$ (or $0 \leqslant r < r_2$), the wholesale price (or the retail price) decreases with the interest rate. On the other hand, the wholesale price (or the retail price) increases with a higher interest rate when it is relatively high as $r_1 \leqslant r \leqslant 1$ (or $r_2 \leqslant r \leqslant 1$).

It is obvious to verify that $r_1 < r_2$. It is interesting to find that the manufacturer will increase the wholesale price, yet the platform will decrease the retail price with a higher interest rate when $r_1 < r < r_2$. This indicates that the manufacturer and the platform act differently on the pricing decisions in response to a higher interest rate. This occurs because the platform has to balance the margin profit and the resulting demand of the green product.

5. Agency Mode-Scenario A

With the agency mode, by paying a slotting fee and commission sales to the platform, the manufacturer takes the ownership over products and directly retails them to the end consumers via the platform's online marketplace. Similarly, the profit functions of the platform and the manufacturer are respectively achieved as follows:

$$\begin{aligned}\pi_M^A(p,e) &= [(1-\theta)p - c]D - F - \frac{ke^2}{2} - r\left(cD + \frac{ke^2}{2} - K\right),\\ \pi_E^A &= \theta p D + F.\end{aligned}\tag{6}$$

It is noticed from the industrial practice that the e-platform publicly and advancingly declares the commissions in response to the product categories for all the potential suppliers every year. For example, JD.com offers and updates the commissions in response to every product category for any potential suppliers [46]. Thus, this paper considers an exogenous commission. Such an assumption can also be seen in the related literature, such as [47, 48] and [6]. Hence, the equilibrium decisions and the individual profits can be obtained in Proposition 2.

Proposition 2. *With the agency mode, the equilibrium decisions are given by*

$$\begin{aligned}p^{A*} &= \frac{(1+r)\left\{ak(1-\theta) + c\left[k(1+r) - (1-\theta)\lambda^2\right]\right\}}{(1-\theta)\left[2k(1+r) - (1-\theta)\lambda^2\right]},\\ e^{A*} &= \frac{\lambda[a(1-\theta) - c(1+r)]}{2k(1+r) - (1-\theta)\lambda^2},\end{aligned}\tag{7}$$

and the individual profits for the manufacturer and the platform are as follows:

$$\pi_M^{A*} = k(1+r)\frac{c^2(1+r)^2 - 2ac(1+r)(1-\theta) + a^2(1-\theta)^2}{2(1-\theta)\left[2k(1+r)-(1-\theta)\lambda^2\right]} + Kr - F,$$
$$\pi_E^{A*} = \frac{k(1+r)^2\left[a(1-\theta)-c(1+r)\right]\theta\left\{ak(1-\theta)+c\left[k(1+r)-(1-\theta)\lambda^2\right]\right\}}{(1-\theta)^2\left[2k(1+r)-(1-\theta)\lambda^2\right]^2} + F. \tag{8}$$

Based on Proposition 2, the resulting demand with the agency mode is achieved as $D^{A*} = (k(1+r)[a(1-\theta)-c(1+r)])/((1-\theta)[2k(1+r)-(1-\theta)\lambda^2])$, and the following results hold in Corollary 2.

Corollary 2. *With the agency mode, the impacts of the commission on the equilibriums are obtained as follows:*

(i) $(\partial e^{A*}/\partial\theta) < 0$;

(ii) $(\partial p^{A*}/\partial\theta) > 0$;

(iii) $(\partial D^{A*}/\partial\theta) < 0$.

Corollary 2 clearly indicates the impacts of the commission on the greenness, retail price, and the resulting demand. It is seen that with a higher commission, the manufacturer will pay more sales to the platform. Naturally, the manufacturer reduces investments in green technology and charges a higher retail price to balance its profit and the revenue share to the platform. Also, the greenness and the retail price of the product play a comprehensive effect on the resulting demand, and it signifies that the negative impact of the greenness on the demandand it signifies that the negative effect caused by the greenness on the demand is much more to balance the positive one caused by the retail price on the demand.

6. Online Channel Mode Selection

In this section, we investigate the optimal online channel mode for the manufacturer and the platform, which is shown in Propositions 3 and 4, respectively.

Proposition 3. *The manufacturer will choose the agency mode under the following circumstance and will choose the reselling mode otherwise, such that*

$$\frac{(a-c(1+r/1-\theta))^2}{2k(1+r/1-\theta)-\lambda^2} - \frac{2F}{k(1+r)} > \frac{[a-c(1+r)]^2}{4\left[2k(1+r)-\lambda^2\right]}. \tag{9}$$

It is noticed from Proposition 3 that the commission rate and the slotting fee jointly play a key role in the manufacturer's optimal online channel mode selection. Herein, we can verify that an increase in either the commission rate or the slotting fee will shift the manufacturer to choose the reselling mode. This is understandable that the manufacturer will pay more sales to the platform with the agency mode when the platform sets a higher commission or a higher slotting fee. Consequently, the manufacturer will turn to the reselling mode instead when suffering a relatively high commission rate or/and a higher slotting fee. The impacts of other key factors on this selection are more complexed, and we apply the numerical experiments to graphically show such effects derived by the interest rate and product cost in the following part.

In the practice, the manufacturer typically decides which online channel is to be selected for its products' sale through the platform's online marketplace. However, to a certain extent, the platform poses more powers over the manufacturer on such type of decision-making, such as pricing and channel distribution and among others. Hence, it is necessary to compare the platform's profit across these two different online channel modes, so as to reach an advantage outcome that satisfies both the manufacturer and the platform.

Next, we investigate the optimal online channel mode for the platform, which is shown in Proposition 4.

Proposition 4. *The platform will choose the agency mode under the following circumstance and will choose the reselling mode otherwise, such that*

$$\frac{F}{k(1+r)} + \frac{(1+r)(a-c(1+r/1-\theta))\theta\left[ak+c\left(k(1+r/1-\theta)-\lambda^2\right)\right]}{\left(2k(1+r)-(1-\theta)\lambda^2\right)^2} > \frac{[a-c(1+r)]^2}{4\left[2k(1+r)-\lambda^2\right]}. \tag{10}$$

Similarly, Proposition 3 reveals the optimal online channel mode selection for the platform. It is easy to verify that a higher slotting fee will push the platform to choose the agency mode. However, the impact of the commission rate on the platform's selection is more comprehensive, and we apply the numerical experiments to show how the commission affects the platform's optimal online channel selection. By following the literature [3, 49–51] and setting the parameters $a = 2$, $c = 0.5$, $r = 0.08$, $\lambda = 0.8$, and $K = 0$, Figure 1 shows that an increase in the commission will shift the platform to choose the agency mode. Furthermore, it is intuitively shown that the slotting fee and the commission jointly play crucial roles in selecting the optimal online channel mode for both the manufacturer and the platform. For example, in terms of the manufacturer (see Figure 1(a)), when the commission rate is very low ($\theta < 0.2$), the manufacturer will choose the agency mode, and it will choose the reselling mode when the commission rate is relatively high ($\theta > 0.42$), regardless of the slotting fee. At a low level of the slotting fee, the manufacturer will choose the agnecy mode, whereas the manufacturer will choose the reselling mode with a relatively high slotting fee. A similar observation can be found for the platform in Figure 1(b).

Obviously, based on Proposition 3 and 4, we can infer that both the manufacturer and the platform will likely choose the same online channel mode to sell the product under certain market conditions. To graphically show this advantage situation satisfying the two parties, Figure 1(c) indicates that when the platform sets a moderate commission, both the manufacturer and the platform will reach an agreement and choose the agency mode. The win-win situation herein holds for the two parties. Also, it signifies that the win-win situation will purely exist when both the manufacturer and the platform choose the agency mode. Furthermore, a higher commission along with a low slotting fee is constructive for the two parties to reach the win-win situation and vice versa.

The following applies the numerical experiments to further reveal the other key factors behind to derive this selection. Figures 2 and 3 investigate the impacts of the interest rate and the product cost on the optimal online channel mode selection, respectively.

Letting Figure 1 be a benchmark, when facing a relatively low interest rate, it is seen that both the manufacturer and the platform will likely choose the agency mode, given a commission rate and a slotting fee. Hence, the region of the win-win situation becomes large in this case as shown in Figure 2(c). This clearly indicates that a sufficiently low interest rate will push both the manufacturer and the platform, which will reach an agreement and choose the agency mode. Similarly, it is seen form Figure 3 that an increase in the product cost will shift the manufacturer to choose the reselling mode and platform to select the agency mode. Obviously, this kind of transforming on the online channel mode selection for the two parties will narrow the region of the win-win situation as shown in Figure 3(c).

7. Extension and Discussion

This section firstly extends to a supply chain with a reverse channel leadership in which the manufacturer acts as the leader and the platform is the follower and then explores and compares the consumer surplus and the social welfare across different business scenarios.

7.1. Extension to a Supply Chain with Different Leadership. It is noticed that the platform generally poses more bargaining powers over the most manufacturers in controlling the retailing channel and consumers' preferences. However, some leading manufacturers with big brand names may have more powers when bargaining with the platform to a certain extent. In this subsection, we consider a situation in which the manufacturer acts as a Stackelberg leader and the platform is the follower. Parallel to Sections 4 and 5, the two different scenarios are, respectively, referred as Scenario R' and Scenario A'. The associated equilibrium decisions can thus be achieved in a similar manner, which is shown in the following proposition.

Proposition 5. *With the reselling mode, the equilibrium decisions are given by*

$$\begin{aligned} w^{R'*} &= \frac{(1+r)\left\{2k[a+c(1+r)]-c\lambda^2\right\}}{4k(1+r)-\lambda^2},\\ e^{R'*} &= \frac{[a-c(1+r)]\lambda}{4k(1+r)-\lambda^2},\\ p^{R'*} &= \frac{(1+r)\left\{3ak+c\left[k(1+r)-\lambda^2\right]\right\}}{4k(1+r)-\lambda^2}, \end{aligned} \tag{11}$$

and the associated equilibrium profits for the manufacturer and the e-platform are

$$\begin{aligned} \pi_M^{R'*} &= \frac{k(1+r)[a-c(1+r)]^2}{8k(1+r)-2\lambda^2}+Kr,\\ \pi_E^{R'*} &= \frac{k^2(1+r)^2[a-c(1+r)]^2}{\left[4k(1+r)-\lambda^2\right]^2}. \end{aligned} \tag{12}$$

Clearly, when the manufacturer acts as the Stackelberg leader with the online agency mode, the equilibrium decisions and the profits are the same as those given in Section 4. To focus on the online channel mode selection for two parties, the following continues to investigate the optimal online channel mode for the manufacturer and the platform, which is shown in Proposition 6 and Proposition 7, respectively.

Proposition 6. *With a different supply chain leadership, the manufacturer will choose the agency mode under the following circumstance and will choose the reselling mode otherwise, such that*

$$\frac{(a-c(1+r/1-\theta))^2}{2k(1+r/1-\theta)-\lambda^2}-\frac{2F}{k(1+r)}>\frac{[a-c(1+r)]^2}{4k(1+r)-\lambda^2}. \tag{13}$$

Parallel to the associated channel mode selections, when the platform acts a leader, Propositions 6 and 7 reveal how to select the optimal online channel mode when the manufacturer serves as a leader. That is, the slotting fee and the commission induce a similar pattern on the effects of the optimal online channel mode for the two parties, which is not elaborated here. Similarly, the following applies the numerical experiments to focus on the other key factors behind to derive this selection.

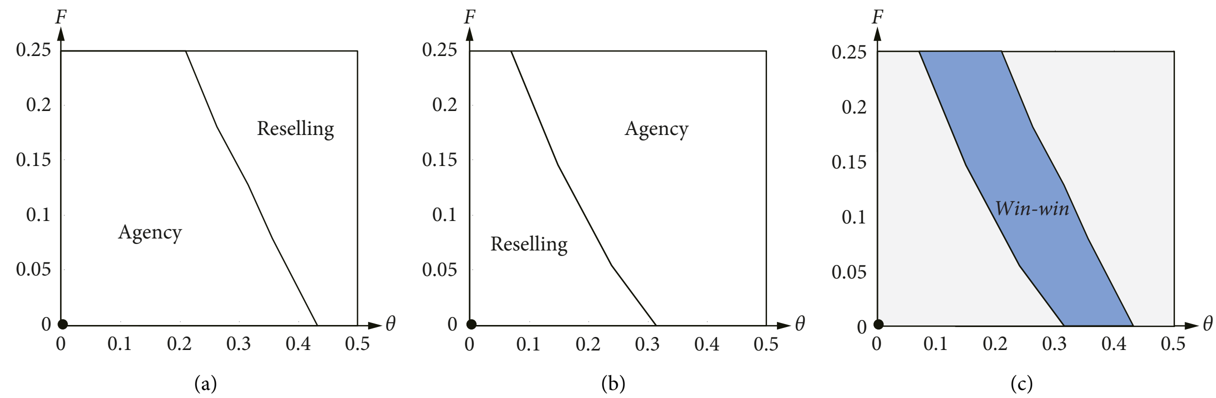


FIGURE 1: Optimal online channel mode selection ($c = 0.5$ and $r = 0.08$). (a) Manufacturer's selection. (b) Platform's selection. (c) Integrated selection.

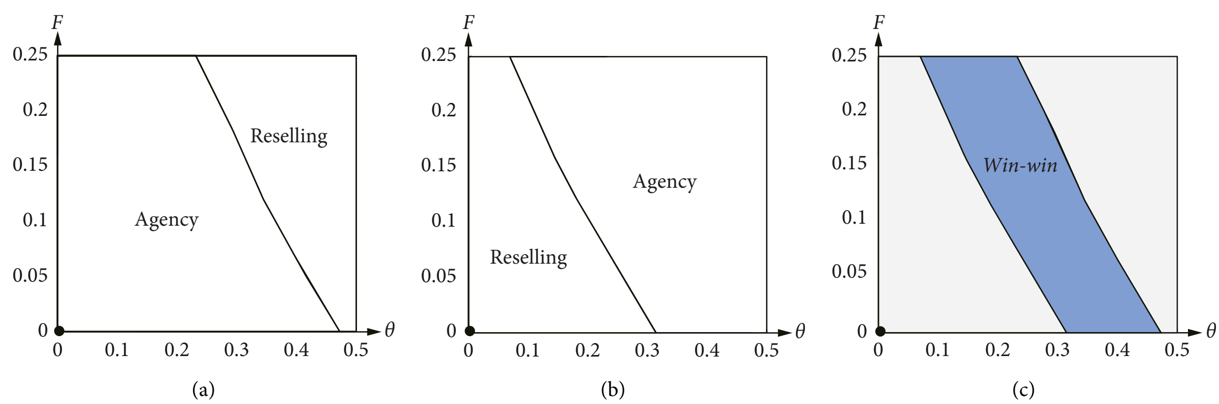


FIGURE 2: Optimal online channel mode selection ($c = 0.5$ and $r = 0.04$). (a) Manufacturer's selection. (b) Platform's selection. (c) Integrated selection.

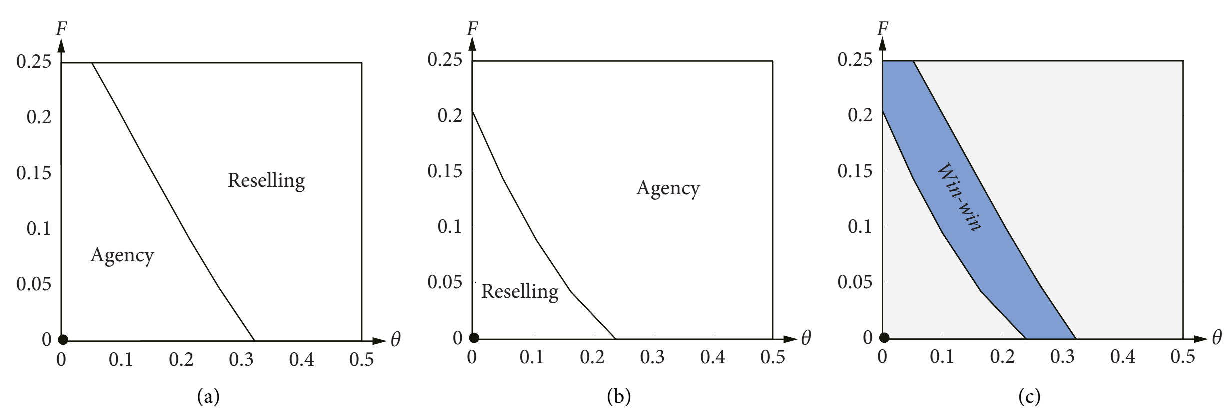


FIGURE 3: Optimal online channel mode selection ($c = 0.8$ and $r = 0.08$). (a) Manufacturer's selection. (b) Platform's selection. (c) Integrated selection.

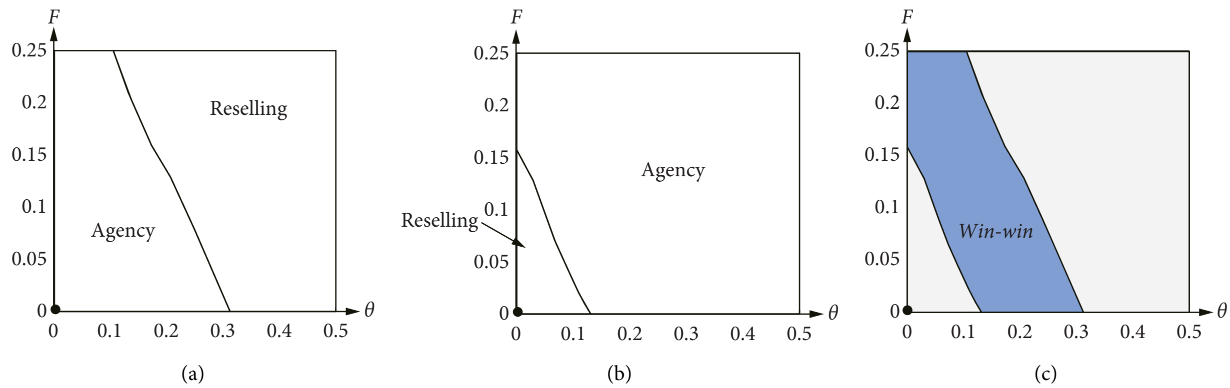


FIGURE 4: Optimal online channel mode selection ($c = 0.5$ and $r = 0.08$). (a) Manufacturer's selection. (b) Platform's selection. (c) Integrated selection.

Proposition 7. *With a different supply chain leadership, the platform will choose the agency mode under the following circumstance and will choose the reselling mode otherwise, such that*

$$\frac{(a-c(1+r/1-\theta))\theta\left[k(a+c(1+r/1-\theta))-c\lambda^2\right]}{\left[2k(1+r)-(1-\theta)\lambda^2\right]^2}+\frac{F}{k(1+r)^2}>\frac{k[a-c(1+r)]^2}{\left[4k(1+r)-\lambda^2\right]^2}. \quad (14)$$

It is seen from Figure 4 that both the slotting fee and the commission induce a similar effect on the optimal online channel mode for the two parties when the manufacturer acts as a leader. To be specific, an increase in the slotting fee and/or the commission will shift the manufacturer to choose the reselling mode yet shift the platform to choose the agency mode. Additionally, a mild commission with an appropriate slotting fee will pose an advantage selection for two parties, where both the manufacturer and the platform select the agency mode.

Furthermore, from Figures 5 and 6, we know that a low interest rate set by bank is likely to derive a win-win situation for the two parties, and a higher product cost will exacerbate the differences between manufacturer and platform on the online channel mode selection.

Combining with Section 6, we know that both the slotting fee and the commission will move the manufacturer and the platform toward different directions on the online channel selection, regardless of the different supply chain leaderships. No matter who leads the supply chain, the platform and the manufacturer will reach a win-win situation when the commission becomes moderate along with an appropriate slotting fee. In the case of the win-win situation, the platform and the manufacturer are willing to choose the agency mode.

7.2. Discussion to the Consumer Surplus and the Social Welfare. Consumer surplus reflects the amount of utility or gain that customers receive when they buy products and services. By designing and developing a green product, consumer surplus is very important for the firms to consider, because consumers that derive a large benefit from buying products are more likely to purchase the green products again in the future. In practice, when the firms make such type of operational decisions, they not only care about their own profits but also take their shareholders' profit into account. As a main stakeholder in the supply chain, consumers have become a key focus of firms in making decisions. This subsection shall next consider how the consumer surplus and the social welfare affect the individual's optimal online channel mode selection in this platform supply chain. By following the literature [52, 53], we measure the consumer surplus as given by

$$\begin{aligned} CS &= \int_{p}^{p_{\max}} D(p,e)\mathrm{d}p \\ &= \int_{p}^{a+\lambda e} (a-p+\lambda e)\mathrm{d}p \\ &= \frac{(a-p+\lambda e)^2}{2}. \end{aligned} \quad (15)$$

Herein, the social welfare for the supply chain is obtained as follows:

$$SW = \pi_E + \pi_M + CS. \quad (16)$$

Based on the associated equilibrium decisions and individual profit, it is easy to compute the consumer surplus and the social welfare, respectively. Furthermore, we compare the consumer surplus and the social welfare across two different supply chain leaderships.

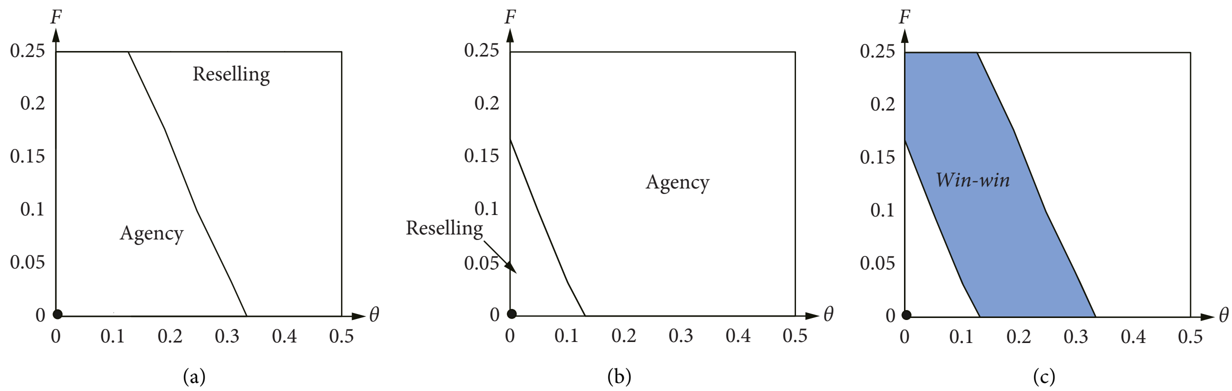


FIGURE 5: Optimal online channel mode selection ($c = 0.5$ and $r = 0.04$). (a) Manufacturer's selection. (b) Platform's selection. (c) Integrated selection.

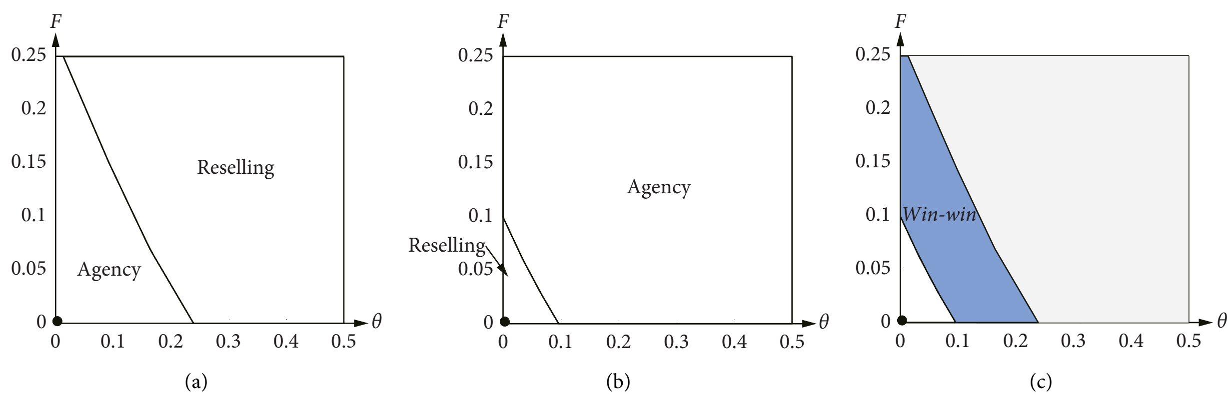


FIGURE 6: Optimal online channel mode selection ($c = 0.8$ and $r = 0.08$). (a) Manufacturer's selection. (b) Platform's selection. (c) Integrated selection.

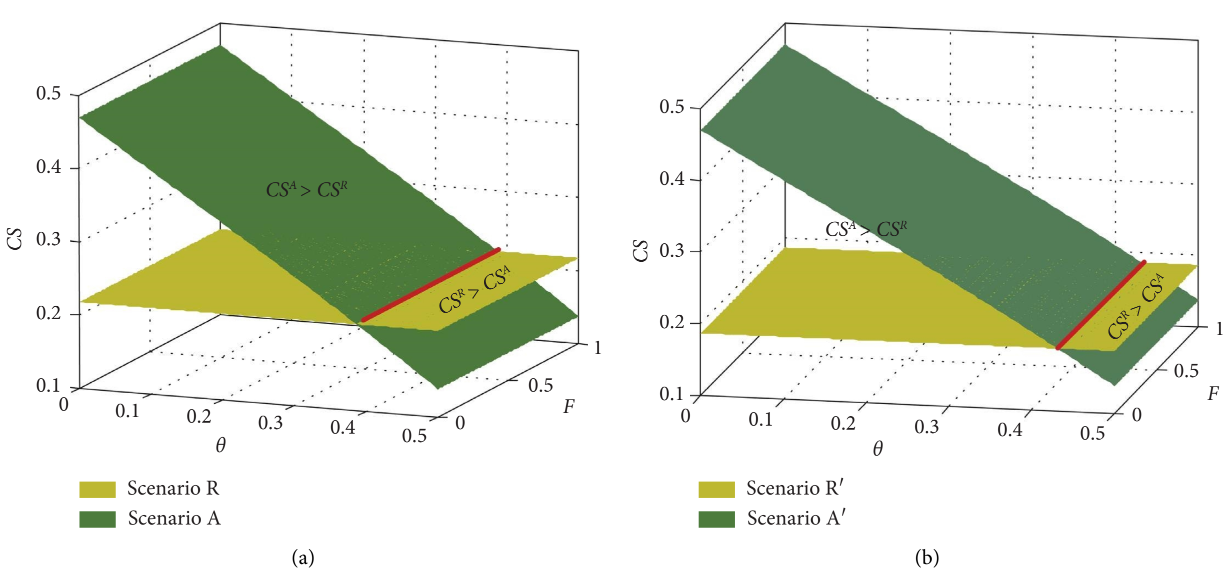
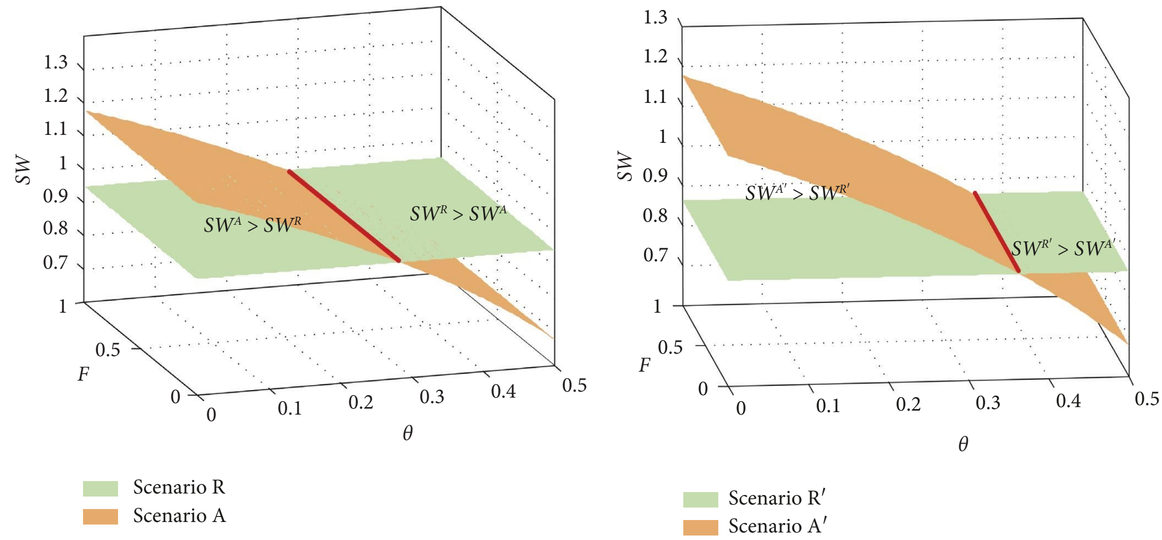
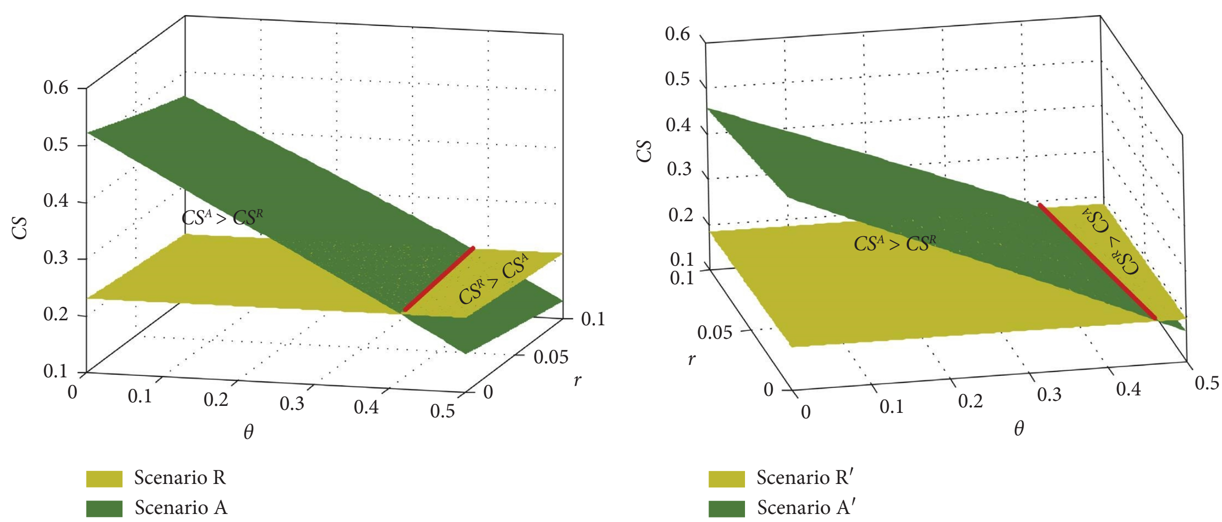


FIGURE 7: Consumer surplus. (a) Platform leads the supply chain. (b) Manufacturer leads the supply chain.



(a) (b)

FIGURE 8: Social welfare. (a) Platform leads the supply chain. (b) Manufacturer leads the supply chain.



(a) (b)

FIGURE 9: Consumer surplus. (a) Platform leads the supply chain. (b) Manufacturer leads the supply chain.

It is seen from Figure 7 that the relative consumer surplus across the two online channel modes relies largely on the commission. To be specific, when the commission is relatively low, the agency mode will benefit the consumers and thus the consumers will obtain more surpluses. Otherwise, the reselling mode is meaningful to boost the consumer surplus when the commission is sufficiently high. This is understandable that when the commission is very low, the manufacturer will naturally pay less revenue to the platform and thus determine a relatively low retail price, thereby stimulating the consume surplus. In addition, we find that the slotting fee exerts no effect on the relative consumer surplus with the two different supply chains with different channel leaderships. The reason behind is that the slotting fee is a fixed revenue that distributes between the platform and the manufacturer, which does not affect the retail prices.

Figure 8 clearly reveals the relative social welfare across the two online channel modes with the two supply chains with different channel leaderships. Similarly, we find that the slotting fee has no effects on the relative social welfare, and the relative social welfare is highly relied on the commission. In particular, the agency mode with a lower commission will benefit the social welfare, mostly compared with the reselling mode. This indicates that when the supply chain concerns more about the social welfare, the platform will pay a relatively low commission to the manufacturers.

Next, we investigate how the interest rate affects the relative consumer surplus and social welfare across different online channel modes and supply chain leaderships. It is seen from Figures 9 and 10 that an increase in the interest rate signifies that the supply chain will enjoy a higher social welfare with more consumer surpluses with the reselling

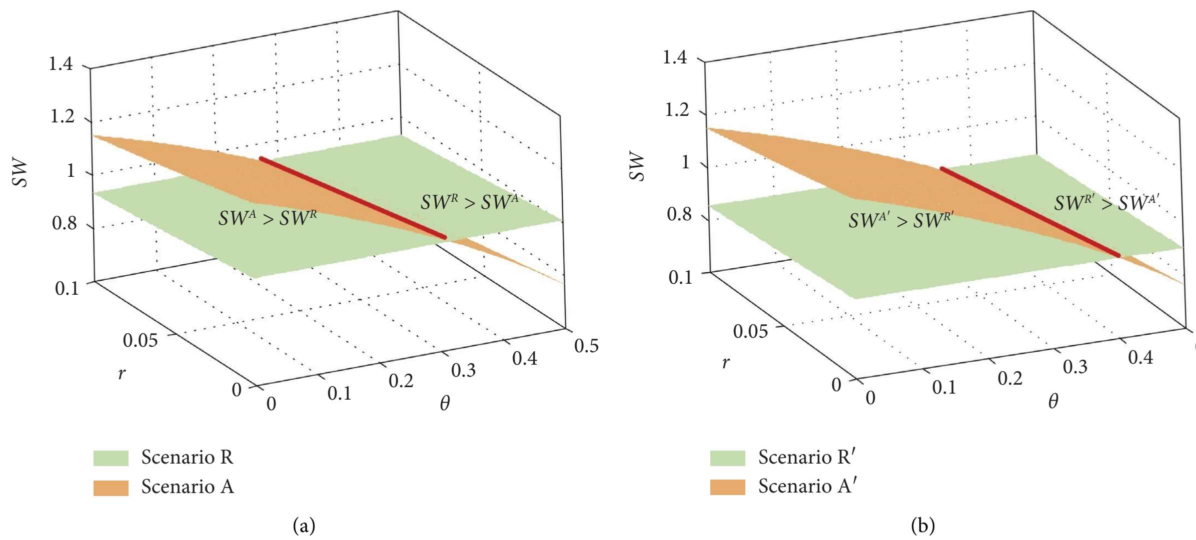


FIGURE 10: Social welfare. (a) Platform leads the supply chain. (b) Manufacturer leads the supply chain.

mode. This indicates that when the capital-constrained manufacturer suffers a relatively high interest rate set by bank, it is optimal for the platform supply chain to choose the reselling mode to achieve a better performance in both consumer surplus and the social welfare.

8. Conclusions

This paper develops an e-commerce platform supply chain that consists of one platform company and one capital-constrained manufacturer. By borrowing the loans from bank, the capital-constrained manufacturer can raise sufficient capital to produce and sell the products through the platform's online marketplace with either the online agency channel mode or the online reselling channel mode. The focal point of this paper is to, respectively, investigate the optimal online channel mode for the manufacturer and the platform. The current work also extends to a different supply chain with a different leadership, based on which we explore the impacts of supply chain leaderships on the consumer surplus as well as the social welfare.

8.1. Key Findings. With the analytical study, the key findings of this paper are collected as follows:

Firstly, we find that the initial capital level has no effect on the equilibrium decisions of the two supply chain members but largely affect the manufacturer's profit with two different online channel modes. It is the interest rate that plays a critical role in determining the respective equilibrium decisions.

Secondly, the optimal online channel mode selections for the manufacturer and the platform are, respectively, investigated and the factors behind deriving these strategic selections are also revealed. It clearly exhibits that an increase in either commission or the slotting fee will make the manufacturer and platform act differently in selecting the optimal online channel mode, that is, the manufacturer will choose the online reselling mode, while the platform will select the online agency mode. Interestingly, we find that the manufacturer and the platform will reach a consensus and choose the online agency mode to achieve a win-win situation under certain market conditions.

Finally, this paper compares the supply chain performances from different perspectives. The impacts of different online channel modes on the consumer surplus and social welfare are explored with different supply chain leaderships. It is found that the commission plays a key role in the relative consumer surplus and social welfare whereas the slotting fee has no such effects on them. The supply chain performs better in both the consumer surplus and social welfare with the reselling mode when bank sets a relatively high interest rate.

8.2. Managerial Implications. Based on the key findings derived in this paper, herein, the contributions to the industrial practice are collected in the following:

Firstly, considering a situation that the green product manufacturer may suffer the capital shortage, this paper incorporates two different online channel modes to an e-commerce platform supply chain with the capital-constrained manufacturer selecting bank loan financing. We explicitly reveal the impacts of the financing on the equilibrium decisions and individual profits. Managerial implications for firms on selecting the optimal online channel mode are obtained, based on which we find a win-win situation benefiting the two parties when choosing the online agency mode under certain market conditions. This results compliment the existing studies on the online channel mode selection [6, 7, 54].

Secondly, this paper then reveals how the different supply chain leaderships affect the individual profits and consumer surplus as well as social welfare. It is well noticed that the commission set by the platform plays a crucial role in determining the relative consumer surplus and social welfare, whereas the slotting fee has no such effects on them across the two different online channel modes. The supply chain will perform better in both consumer surplus and social welfare when applying the online reselling mode along with facing a relatively high interest rate set by bank. This provides managerial insights for industrial practicer on how to effectively make such decision-making in platform economy.

8.3. Limitations and Further Research. The following summarizes the limitations and the researching opportunities of the current paper: Firstly, this paper purely considers the bank loan financing for the capital-constrained manufacturer. In practice, the capital-constrained manufacturer may have several different financing resources, such as financing from an e-commerce platform or trade credit financing. Herein, it would be interesting to investigate other financing strategies in such a platform supply chain and compare the impacts of different financing resources on the supply chain performances. Secondly, this paper develops an e-commerce platform supply chain in which the manufacturer can choose either the agency mode or the reselling mode in an online marketplace. Recently, it poses an uptrend that the manufacturer can distribute its products simultaneously through both the online agency mode and the online reselling mode. A promising extension of this paper is to incorporate these two online channel modes simultaneously for a capital-constrained manufacturer in this platform supply chain. Thirdly, in practice, the government often provides some subsidies of the green investments to the manufacturer. Hence, it is valuable to investigate the optimal subsidy policy for the government. Lastly, this paper considers the demand of the green product to be deterministic. Another promising and challenging extension of this paper is to explore the case with a stochastic demand of the green product in such an e-commerce platform supply chain.

Appendix

A. Proof of Proposition 1

With the reselling mode, the platform moves first and sets the markup t for the product, then the manufacturer determines the wholesale price w and the green effort e, where $t = p - w$. According to equation (3), we can compute the Hessian matrix of π_M as

$$H_{\pi_M} = \begin{vmatrix} \frac{\partial^2 \pi_M}{\partial w^2} & \frac{\partial^2 \pi_M}{\partial w \partial e} \\ \frac{\partial^2 \pi_M}{\partial e \partial w} & \frac{\partial^2 \pi_M}{\partial e^2} \end{vmatrix} = \begin{vmatrix} -2 & \lambda \\ \lambda & -k(1+r) \end{vmatrix}. \tag{A.1}$$

Clearly, H_{π_M} is negatively defined when $2k(1+r) > \lambda^2$. Hence, we can obtain the optimal wholesale price and the green effort for the manufacturer as $w = ((1+r)[ak - kt + c(k + kr - \lambda^2)])/(2k(1+r) - \lambda^2)$ and $e = ([a - c(1+r) - t]\lambda)/(2k(1+r) - \lambda^2)$ by simultaneously solving $(\partial \pi_M / \partial w) = 0$ and $(\partial \pi_M / \partial e) = 0$. By substituting w and e, we have $(\partial^2 \pi_E / \partial t^2) = -(2k(1+r))/(2k(1+r) - \lambda^2) < 0$. Thus, π_E is strictly concave on t, and the optimal markup for the platform is $t = (a - c(1+r)/2)$ by solving $(\partial \pi_E / \partial t) = 0$. The equilibrium decisions and the individual profits can thus be easily obtained in Proposition 1.

B. Proof of Corollary 1

(i) Based on Proposition 1, it always has $(\partial e^{R*}/\partial r) = -(\lambda(2ak - c\lambda^2))/(2[2k(1+r) - \lambda^2]^2) < 0$ and $(\partial e^{R*}/\partial r) = -(k[a\lambda^2 + 2c(1+r)\ (k + kr - \lambda^2)])/\ (2[2k(1+r) - \lambda^2]^2) < 0$.

(ii) $(\partial w^{R*}/\partial r) = (-ak\lambda^2 + 2c[3k^2(1+r)^2 - 3k(1+r)\lambda^2 + \lambda^4])/(2[2k(1+r) - \lambda^2]^2)$. Let $(\partial w^{R*}/\partial r) = 0$, then we have $r_1 = (-3c(2k - \lambda^2) + \sqrt{3}\lambda\sqrt{c(2ak - c\lambda^2)})/(6ck)$, so as to if $0 < r < r_1$ then $(\partial w^{R*}/\partial r) < 0$; if $r > r_1$, then $(\partial w^{R*}/\partial r) > 0$ holds.

(iii) $(\partial p^{R*}/\partial r) = (-ak\lambda^2 + c[2k^2(1+r)^2 - 2k(1+r)\lambda^2 + \lambda^4])/(2[2k(1+r) - \lambda^2]^2)$. Let $(\partial p^{R*}/\partial r) = 0$, then we have $r_2 = (-c(2k - \lambda^2) + \lambda\sqrt{c(2ak - c\lambda^2)})/(2ck)$, so as to if $0 < r < r_2$ then $(\partial p^{R*}/\partial r) < 0$; if $r > r_2$, then $(\partial p^{R*}/\partial r) > 0$ holds.

(iv) $(\partial \pi_E^{R*}/\partial r) = (a - c(1+r)/2)(\partial D^{R*}/\partial r) - (c/2)D^{R*} < 0$ and $(\partial \pi_M^{R*}/\partial r) = K - (k(a - c(1+r))(a\lambda^2 + c(1+r)(4k(1+r) - 3\lambda^2)))/(8(2k(1+r) - \lambda^2)^2)$ and $K < cD^R * + (ke^{R*^2}/2)$, it holds $(\partial \pi_S^{R*}/\partial r) < 0$.

Corollary 1 is thus completed.

C. Proof of Proposition 2

With the the agency mode, the manufacturer sets the retail price and the green effort simultaneously. Similarly, the Hessian matrix of π_M can be computed as

$$H_{\pi_M^A} = \begin{vmatrix} \frac{\partial^2 \pi_M^A}{\partial p^2} & \frac{\partial^2 \pi_M^A}{\partial p \partial e} \\ \frac{\partial^2 \pi_M^A}{\partial e \partial p} & \frac{\partial^2 \pi_M^A}{\partial e^2} \end{vmatrix} = \begin{vmatrix} -2(1-\theta) & \lambda(1-\theta) \\ \lambda(1-\theta) & -k(1+r) \end{vmatrix}. \tag{C.1}$$

Clearly, the H_{π_M} is negatively defined when $2k(1+r) > \lambda^2(1-\theta)$. Hence, we can compute the optimal decisions for the manufacturer as $p = ((1+r)\{ak(1-\theta) + c[k(1+r) - (1-\theta)\lambda^2]\})/((1-\theta)[2k(1+r) - (1-\theta)\lambda^2])$ and $e = (\lambda[a(1-\theta) - c(1+r)])/(2k(1+r) - (1-\theta)\lambda^2)$.

Proposition 2 is thus completed.

D. Proof of Corollary 2

Based on Proposition 2, it always has

$$\frac{\partial e^{A*}}{\partial \theta} = -\frac{(1+r)\lambda\left(2ak - c\lambda^2\right)}{\left[2k(1+r) - (1-\theta)\lambda^2\right]^2} < 0,$$
$$\frac{\partial p^{A*}}{\partial \theta} = \frac{(1+r)\left(2ck^2(1+r)^2 - k(1-\theta)(a + 2c(1+r) - a\theta)\lambda^2 + c(1-\theta)^2\lambda^4\right)}{(1-\theta)^2\left[2k(1+r) - (1-\theta)\lambda^2\right]^2} > 0, \tag{D.1}$$
$$\frac{\partial D^{A*}}{\partial \theta} = -\frac{k(1+r)\left\{a(1-\theta)^2\lambda^2 + 2c(1+r)\left[k(1+r) - (1-\theta)\lambda^2\right]\right\}}{(1-\theta)^2\left[2k(1+r) - (1-\theta)\lambda^2\right]^2} < 0.$$

Proposition 2 is thus completed.

E. Proofs of Propositions 3 and 4

Based on Propositions 1 and 2, we have $\pi_M^{R*} = (k(1+r)[a - c(1+r)]^2)/(8[2k(1+r) - \lambda^2]) + Kr$, and $\pi_M^{A*} = k(1+r)(c^2(1+r)^2 - 2ac(1+r)(1-\theta) + a^2(1-\theta)^2)/(2(1-\theta)[2k(1+r) - (1-\theta)\lambda^2]) + Kr - F$. Thus, it can be computed that $\pi_M^{A*} - \pi_M^{R*} = k(1+r)(([a - (c(1+r))/(1-\theta)]^2/(2k(1+r))/(1-\theta) - \lambda^2) - (2F)/(k(1+r)) - ([a - c(1+r)]^2/4[2k(1+r) - \lambda^2]))$. Similarly, for the platform, we have $\pi_E^{R*} = (k(1+r)[a - c(1+r)]^2)/(4[2k(1+r) - \lambda^2])$, and $\pi_E^{A*} = (k(1+r)^2[a(1-\theta) - c(1+r)]\theta\{ak(1-\theta) + c[k(1+r) - (1-\theta)\lambda^2]\})/((1-\theta)^2[2k(1+r) - (1-\theta)\lambda^2]^2) + F$. Thus, it is easy to compute that $\pi_E^{A*} - \pi_E^{R*} = k(1+r)(((1+r)[a - (c(1+r))/(1-\theta)]\theta\{ak + c[k(1+r)/(1-\theta) - \lambda^2]\}/[2k(1+r) - (1-\theta)\lambda^2]^2) + (F/k(1+r)) - ([a - c(1+r)]^2/4[2k(1+r) - \lambda^2]))$.

Propositions 3 and 4 can thus be easily obtained.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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