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Green Supply Chain Coordination During the COVID-19 Pandemic Based on Consignment Contract

Yi Wang[1]*, *Geovanny Genaro Reivan Ortiz*[2], *William Dextre-Martinez*[3†] and *Liandi Zhang*[1]

[1]College of Science, Tianjin University of Commerce, Tianjin, China, [2]Laboratory of Basic Psychology, Behavioral Analysis and Programmatic Development PAD-LAB, Catholic University of Cuenca, Cuenca, Ecuador, [3]School of Management and Tourism, Universidad Nacional Santiago Antúnez de Mayolo, Huaraz, Peru

COVID-19 has further strengthened consumers' online consumption habits and brought a new boom in which enterprises can use online transactions and green products to avoid risk and gain profits in the pandemic. A green supply chain model is established containing one e-commerce platform and one manufacturer. The Nash bargaining contract and Rubinstein bargaining contract are applied to mitigate conflicts of profits in the model. From the coordination analysis, we show that both Nash and Rubinstein bargaining contracts can achieve coordination and mitigate conflict of profits through the adjustment of platform usage rates. According to each member's bargaining power and patience, the optimal platform usage rate is determined, the supply chain profits of both sides are allocated, the green production's research and development are promoted, and a win-win situation is realized. Specifically, in the Nash bargaining contract, the excess profit of each member depends on their bargaining power. The stronger the bargaining power, the more excess profits will go to the e-commerce platform, and the less excess profits will go to the manufacturer. In the Rubinstein bargaining contract, the excess profit of each member depends on the lowest profit bound and bargaining patience. The higher the manufacturer's (or e-commerce platform's) patience, the higher his profit. When the patience of both is high (or low), the e-commerce platform (or the manufacturer) plays a leading role and obtains more profits.

Keywords: COVID-19, green supply chain, consignment contract, sustainable development, environmental sustainability

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***Correspondence:**
Yi Wang
lxywangyi@tjcu.edu.cn

†ORCID:
William Dextre-Martinez
orcid.org/0000-0003-1481-0584

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INTRODUCTION

With population growth, the contradiction among economic development, resource utilization, and environmental protection has become increasingly prominent. A great deal of enterprises are only concerned about economic interests and ignore ecological protection, resulting in the increasingly severe problem of environmental pollution. According to the current population growth trend, the world population will reach 9.8 billion by 2050. The continuous growth of the population has brought a great burden to the Earth, while the energy crisis and environmental pollution will in turn affect human survival. How can awareness be raised to protect the Earth and the environment? In 1970, the United States first proposed "World Earth Day," which was the first large-scale environmental protection movement in human history. World Earth Day has been held 52 times with different topics until 2021. The purpose is to raise public awareness of environmental protection and advocate for sustainable development. Environmental protection needs everyone to participate. Whether individuals, enterprises, or governments, all can become green concept advocates and practitioners in promoting green action to protect the Earth on which we live. At present, the development of production and living favors are mostly integrated into environmental protection. Because of the outbreak of COVID-19, the economies of all countries and the lives of all people are affected. To reduce exposure, slow down the spread, and minimize the impact of COVID-19, consumers prefer to use online shopping platforms instead of physical stores, which indirectly affects the competition among enterprises. Amid the COVID-19 pandemic, everyone has realized the convenience of the era of the network period and the importance of online communication, especially online shopping. It not only changed people's lifestyle, but also brought uncertainty to the world's economic development. Deeply affected by COVID-19, more and more people worldwide have to use online shopping platforms to meet their daily needs, such as, Amazon, eBay, Wish, Alibaba, etc. Since it is difficult for physical stores to maintain economic profits, many manufacturers choose to sell through online platforms to combat COVID-19.

To investigate the performance of online shopping, the usual method is to establish an economic model containing all participants. To mitigate conflicts of interests in an established model, coordination under consignment contracts appears particularly important. The Nash bargaining contract and Rubinstein bargaining contract are two favorite cooperation contracts in characterizing the problem. In 1950, the Nash equilibrium was first proposed by John Forbes Nash in his doctoral thesis (Nash, 1950a). This is an equilibrium analysis theory of non-cooperative game, which reveals the internal relationship between game equilibrium and economic equilibrium. It has a significant impact on game theory and economics, and the 1994 Nobel Memorial Prize in Economic Sciences was awarded to Nash (Nash, 1950b; Nash, 1951; Nash, 1953). In 1982, Ariel Rubinstein simulated the basic and indefinite complete information bargaining process with the method of complete information dynamic game, and established a complete information alternating bidding bargaining model, which is called the Rubinstein bargaining model (Rubinstein, 1982). Enterprises sell their green products *via* e-commerce platforms, sharing profits with e-commerce platforms through Nash or Rubinstein consignment contracts. In the contract, e-commerce platforms will gain profits from manufacturers in using his platform.

Benefitted from the Nash and Rubinstein bargaining contracts, partners will make joint efforts to cooperate in a model to reach a win-win state, which will promote sustainable development of the global economy. For sustainable development, countries have strengthened the management and restriction on enterprises' environmental problems. Therefore, environmental issues have also become a problem for the development of enterprises. Only enterprises that comply with the green era can have sustainable competitiveness in the face of fierce competition. To deal with the effect of a competitive environment and technological innovation, enterprises have to explore cooperative opportunities to survive in a competitive market. The supply and demand relationship between enterprises constitutes a supply chain, and their cooperation between enterprises generates the mode named supply chain management. How to get the optimal decisions of the sharing ratio among each member be achieved through Nash and Rubinstein bargaining contracts? This can be solved by green supply chain management, which is a very practical issue worth studying.

The supply chain combined with "environmental protection" and "green" is called a green supply chain, which aims to lower the waste of resources, reduce environmental pollution, and lessen production costs. Governments worldwide have made great efforts in encouraging enterprises to produce green products. For example, China determined to achieve low-carbon life by implementing limitations of carbon dioxide emissions. In 2030, an emission peak will be reached; in 2060, carbon neutrality will be accomplished. Environmental protection not only has attracted increasing attention of enterprises, but also draws the attention of consumers looking to buy green food. The question of how to obtain optimal profits, reduce manufacturing costs, and minimize environmental pollution becomes the critical point of supply chain management.

In this paper, we established a model of green products under consignment contracts in. Comparing to the current results, we have the following contributions. Firstly, we investigated effects under consignment contracts on green supply chain performance, greenness, and prices of green products. Secondly, by using Nash and Rubinstein bargaining contracts, we coordinated the supply chain. Thirdly, through a coordination mechanism, we redistributed profits of supply chain members to promote the sustainable development of green products and a win-win situation for two parties.

LITERATURE REVIEW

We reviewed the related literature in three topics: the game model based on consignment contracts, the green supply chain model, and the coordination of the green supply chain.

Game Model Based on Consignment Contracts

The development trend of economic globalization and the trade scale of the global economy urgently need a new economic operation mode and business operation mode. In the background of economic globalization, how can a global strategy be implemented to improve one's viability and competitiveness, and overcome constraints of space and time? Organizations such as modern enterprises, merchants, and state machines must seek and adopt new development models. This brings the development of e-commerce platforms. A consignment contract, as a legal provision, standardizes the consumer market, and attracts the attention of researchers. Researchers have made great efforts in coordinating models by the Nash and Rubinstein bargaining contracts.

Li et al. (2009) used the Nash bargaining model to analyze a chain model containing two members. They researched conditions to coordinate their supply chain, and gave optimal decisions of their members and whole channel. Yildiz (2011) studied a final-offer arbitration model under the Nash and Rubinstein bargaining game. Adida and Ratisoontorn (2011) set a model of three members under consignment contracts. They found that the contract which most benefits the manufacturer will not be fixed, but for the retailer, the consignment price contract is better than the other two contracts. Hu et al. (2014) investigated an inventory control model on consignment contracts. They gave optimal control strategies and analyzed the vendor's return policy. Avinadav et al. (2015) focused on a model influenced by risk sensitivity corresponding to mobile applications. They obtained optimal decisions by different risk attitudes, such as averse, neutral, seeking. Guha (2019) searched the performance of malice and patience in the Rubinstein bargaining model. De Giovanni et al. (2019) issued the supply chain management of a marketing-operations interface under a consignment contract. They found that a cooperative program will be beneficial to a retailer, but not good for manufacturers. Zhao et al. (2020) developed a supply chain shelf model on a consignment contract. They presented each member's optimal decisions in horizontal scenarios, and investigated strategies under horizontal collusion. Zhou et al. (2022) described a competitive model with third-party platform-integration under Nash bargaining. Shi et al. (2021) established a platform supply chain. By Nash game theory, they found that the usage of a platform only benefits partners with low competition, occurring in different four different channels. Xu et al. (2021) constructed a sea-cargo supply chain, and analyzed the impact on their model through the Stackelberg-Nash game. Ye et al. (2021) built a model containing a platform. By Nash game theory, they examined competition between partners, and examined performance in a long-run or short-run. Hasiloglu and Kaya (2021) considered a model containing e-commerce platforms and analyzed the influence of each factor by game theory. Zhang and Wang (2021) (Zhang and Wang, 2021) investigated a sustainable supply chain under the Rubinstein game model. Caparr o′ s and Pereau (2021) (Caparrós and Pereau, 2021) showed different results in two cooperation negotiating procedures under Rubinstein game theory. Tang et al. (2021a) studied a model under credit term-based contracts. They obtained optimal decisions, and a win-win state was proposed. Ouyang et al. (2021) issued a framework to warn for COVID-19 by some contracts. They found that their framework is beneficial in decentralized decision-making channels. Avinadav et al. (2022) searched a model of an app developer and a distributer, and analyzed their revenue sharing by a consignment contract.

Green Supply Chain Model

For application in actual production, various models have been built to investigate optimal decisions. For example, Ghosh and Shah (2015) researched the optimal solutions in a model under different contracts. Xu et al. (2016) investigated the optimal strategy for each link in a three-tier chain model when the green level of upstream suppliers affects the carbon emissions of the core manufacturer. Cao and Liu (2017) investigated the feasibility of proactive implementation in a supply chain model without government incentives under information asymmetry. They demonstrated the superiority of cooperative decision-making under information asymmetry by comparing games of whether or not to cooperate. Zhang et al. (2017) established a model due to consumer strategy behavior for three cases: no government subsidy, a government subsidy to the green product manufacturer, or to the green consumer, and the study showed that government subsidy to the green product manufacturer is more beneficial to the development of green products. Sinayi and Rasti-Barzoki (2018) studied optimal product price, greenness, and social welfare strategies for green supply chains under government intervention. Wen et al. (2018) constructed a model considering consumers' green preferences and intervention by governments.

Coordination of Green Supply Chain

To seek maximization in a decentralized channel's overall profits, as well as the maximization of members' profits, the channel's cooperation is the standard method to achieve this goal. Researchers have made great efforts in coordinating different models.

Seifert et al. (2012) established a model of three parties: supplier, manufacturer, and retailer. They analyzed coordination of the supply chain in price-contracts. They found that distinguishing between two sub-supply chains equals the transfer of the channel's shortage cost. Huo et al. (2015) studied a model and tested it with 617 manufacturers. They researched the effect of IT and inter-organizational relationship on coordination capability. Hu et al. (2018) investigated whether different contracts can coordinate their supply chain. Results showed that a conventional option contract will not coordinate the model. Xu et al. (2020) issued a supply chain coordination corresponding of online platforms by cost-sharing contracts. Whether or not the model can be coordinated depends on the factors, such as contracts, delivery time sensitivity, and platform power. Chandra and Vipin (2021) researched a vaccine supply chain by coordinating contracts. The results showed that their supply chain cannot be coordinated by a wholesale price contract. Tang et al. (2021b) researched a coordination of carbon taxation among enterprises and consumers. Song et al. (2022) explored a model containing two different products. They analyzed optimal decisions, and showed contracts in coordinating their model. Qiu et al. (2022) investigated O2O supply chain coordination. A comparison showed among three kinds of contracts in coordinating their model. Overall a large extent of literature considers different attributes of COVID-19, such as socio-economic impacts (Irfan et al., 2021; Ahmad et al., 2022), environmental consequences (Razzaq et al., 2020; Irfan et al., 2022; Razzaq et al., 2022), and logistics operations (Khan et al., 2021a; Yu et al., 2021), and few studies generally discuss industry 4.0 practices at the firm level (Khan et al., 2021b), and other

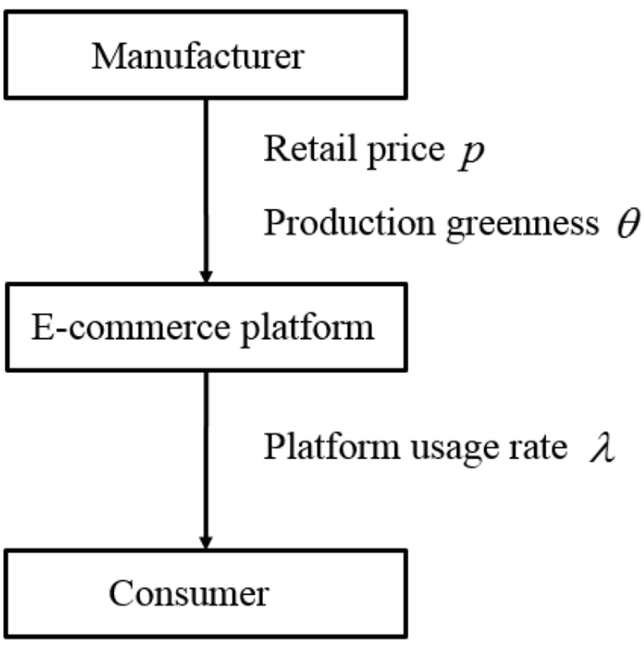

FIGURE 1 | Structure of the supply chain model.

investment factors (Razzaq et al., 2021). However, little is known regarding the proposed relationship.

Under the pandemic, the online transaction has become a mainstream consumption mode. Compared to the reviewed literature streams, we extended the research area of the green supply chain in combining the e-commerce platform and green product manufacturer. We described two partners' decisions in two structures (centralized and decentralized channel), and introduced Nash and Rubinstein bargaining consignment contracts in coordinating the decentralized chain.

DESCRIPTION OF THE PROBLEM

The model in our paper contains a green product manufacturer and an e-commerce platform. Referring to Savaskan et al. (2004), this paper assumes market demand $q (q > 0)$ as a linear function of product price p and greenness θ. Let $q(p, \theta) = a - bp + \alpha\theta$, where $\alpha (\alpha > 0)$ is the potential market demand, implying that consumers prefer cheaper production with high greenness. Referring to the study of Zhu and Dou (2011), this paper assumes that research and development investment is a quadratic function of its greenness $I\theta^2$, with $I (I > 0)$ the green investment parameter. The manufacturer undertakes research and development costs. Referring to Luo et al. (2017), a significant difference of the e-commerce platform consignment model and the traditional wholesale and retail model shows that the manufacturer decides productions' price and greenness, and e-commerce platform charges the manufacturer a certain platform usage fee, i.e., a certain percentage λ $(0 < \lambda < 1)$ of the revenue from the sale of the green product. The marketing cost of an e-commerce platform denotes as $c (a > bc > 0)$. **Figure 1** is the structure of our model.

GAME MODEL UNDER CONSIGNMENT CONTRACTS

Channel Performance With Centralized Decision-Making

Under a centralized channel, two members perform as one form in deciding optimal decisions to maximize the channel's total profits. The whole channel's profit is:

$$\Pi^C(p, \theta) = (p - c)(a - bp + \alpha\theta) - I\theta^2. \tag{1}$$

By optimizing **Eq. 1**, the following Theorem 1 is obtained.

THEOREM 1. When $\alpha^2 < 4bI$, the optimal greenness, price, and total channel's profit under the centralized decision are, respectively:

$$p_c^* = \frac{2I(a - bc)}{4bI - \alpha^2} + c, \theta_c^* = \frac{\alpha(a - bc)}{4bI - \alpha^2}, \ \Pi^{C*} = \frac{I(a - bc)^2}{4bI - \alpha^2}.$$

Proof By the first-order optimality conditions,

$$\frac{\partial \Pi^C}{\partial p} = a - 2bp + \alpha\theta + bc = 0, \frac{\partial \Pi^C}{\partial \theta} = p\alpha - c\alpha - 2I\theta = 0.$$

We have

$$p_c^* = \frac{2I(a - bc)}{4bI - \alpha^2} + c, \theta_c^* = \frac{\alpha(a - bc)}{4bI - \alpha^2}. \tag{2}$$

Let $A_1 = \frac{\partial^2 \Pi^C}{\partial p^2} = -2b, B_1 = \frac{\partial^2 \Pi^C}{\partial \theta \partial p} = \alpha, C_1 = \frac{\partial^2 \Pi^C}{\partial \theta^2} = -2I$. Since $A_1 < 0$ and $A_1 B_1 - C_1^2 = 4bI - \alpha^2 > 0$, so **Eq. 2** is the optimal solution. Finally, substituting p_c^* and θ_c^* into **Eq. 1**, we get the optimal channel's profit Π_c^*.

Next, we aim to investigate the optimal decisions in the decentralized channel.

Channel Performance With Decentralized Decision-Making

In a decentralized model, partners all aim to maximize self-interest. The leadership of the model is an e-commerce platform, and followership is the manufacturer. Firstly, this e-commerce platform determines the usage rate; Secondly, the manufacturer decides the production's price and greenness after being informed of the usage rate determined by the platform.

For given platform usage rate λ, the manufacturer has profit:

$$\Pi_d^M(p, \theta; \lambda) = (1 - \lambda)p(a - bp + \alpha\theta) - I\theta^2. \tag{3}$$

Meanwhile, for any given price p and greenness θ, e-commerce platform holds profit:

$$\Pi_d^R(\lambda; p, \theta) = \lambda p(a - bp + \alpha\theta) - c(a - bp + \alpha\theta). \tag{4}$$

In the framework of the Stackelberg game, maximizing **Eqs 3**, **4**, Theorem 2 is obtained.

THEOREM 2. When $\alpha^2 < 4bI$, the optimal price and greenness of the product under the decentralized channel are:

TABLE 1 | Optimal profit and optimal solutions under different models.

Model		Profit of manufacturer	Profit of e-commerce platform	Total profit of supply chain	Price	Greenness	Platform usage rate
Centralized channel				12250	41	70	
Decentralized channel		1875	2112.5	3987.5	13	7.5	0.7115
Nash bargaining	μ						
	0	10137.5	2112.5	12250	41	70	0.1758
	0.25	8071.875	4178.125	12250	41	70	0.2046
	0.5	6006.25	6243.75	12250	41	70	0.2334
	0.75	3940.625	8309.375	12250	41	70	0.2622
	1	1875	10375	12250	41	70	0.2909
Rubinstein bargaining	(δ_M, δ_R)						
	$(1, 0.8)$	10137.5	2112.5	12250	41	70	0.3848
	$(1, 0.5)$	10137.5	2112.5	12250	41	70	0.3848
	$(1, 0.2)$	10137.5	2112.5	12250	41	70	0.3848
	$(0.8, 1)$	1875	10375	12250	41	70	0.3537
	$(0.5, 1)$	1875	10375	12250	41	70	0.3537
	$(0.2, 1)$	1875	10375	12250	41	70	0.3537
	$(0.5, 0.5)$	8166.7	4083.3	12250	41	70	0.2033
	$(0.7, 0.7)$	7205.9	5044.1	12250	41	70	0.2166
	$(0.9, 0.9)$	6447.4	5802.6	12250	41	70	0.2272

$$p_d^* = \frac{2aI - c\alpha^2}{2(4bI - \alpha^2)},\ \theta_d^* = \frac{\alpha^2(a - bc) - 2abI}{\alpha(4bI - \alpha^2)}.$$

The optimal usage rate for the platform is:

$$\lambda_d^* = \frac{(2aI + c\alpha^2)(4bI - \alpha^2)}{\alpha^2(2aI - c\alpha^2)}.$$

Manufacturer's optimal profit is

$$\Pi_d^{M*} = \frac{aI[\alpha^2(a - bc) - 2abI]}{\alpha^2(4bI - \alpha^2)},$$

and e-commerce platform has profit

$$\Pi_d^{R*} = \frac{b(2aI - c\alpha^2)^2}{4\alpha^2(4bI - \alpha^2)}.$$

Proof By reasoning process, we first consider the case that manufacturer first decides price and greenness by maximizing its corporate profit based on the platform usage rate determined by the e-commerce platform, whose optimization problem is:

$$\max_{p,\theta} \Pi_d^M(p, \theta|\lambda).$$

The first-order optimality condition yields:

$$\frac{\partial \Pi_d^M}{\partial p} = (1 - \lambda)(a - 2bp + \alpha\theta) = 0, \frac{\partial \Pi_d^M}{\partial \theta} = (1 - \lambda)p\alpha - 2I\theta = 0.$$

Let $A_2 = \frac{\partial^2 \Pi_d^M}{\partial p^2} = -2b(1 - \lambda)$, $B_2 = \frac{\partial^2 \Pi_d^M}{\partial p \partial \theta} = (1 - \lambda)\alpha$, $C_2 = \frac{\partial^2 \Pi_d^M}{\partial \theta^2} = -2I$. It is known that when $4bI - \alpha^2 > 0$, $A_2 C_2 - B_2^2 = (1 - \lambda)[4bI - (1 - \lambda)\alpha^2] > 0$ and $A_2 < 0$, there exists a unique optimal solution:

$$p_d^*(\lambda) = \frac{2aI}{4bI - (1 - \lambda)\alpha^2},\ \theta_d^*(\lambda) = \frac{a\alpha(1 - \lambda)}{4bI - (1 - \lambda)\alpha^2}. \quad (5)$$

Substituting **Eq. 5** into **Eqs 3**, **4**, the optimal profit for two members is respectively:

$$\Pi_d^M = \frac{a^2 I(1 - \lambda)}{4bI - (1 - \lambda)\alpha^2},$$

$$\Pi_d^R(\lambda) = \frac{2abI\{2aI\lambda - c[4bI - (1 - \lambda)\alpha^2]\}}{[4bI - (1 - \lambda)\alpha^2]^2}.$$

Second, consider the first stage of the Stackelberg game, when the e-commerce platform aims to maximize its profit, and its optimization problem is

$$\max_{\lambda} \Pi_d^R(\lambda).$$

According to the first-order condition in optimizing λ:

$$\frac{d\Pi_d^R}{d\lambda} = \frac{A - B\lambda}{[4bI - (1 - \lambda)\alpha^2]^3} = 0,$$

with $A = 2abI[(2aI + c\alpha^2)(4bI - \alpha^2)]$, $B = 2abI\alpha^2(2aI - c\alpha^2)$, we have

$$\lambda_d^* = \frac{(2aI + c\alpha^2)(4bI - \alpha^2)}{\alpha^2(2aI - c\alpha^2)}.$$

By second-order condition,

$$\frac{d^2\Pi_d^R}{d\lambda^2} = -\frac{8a^2 bI^2\alpha^2}{[4bI - (1 - \lambda)\alpha^2]^4} < 0.$$

Therefore, λ_d^* is the unique optimal solution, which leads to Theorem 2.

The following proposition is easy to follow.

PROPOSITION 1. $p_c^* > p_d^*$, $\theta_c^* > \theta_d^*$, $\Pi^{C*} > \Pi_b^{M*} + \Pi_b^{R*}$.

Proof: Because $p_c^* - p_d^* = \frac{4bcI + 2aI - c\alpha^2}{2(4bI - \alpha^2)} > 0$, so $p_c^* > p_d^*$. Because $\theta_c^* - \theta_d^* = \frac{2abI}{\alpha(4bI - \alpha^2)} > 0$, so $\theta_c^* > \theta_d^*$. Because $\Pi^{C*} - (\Pi_d^{M*} + \Pi_d^{R*}) = \frac{bc^2\alpha^2(4bI - \alpha^2) + 4a^2bI^2}{4\alpha^2(4bI - \alpha^2)} > 0$, so $\Pi^{C*} > \Pi_d^{M*} + \Pi_d^{R*}$.

By Proposition 1, selling price, greenness, and total profits are all higher in the centralized channel than the decentralized one. Since the two parties all pursue the maximization of their profit, it will inevitably create a conflict of interest between them, and goes against the interest of the research and development of green production, so it is essential to establish a coordination contract to raise the partners' profits.

COORDINATION BASED ON CONSIGNMENT CONTRACTS

Decision-making in a decentralized channel reduces total profit compared with the centralized channel. To mitigate conflicts between partners, it is crucial to establish coordination contracts to optimize the performance of the entire supply chain.

Nash Bargaining Contract

To win more profits for supply chain members, we first take the Nash bargaining contract. Let x be the portion received in total profits by the e-commerce platform. Thus, the manufacturer undertakes the remaining $(1-x)$ portion $(0 \le x \le 1)$. Then the profit of the total channel should be

$$\max_{x\epsilon[0,1]} f(x) = \left(x\Pi^{C*} - \Pi_d^{R*}\right)^{\mu}\left[(1-x)\Pi^{C*} - \Pi_d^{M*}\right]^{1-\mu},$$

with $\mu\epsilon[0,1]$ as the bargaining power of platforms. If $\mu = 0$, then the manufacturer has absolute bargaining power; if $\mu = 1$, then platforms have absolute bargaining power; if $\mu = 0.5$, then both two members have equal bargaining power. Through bargaining, both manufacturer and e-commerce platforms aim to get more profits than the decentralized situation. Note that the optimal solution is

$$x^* = \frac{\mu\left(\Pi^C - \Pi_d^M - \Pi_d^R\right) + \Pi_d^R}{\Pi^C},$$

and we will get the following result.

PROPOSITION 2. By the Nash bargaining contract, the optimal profits of each member are:

$$\Pi_n^{M*} = \frac{aI\left[\alpha^2(a-bc) - 2abI\right]}{\alpha^2(4bI-\alpha^2)} + \frac{(1-\mu)b\left[c^2\alpha^2(4bI-\alpha^2) + 4a^2I^2\right]}{4\alpha^2(4bI-\alpha^2)}, \tag{6}$$

$$\Pi_n^{R*} = \frac{b\left(2aI - c\alpha^2\right)^2}{4\alpha^2(4bI-\alpha^2)} + \frac{\mu b\left[c^2\alpha^2(4bI-\alpha^2) + 4a^2I^2\right]}{4\alpha^2(4bI-\alpha^2)}. \tag{7}$$

THEOREM 3. By the Nash bargaining contract, when $a > 2bc$, the optimal platform usage rate is:

$$\lambda_n^* = \frac{(4bI-\alpha^2)\left\{\left(2aI + c\alpha^2\right)^2 - 8bc^2I\alpha^2 + \mu\left[c^2\alpha^2(4bI-\alpha^2) + 4a^2I^2\right]\right\}}{8I\alpha^2(a-bc)(2aI - c\alpha^2 + 2bcI)}. \tag{8}$$

Proof: Substitute $p_n^* = p_c^*$ and $\theta_n^* = \theta_c^*$ into **Eq. 3**. When it equals **Eq. 6**, we get the optimal platform usage rate as **Eq. 8** in the case $a > 2bc$.

Under certain conditions, the Nash bargaining contract can raise both members' profit, which coordinates better than the decentralized channel. Since λ_n^* is the optimal decision, this ensures a win-win situation. Regarding the excess profit, it will depend on the members' bargaining power.

Rubinstein Bargaining Contract

Nash bargaining ends in negotiations between manufacturers and e-commerce platforms in one stage. However, in practice, every member can make a bargain by rejecting a previous idea and creating a new offer. Therefore, Rubinstein bargaining contracts come to this stage. More specifically, the manufacturer and e-commerce platforms take turns quoting the channel profit of the centralized decision. They will not reach an agreement until a mutually satisfactory distribution plan is obtained.

Suppose the manufacturer first proposes a distribution scheme $(\Pi^{C*} - y, y)$, and then the e-commerce platform decides to accept or reject it. If he accepts it, this process ends; if the platform rejects the plan, he will propose a new distribution scheme in stage 2, and the manufacturer makes a decision. If he accepts, the negotiation process ends; if he refuses, he will propose a new distribution scheme plan in the third period, and so on, until the two parties reach a consensus distribution scheme. Since patience is limited in the negotiation process, it is assumed that the discount factor of the manufacturer is δ_M, and the platform is δ_R, which is determined by patience of negotiating parties. Under the decentralized channel, each member can obtain at least profits Π_d^{M*} and Π_d^{R*}, which is the lowest bound of the bargaining scheme. The following starts from the finite-term situation (the game is played in 1, 2, and 3 stages):

If the negotiation process ends in stage 1, by the optimal principle, then the manufacturer will propose the distribution scheme as $(\Pi^{C*} - \Pi_d^{R*}, \Pi_d^{R*})$, implying that the manufacturer's optimal profit is $\Pi^{C*} - \Pi_d^{R*}$, and the e-commerce platform undertakes Π_d^{R*}.

If the negotiation is carried out in stage 2, after the first negotiation in stage 1, the manufacturer can no longer propose a distribution scheme. Meanwhile, the e-commerce platform will propose $(\Pi_d^{M*}, \Pi^{C*} - \Pi_d^{M*})$ in stage 2. The e-commerce platform's profit is equivalent to $\delta_R(\Pi^{C*} - \Pi_d^{M*})$ in stage 1. In stage 1, the e-commerce platform can get profit distributed by the manufacturer of no less than $\Pi_R^{(2)} = \max\{\Pi_d^{R*}, \delta_R(\Pi^{C*} - \Pi_d^{M*})\}$. This results in the optimal decision in stage 2, that is, $(\Pi^{C*} - \Pi_R^{(2)}, \Pi_R^{(2)})$.

PROPOSITION 3.

1) If $\delta_R \le \frac{\Pi_d^{R*}}{\Pi^{C*} - \Pi_d^{M*}}$, then $\Pi_R^{(2)} = \Pi_d^{R*}$, the optimal results in stage 1 and stage 2 are the same
2) If $\delta_R > \frac{\Pi_d^{R*}}{\Pi^{C*} - \Pi_d^{M*}}$, then $\Pi_R^{(2)} = \delta_R(\Pi^{C*} - \Pi_d^{M*}) > \Pi_d^{R*}$. Compared to the results of stage 1, the manufacturer will obtain less profit, but the e-commerce platform will get more;

If the negotiation is carried out in stage 3, then we will deduce the result reversely. First, in stage 3, the manufacturer will provide the scheme $(\Pi^{C*} - \Pi_d^{R*}, \Pi_d^{R*})$, which is equal to the profit in stage 2, say $\delta_M(\Pi^{C*} - \Pi_d^{R*})$. Since the e-commerce platform in stage 2 set the distribution scheme as $\max\{\Pi_d^{M*}, \delta_M(\Pi^{C*} - \Pi_d^{R*})\}$, they will obtain the profit $\Pi^{C*} - \max\{\Pi_d^{M*}, \delta_M(\Pi^{C*} - \Pi_d^{R*})\}$. This is equal to the profit $\delta_R(\Pi^{C*} - \max\{\Pi_d^{M*}, \delta_M(\Pi^{C*} - \Pi_d^{R*})\})$ in stage 1. Therefore, when in stage 1, the manufacturer will set e-commerce platform's profit no less than $\Pi_R^{(3)} = \boldsymbol{max}\{\Pi_d^{R*}, \boldsymbol{\delta}_R(\Pi^{C*} - \boldsymbol{max}\{\Pi_d^{M*}, \boldsymbol{\delta}_M(\Pi^{C*} - \Pi_d^{R*})\})\}$. Then in Rubinstein bargaining contract of stage 3, the optimal distribution scheme is $(\Pi^{C*} - \Pi_R^{(3)}, \Pi_R^{(3)})$.

PROPOSITION 4.

1) If $\boldsymbol{\delta}_M \le \frac{\Pi_d^{M*}}{\Pi^{C*}-\Pi_d^{R*}}$, $\boldsymbol{\delta}_R \le \frac{\Pi_d^{R*}}{\Pi^{C*}-\Pi_d^{M*}}$ or $\boldsymbol{\delta}_M > \frac{\Pi_d^{M*}}{\Pi^{C*}-\Pi_d^{R*}}$, $\boldsymbol{\delta}_M\boldsymbol{\delta}_R \ge \frac{\boldsymbol{\delta}_R\Pi^{C*}-\Pi_d^{R*}}{\Pi^{C*}-\Pi_d^{R*}}$, then $\Pi_R^{(3)} = \Pi_d^{R*}$, implying that the distribution scheme in stage 3 is the same as stage 1
2) If $\boldsymbol{\delta}_M \le \frac{\Pi_d^{M*}}{\Pi^{C*}-\Pi_d^{R*}}$, $\boldsymbol{\delta}_R > \frac{\Pi_d^{R*}}{\Pi^{C*}-\Pi_d^{M*}}$, then $\Pi_R^{(3)} = \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*}) > \Pi_d^{R*}$. Compared with scheme in stage 1, the manufacturer gets more profit, but the e-commerce platform gets less profit
3) If $\boldsymbol{\delta}_M > \frac{\Pi_d^{M*}}{\Pi^{C*}-\Pi_d^{R*}}$, $\boldsymbol{\delta}_M\boldsymbol{\delta}_R < \frac{\boldsymbol{\delta}_R\Pi^{C*}-\Pi_d^{R*}}{\Pi^{C*}-\Pi_d^{R*}}$, then $\Pi_R^{(3)} = \boldsymbol{\delta}_R(\Pi^{C*} - \boldsymbol{\delta}_M(\Pi^{C*} - \Pi_d^{R*})) > \Pi_d^{R*}$. Compared to results in stage 1, the manufacturer obtains fewer profits, but the e-commerce platforms hold greater profits.

If negotiating indefinitely, then the e-commerce platform has profit $\boldsymbol{y} = \boldsymbol{max}\{\Pi_d^{R*}, \boldsymbol{\delta}_R(\Pi^{C*} - \boldsymbol{max}\{\Pi_d^{M*}, \boldsymbol{\delta}_M(\Pi^{C*} - \boldsymbol{y})\})\}$. This is because of the subgame is isomorphic to the whole bargaining game.

THEOREM 4.1) If

$$\boldsymbol{\delta}_M \le \frac{\Pi_d^{M*}}{\Pi^{C*} - \Pi_d^{R*}}, \boldsymbol{\delta}_R \le \frac{\Pi_d^{R*}}{\Pi^{C*} - \Pi_d^{M*}} \text{ or } \boldsymbol{\delta}_M > \frac{\Pi_d^{M*}}{\Pi^{C*} - \Pi_d^{R*}}, \boldsymbol{\delta}_M\boldsymbol{\delta}_R \ge \frac{\boldsymbol{\delta}_R\Pi^{C*} - \Pi_d^{R*}}{\Pi^{C*} - \Pi_d^{R*}}$$

, then the distribution scheme of indefinite Rubinstein bargaining contract is $(\Pi^{C*} - \Pi_d^{R*}, \Pi_d^{R*})$, and the platform usage rate is $\boldsymbol{\lambda}_{RB}^* = \frac{(4bI-\alpha^2)[(2aI+c\alpha^2)^2+8cI\alpha^2(a-bc)]}{8I\alpha^2(a-bc)(2aI-c\alpha^2+2bcI)}$

2) If$\boldsymbol{\delta}_M\boldsymbol{\delta}_R \ge \frac{\boldsymbol{\delta}_M\Pi^{C*}-\Pi_d^{M*}}{\Pi^{C*}-\Pi_d^{M*}}$, $\boldsymbol{\delta}_R > \frac{\Pi_d^{R*}}{\Pi^{C*}-\Pi_d^{M*}}$, then the distribution scheme of the indefinite Rubinstein bargaining contract is $(\Pi^{C*} - \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*}), \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*}))$, and the platform usage rate is $\boldsymbol{\lambda}_{RB}^* = \frac{\boldsymbol{\delta}_R(4bI-\alpha^2)[a(2aI+c\alpha^2)+bc^2\alpha^2]}{2\alpha^2(a-bc)(2aI-c\alpha^2+2bcI)}$
3) If $\frac{\boldsymbol{\delta}_M(1-\boldsymbol{\delta}_R)}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M} > \frac{\Pi_d^{M*}}{\Pi^{C*}}$, $\frac{\boldsymbol{\delta}_R(1-\boldsymbol{\delta}_M)}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M} > \frac{\Pi_d^{R*}}{\Pi^{C*}}$, then the distribution scheme of the indefinite Rubinstein bargaining contract is $(\frac{1-\boldsymbol{\delta}_R}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M}\Pi^{C*}, \frac{\boldsymbol{\delta}_R(1-\boldsymbol{\delta}_M)}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M}\Pi^{C*})$, and the platform usage rate is $\boldsymbol{\lambda}_{RB}^* = \frac{(4bI-\alpha^2)[\boldsymbol{\delta}_R(1-\boldsymbol{\delta}_M)(a-bc)+2bc(1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M)]}{2b(2aI-c\alpha^2+2bcI)(1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M)}$.

Proof: For $\boldsymbol{y} = \boldsymbol{max}\{\Pi_d^{R*}, \boldsymbol{\delta}_R(\Pi^{C*} - \boldsymbol{max}\{\Pi_d^{M*}, \boldsymbol{\delta}_M(\Pi^{C*} - \boldsymbol{y})\})\}$, if $\Pi_d^{M*} \ge \boldsymbol{\delta}_M(\Pi^{C*} - \boldsymbol{y})$, then $\boldsymbol{y} = \boldsymbol{max}\{\Pi_d^{R*}, \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*})\}$; if $\Pi_d^{R*} \ge \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*})$, then $\boldsymbol{y} = \Pi_d^{R*}$, and hence $\boldsymbol{\delta}_M \le \frac{\Pi_d^{M*}}{\Pi^{C*}-\Pi_d^{R*}}$, $\boldsymbol{\delta}_R \le \frac{\Pi_d^{R*}}{\Pi^{C*}-\Pi_d^{M*}}$. Set $\boldsymbol{p}_{RB}^* = \boldsymbol{p}_c^*$, $\boldsymbol{\theta}_{RB}^* = \boldsymbol{\theta}_c^*$, the optimal platform usage rate is $\boldsymbol{\lambda}_{RB}^* = \frac{(4bI-\alpha^2)[(2aI+c\alpha^2)^2+8cI\alpha^2(a-bc)]}{8I\alpha^2(a-bc)(2aI-c\alpha^2+2bcI)}$.

If $\Pi_d^{R*} < \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*})$, then $\boldsymbol{y} = \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*})$, and hence $\boldsymbol{\delta}_M\boldsymbol{\delta}_R \ge \frac{\boldsymbol{\delta}_M\Pi^{C*}-\Pi_d^{M*}}{\Pi^{C*}-\Pi_d^{M*}}$, $\boldsymbol{\delta}_R > \frac{\Pi_d^{R*}}{\Pi^{C*}-\Pi_d^{M*}}$. Set $\boldsymbol{p}_{RB}^* = \boldsymbol{p}_c^*$ and $\boldsymbol{\theta}_{RB}^* = \boldsymbol{\theta}_c^*$, we get the platform usage rate $\boldsymbol{\lambda}_{RB}^* = \frac{\boldsymbol{\delta}_R(4bI-\alpha^2)[a(2aI+c\alpha^2)+bc^2\alpha^2]}{2\alpha^2(a-bc)(2aI-c\alpha^2+2bcI)}$.

If $\Pi_d^{M*} < \boldsymbol{\delta}_M(\Pi^{C*} - \boldsymbol{y})$, then $\boldsymbol{y} = \boldsymbol{max}\{\Pi_d^{R*}, \boldsymbol{\delta}_R(\Pi^{C*} - \boldsymbol{\delta}_M(\Pi^{C*} - \boldsymbol{y}))\}$; if $\Pi_d^{R*} \ge \boldsymbol{\delta}_R(\Pi^{C*} - \boldsymbol{\delta}_M(\Pi^{C*} - \boldsymbol{y}))$, then $\boldsymbol{y} = \Pi_d^{R*}$, and hence $\boldsymbol{\delta}_M > \frac{\Pi_d^{M*}}{\Pi^{C*}-\Pi_d^{R*}}$, $\boldsymbol{\delta}_M\boldsymbol{\delta}_R \ge \frac{\boldsymbol{\delta}_R\Pi^{C*}-\Pi_d^{R*}}{\Pi^{C*}-\Pi_d^{R*}}$; if $\Pi_d^{R*} < \boldsymbol{\delta}_R(\Pi^{C*} - \boldsymbol{\delta}_M(\Pi^{C*} - \boldsymbol{y}))$, then $\boldsymbol{y} = \boldsymbol{\delta}_R(\Pi^{C*} - \boldsymbol{\delta}_M(\Pi^{C*} - \boldsymbol{y}))$, that is, $\boldsymbol{y} = \frac{\boldsymbol{\delta}_R(1-\boldsymbol{\delta}_M)}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M}\Pi^{C*}$. Then $\frac{\boldsymbol{\delta}_M(1-\boldsymbol{\delta}_R)}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M} > \frac{\Pi_d^{M*}}{\Pi^{C*}}$, $\frac{\boldsymbol{\delta}_R(1-\boldsymbol{\delta}_M)}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M} > \frac{\Pi_d^{R*}}{\Pi^{C*}}$. Set $\boldsymbol{p}_{RB}^* = \boldsymbol{p}_c^*$ and $\boldsymbol{\theta}_{RB}^* = \boldsymbol{\theta}_c^*$, then the platform usage rate is $\boldsymbol{\lambda}_{RB}^* = \frac{(4bI-\alpha^2)[\boldsymbol{\delta}_R(1-\boldsymbol{\delta}_M)(a-bc)+2bc(1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M)]}{2b(2aI-c\alpha^2+2bcI)(1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M)}$.

The Rubinstein bargaining contract can perfectly coordinate our supply chain. The optimal platform usage rate and distribution scheme of channel profits depend on the lower profit limit and patience of each member. In this case, members' profits can be guaranteed. When the patience of each member is weak or the manufacturer's patience performs higher than some threshold, the optimal decision of manufacturer and platform is $(\Pi^{C*} - \Pi_d^{R*}, \Pi_d^{R*})$; when the patience of the manufacturer increases and platform's patience is higher than some threshold, then optimal allocation is $(\Pi^{C*} - \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*}), \boldsymbol{\delta}_R(\Pi^{C*} - \Pi_d^{M*}))$; when the patience of each member is high enough, then the manufacturer and e-commerce platform will press proportional profit distribution, the optimal distribution is $(\frac{1-\boldsymbol{\delta}_R}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M}\Pi^{C*}, \frac{\boldsymbol{\delta}_R(1-\boldsymbol{\delta}_M)}{1-\boldsymbol{\delta}_R\boldsymbol{\delta}_M}\Pi^{C*})$.

CASE STUDY

In this section, the previous theoretical analysis is verified through numerical calculations and managerial insights. Set $\boldsymbol{a} = 1000$, $\boldsymbol{b} = 50$, $\boldsymbol{c} = 6$, $\boldsymbol{I} = 10$, $\boldsymbol{\alpha} = 40$. **Table 1** shows results of optimal profit and optimal solution under different models.

Data in **Table 1** verifies that price, greenness, and total profit in centralized channels are all higher compared to the decentralized one. This is a motivation to find a method to coordinate the decentralized channel in reaching the centralized channel's profit. At the same time, every member obtains more than the lowest profit bound, that is, the profit in the decentralized channel. Under the Nash bargaining coordination contract, the platform usage rate increases in bargaining power $\boldsymbol{\mu}$. Excess profit depends on bargaining power. When the bargaining power increases, profit of the e-commerce platform increases, but the profit of the manufacturer decreases. Although the platform usage rate decreases under the Nash bargaining contract, both members obtained more profits than the decentralized case, achieving a win-win state. Under the Rubinstein bargaining coordination contract, the decentralized channel can also be coordinated. Each member's profit depends on the lowest profit bound and bargaining patience:

1) When the manufacturer is very patient, that is, $\boldsymbol{\delta}_M = 1$, no matter how the e-commerce platform's patience changes, the manufacturer plays a leading role in obtaining the most profit. Still, the e-commerce platform holds the same profit as in the decentralized channel. This is consistent with the first profit distribution scheme of Theorem 4.
2) When the e-commerce platform performs very patiently, i.e., $\boldsymbol{\delta}_R = 1$, they will get the most profit regardless of how

the manufacturer's patience changes. In contrast, the manufacturer obtains the same profit as in the decentralized channel, which is consistent with the second profit distribution scheme of Theorem 4.

3) When the patience of both sides of the game is higher (less than 1), two members will distribute profits proportionally, which is consistent with the third profit distribution scheme of Theorem 4. In this case, as the patience of both sides increases, the e-commerce platform's patience increases, while the manufacturer's profit decreases, showing that the e-commerce platform plays a leading role. This implies that the stronger the patience of the two members, the more profit the e-commerce platform will get.

Under the first distribution scheme of the Rubinstein bargaining contract, the manufacturer has the strongest degree of patience and the largest profit, which is consistent with the profit distribution scheme when $\boldsymbol{\mu} = 0$ under the Nash bargaining coordination contract. Under the second distribution scheme of the Rubinstein bargaining contract, the e-commerce platform has the strongest degree of patience. His profit is also the largest, and it is consistent with the profit distribution plan when $\boldsymbol{\mu} = 1$ under the Nash bargaining coordination contract. Profits of chain members are quite different under the first two distribution plans, but under the third distribution plan, the difference between members is relatively small.

Whether using the Nash or Rubinstein bargaining coordination contract, it all achieved the performance in a centralized channel. Although the platform usage rates of the two bargaining coordination contracts are both lower compared to the decentralized case, they still obtain more profit than the decentralized cases. The platform and the manufacturer get profits shared according to their bargaining power or patience, and their respective profits all come out higher than the decentralized channel. These two contracts coordinate the conflicts well in a decentralized supply chain, which achieves a win-win situation.

RESULT

During the COVID-19 pandemic, the supply chain has entered a new stage of convergence with e-commerce. Consignment contracts based on electronic markets have become the main development trend of corporate marketing in practice. In our paper, a green supply chain model under consignment contracts is studied. We compare and analyze the effects of a centralized channel and decentralized channel under consignment contracts on price, greenness, and total profit. the centralized channel is beneficial to improve the greenness of products and the profitability of the total supply chain. Not only the price, greenness, and profit of manufacturers are reduced, but also the research and development will be promoted.

In the decentralized channel, the competition of partners will lower the total channel's profit, and each member's profit. To improve the profits of chain members, effectively alleviate conflicts of interest between them, and promote the level of research and development, this paper proposes both Nash and Rubinstein bargaining contract of cooperative game to coordinate a chain model. Manufacturers and e-commerce platforms can negotiate prices, enhance coordination awareness, and reallocate overall profits. After determining a new optimal platform usage rate, they can obtain profits that are not lower than those under a decentralized channel, and achieve a win-win situation.

From the coordination analysis, we show that both the Nash and Rubinstein bargaining contracts can achieve coordination through the adjustment of platform usage rates. It can be seen from the numerical calculation that in Nash bargaining, both members in the supply chain will obtain higher profits as their bargaining power improves; in Rubinstein bargaining, the profits shared by both members in the supply chain are closely related to their respective degrees of patience. Compared with the decentralized channel, the e-commerce platform indirectly promotes the manufacturer to increase research and development by reducing platform usage rate, thereby increasing retail price, greenness, and total profits of the channel.

DISCUSSION

This paper discussed green supply chain coordination under bargaining contracts, which contains one e-commerce platform and one manufacturer. The results have practical significance in a socio-economic environment. Partners can obtain profits based on their bargaining power and patience. To get extra profits than the decentralized channel, they can choose a different bargaining contract to benefit themselves. Comparing to Wang et al. (2019), our model added the greenness into discussion, which extended the research area in green supply chain. But there still exist limitations, which will be the topic of future studies.

Limitations and Future Work

1) With regard to the complexity of our model, there are two members: one e-commerce platform and one green manufacturer. But in reality, there may be more participants in the channel. We aim to investigate the optimal decisions in the model, and to coordinate the decentralized channel by consignment contracts.
2) By the assumption of our paper, the model is static, and this can be extended to a dynamic one. Moreover, there exist uncertainty factors in the consumer market, such as product recommendations, credit payment discounts, advertisement, consumer preference, etc., so the demand function can be extended to a stochastic one.

3) In order to encourage the development of the green supply chain, governments across the world have unveiled "Environmental Economic and Policy." It turns out that the participation of government is very necessary. In our future work, we can consider the participation of government, such as subsidy or tax. Under this circumstance, enterprises will take active participation in greening products, protecting the environment, and achieving a win-win situation.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

YW issued the idea and designed for the research. YW and LZ analyzed the model and drafted the paper. GR and WD-M edited and revised the paper critically.

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