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Article

Research on retailer's pricing and stocking strategy in two-stage green supply chain considering bounded rationality and non-green product

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Abstract: Due to the bounded rationality of decision-makers and the substitution effect of non-green products, retailers are not always profitable when selling green products. To assist retailers who may be disadvantaged in the game, this study constructs a two-stage green supply chain game model, considering the bounded rationality of decision-makers and the substitution effect of non-green products, and analyzes the impacts of two operational strategies that retailers can adopt—price-cutting strategy and early replenishment strategy. The research reveals that retailers tend to lower prices in the second stage when price reductions stimulate consumer purchases, enhancing their profitability. However, strategic retailers may raise prices in the first stage to create room for discounts later, potentially harming consumer interests. Contrary to expectations, anticipating future demand does not always improve supply chain profitability in the early replenishment strategy, which mainly depends on the market environment. Early replenishment deprives retailers of negotiation leverage in the second stage, and bulk orders may lead manufacturers to over-invest in green innovation. Therefore, this strategy is effective only when green innovation costs are low, consumer environmental awareness is high, or price sensitivity is low.

Keywords: dynamic pricing; substitution effect; incomplete rationality; pre-stocking strategy; two-stage green supply chain

1. Introduction

In recent years, as the socio-economic landscape continues to evolve and people's living standards steadily improve, the focus of societal attention has gradually shifted from rapid development to high-quality development. Consequently, issues such as "green environmental protection", "ecology", and "energy conservation" have increasingly come into the public eye. To enhance competitive advantages and expand social influence, entrepreneurs are increasingly mindful of the environmental impact of their products and services (Ye and Zhou, 2021). Many companies are also actively producing more environmentally friendly products (Mahmoum et al., 2021). Challenges arise accordingly. Among which, the most significant one is that many enterprises are not clear whether green research and development can bring benefits to them (Sun et al., 2019).

As an important link connecting consumers and manufacturers, the retailers in green supply chains deserve special attention. Focusing on the interests of them, we have found that there are mainly the following factors that constrain retailers' profitability:

Firstly, retailers are boundedly rational. Decision-makers are limited by various factors in the decision-making process, such as the vagueness of objectives, the incompleteness of knowledge and information, and the limitations of reasoning and judgment abilities. Chow et al. (2014) studied the buyback supply contracts with risk-sensitive retailers under asymmetric information, and included the bounded rationality of enterprises in the supply chain into the research. Chen et al. (2013) analyzed the resource allocation game in the bounded rational supply chain consisting of a supplier and two retailers. The retailers chose their order sizes, and if the sizes exceeded their capacities, the supplier would allocate the production volume of the goods proportionally. Khanlarzade and Farughi (2024) studied the Stackelberg game of inventory deterioration in a two-level supply chain based on bounded rationality. Xi and Zhang (2020) studied pricing decisions, carbon emission reduction, and government subsidy intensity in the supply chain system, and investigated the competition model between the government and heterogeneous agricultural enterprises based on bounded rationality. All of the aforementioned studies pointed out the adverse impact of bounded rationality on supply chains.

Besides, as many functions of green products are not yet perfected, and there are a large number of substitutes in the consumer market, green products are not very effective in attracting consumers. At the same time, many studies focus on the impact of non-green products on green supply chains, and believe that the competition of non-green substitution benefits is the main factor leading to the decline of green products' competitiveness. Peng et al. (2022) studied pricing in dual-channel supply chains and competition and cooperation strategies in green marketing, considering customer satisfaction, and explored three cooperation models. Mahmoudi et al. (2021) constructed a dual-channel supply chain that produces both green and non-green products, exploring the impact of government intervention and third-party logistics on product pricing. They found that collaboration with third-party logistics companies can increase public awareness of environmental issues and promote the sustainable development of the supply chain. Song et al. (2022) compared three power structures in a supply chain that produces both green and non-green products: centralized decision-making, retailer-led decision-making, and manufacturer-led decision-making. Mondal and Giri (2024) studied bundling sales strategies in supply chains and found that the degree of product complementarity and bundling price discounts play an important role in determining appropriate bundling strategies.

Based on the above two issues, and in order to help retailers improve their profitability, this study constructs a two-stage green supply chain, considering the impact of bounded rationality and substitutes on the green supply chain, and proposes two operational strategies, pricing strategic and pre-stocking strategy, to help retailers increase profits.

2. Literature review

This study first explores the dynamic pricing in a two-stage supply chain and how to achieve profit maximization by setting different product prices at different stages of the game. Zhang and Liu (2021) constructed a two-stage dual-channel supply chain model based on consideration of public green preferences, comparing two dynamic pricing strategies: "pre-announced pricing" and "responsive pricing". Li and Rao (2021) studied the equilibrium decision-making and profit coordination methods of GPSC (Green Product Supply Chain), and found that pricing strategies have a significant impact on the profit levels of supply chain members, but have no effect on the green level of products. Ye et al. (2021) examined the aspect of low-carbon reputation and the extent of carbon footprint in products, adopting a dynamic viewpoint. They incorporated the Nash bargaining theory to devise a framework for equitable referencing, focusing on how collaborative efforts among supply chain participants, driven by a sense of fairness, can facilitate and harmonize the collective reduction of emissions within the supply chain system. Wang et al. (2021) emphasized the significance of demand shifts and consumer awareness towards environmental sustainability, introducing a mutually beneficial profit-sharing agreement to foster a cooperative relationship between manufacturers and retailers, ultimately aiming for a win-win outcome. He et al. (2024) explored the long-term dynamic coordination issues in the green building supply chain under different subsidies, and constructed a supply chain differential game model composed of developers and contractors with government participation from the perspective of long-term dynamic operation. Adenso-Díaz et al. (2017) proposed a deterministic mathematical model to address dynamic pricing strategies aimed at maintaining the freshness of perishable products through a parameterized bi-objective approach. Xu et al. (2016) investigated a differential game model, where product carbon emission reduction was affected by the manufacturer's green efforts. Jiang et al. (2017) provided a dynamic game model for advertising competition models considering promotions. Although these studies all explored dynamic pricing issues, none of them considered the impact of traditional products on the green supply chain or the scenario where retailers simultaneously adopt dynamic pricing strategies and early replenishment strategies.

Another operational strategy that this study explores to potentially improve retailers' profitability is the early replenishment strategy. Many existing studies have explored the scenario of improving supply chain operations by storing a certain amount of products. Qiu et al. (2022) introduced a robust optimization method to effectively handle multi-product inventory in dual-channel warehouses, considering the impact of uncertain demand. Saputro and Figueira (2020) proposed a comprehensive model for supplier selection considering inventory management and inbound transportation, and developed a method to mitigate supply disruptions. Dong and Liu (2021) proposed a two-stage model, revealing that manufacturers tend to maintain inventory levels, which is significant for supply chain decision-making and the overall profitability of all participants. Wang et al. (2020) found that under intense supplier competition, suppliers are more inclined to discourage retailers from holding inventory. However, none of the above studies have considered the impact of dynamic pricing strategies.

Based on the assumptions and limitations of existing research, this study constructs a two-stage green supply chain game model, and takes into account the bounded rationality of the supply chain and the influence of non-green products through mathematical modeling, and simultaneously considered the impact of both operational strategies of product promotion and early replenishment.

The main innovations of this study are as follows: 1) This study discusses the impact of manufacturers' bounded rationality, and on this basis, incorporates the game results of non-green supply chains into the research as substitution benefits for green products. 2) Simultaneously considered the impact of both operational strategies of product promotion and early replenishment.

3. Materials and methods

This paper studies a two-stage supply chain problem that consists of a traditional supply chain and a green supply chain. Each supply chain is composed of a supplier and a retailer and will go through two decision-making stages. Meanwhile, all decision-makers in the supply chain are bounded rational. Given that decision-makers are not always immune to emotional interference and are constrained by limited decision-making time, it is infeasible for them to make decisions from a completely rational perspective (McKelvey and Palfrey, 1995). So, at the beginning of each decision-making stage, both the manufacturer and the retailer make decisions solely with the aim of maximizing profits in the current stage.

In this model, the traditional supply chain and the green supply chain face potential green and traditional markets with sizes of a_t and a_g , respectively. Obviously, $a > 0$. At the beginning of the first stage, the traditional manufacturer and the green manufacturer, as the leaders in their respective supply chain games, simultaneously choose the degree of research and development and wholesale prices for their respective products. According to the research on corporate research and development costs conducted by Genc and De Giovanni (2020), Du et al. (2021), Cui Sun (2023), and many others in the past, the traditional manufacturer can obtain a non-green product with a service innovation degree of u after paying a research and development cost of $\theta_t = \frac{\alpha u^2}{2}$ through service innovation, and resell it to the retailer at a wholesale price of w_{1t}. Here, α represents the cost coefficient of corporate service innovation. Similarly, the green manufacturer can also obtain a green product with a greenness level of r after paying a research and development cost of $\theta_g = \frac{\beta r^2}{2}$, and resell it to the retailer at a wholesale price of w_{1g}. Here, β represents the cost coefficient of corporate green innovation. After observing the manufacturers' decisions, the retailer chooses the retail prices p_{1t} and p_{1g} for the traditional and green products, respectively. At the beginning of the second stage, the manufacturers continue to produce the products they innovated in the first stage and sell them to the retailer at wholesale prices of w_{2t} and w_{2g} for traditional and green products, respectively, while the retailer, as a follower in decision-making, chooses its retail prices p_{2t} and p_{2g}.

Drawing upon previous studies by Erkoc et al. (2022), Feng and Jin (2022), and others, we adopt a linear demand function to describe the impact of innovation and pricing, as expressed in the following equation:

$$q_{it} = a_t - p_{ti} + cu - k(i-1)(p_{2t} - p_{1t}) \tag{1}$$

$$q_{ig} = a_g - p_{gi} + br - k(i-1)\left(p_{2g} - p_{1g}\right) - ou \tag{2}$$

where $i = 1, 2$, represent the first stage and the second stage respectively. On the other hand, o represents the cross-influence coefficient of traditional products on the green supply chain, reflecting the extent to which the demand for green products is affected by their inferior practicality compared to traditional products. Therefore, we assume that $o > 0$. The symbol b denotes consumers' green sensitivity, or their awareness of environmental sustainability. This implies that as consumers' green consciousness increases, they are more likely to purchase green products. Obviously, $b > 0$. The parameter c represents the sensitivity of consumers to the degree of service innovation in the product. Evidently, consumers with higher sensitivity are more willing to pay for a company's service innovation efforts. In production practices, it is generally assumed that no consumers dislike more innovative products, hence we assume that $c > 0$. To explore the impact of retailers adopting promotional strategies, we assume that in the second stage, consumers not only pay attention to the current price of the product, but also focus on the difference between the current price and the price in the previous stage. If the product price is lower than that in the previous stage, it will have a stimulatory effect on demand. Where $j = t$ or g represents the traditional products and green products. The coefficient k represents the sensitivity of consumers to price changes. Here, we assume that $k > 0$, which means that consumers are more interested in price cuts than price hikes. This assumption is obviously in line with most scenarios. Drawing on the research by Zhang et al. (2021) and others, we assume that the impact of price changes on demand is represented by $k(p_{2j} - p_{1j})$, where k is the sensitivity coefficient of consumers to price changes. For the purpose of facilitating discussion, we assume that $k > 0$ and $k < 1$ to ensure that consumers pay more attention to current prices rather than price fluctuations. It is not difficult to find that the scenario of $k = 0$ refers to the case where the retailer does not adopt a price-cutting strategy.

Based on the above assumptions, we can derive the profit functions of manufacturers (*M*) and retailer (*R*) in the supply chain, as shown below:

$$M_{it} = q_{it}w_{it} + (i-2)\theta_t \tag{3}$$

$$M_{ig} = q_{ig}w_{ig} + (i-2)\theta_g \tag{4}$$

$$R_{ij} = q_{ij}p_{ij} \tag{5}$$

By applying backward induction to solve the above equations, when $\beta > \frac{b^2}{4}$, the Hessian matrix of green Manufacturer's objective function in the first stage is strictly positive definite. At this point, we can obtain the optimal decisions for each participant in the game at each stage. The optimal pricing and the optimal level of green innovation for the product are specifically described as follows:

$$r^{NS} = \frac{b\left(a_g c^2 + a_t oc - 4a_g\alpha\right)}{(-c^2 + 4\alpha)(b^2 - 4\beta)} \tag{6}$$

$$p_{1g}^{NS} = \frac{3\beta\left(a_1 c^2 + a_2 oc - 4a_g\alpha\right)}{(-c^2 + 4\alpha)(b^2 - 4\beta)} \tag{7}$$

$$p_{2g}^{NS} = \frac{3\beta(3k+4)\left(a_g c^2 + a_t oc - 4a_g\alpha\right)}{4(k+1)(-c^2 + 4\alpha)(b^2 - 4\beta)} \tag{8}$$

1) The Dilemma of Green Manufacturers

Only when $a_g c^2 + a_t oc - 4a_g\alpha < 0$, that is, $ou^* < a_g$, can there be an optimal solution for the level of green innovation and pricing of green products. This can be interpreted as follows: since green consumers will consider the utility of products when purchasing green products, when the utility of traditional products is much higher than that of green products, or when green products are too impractical, consumers will be discouraged from purchasing green products. This also means that products that are only environmentally friendly but lack practicality will not be accepted by the market. For the sake of simplicity, we will only discuss the scenario where $a_g c^2 + a_t oc - 4a_g \alpha < 0$ in the following subsections.

4. Model 2—Retailers adopting pre-stocking strategy

In this section, we will explore a possible method to promote green enterprises to carry out green research and development—pre-stocking strategy. Assuming that the green retailer reasonably predicts the market demand for the next two stages and purchases all the required products at the wholesale price w_1 in the first stage, it then makes decisions with the aim of maximizing profits in both stages. For the convenience of discussion, we do not consider the storage costs resulting from over-purchasing products. Actually, as a party directly in contact with the consumer market, retailers have stronger incentives to predict future market demand. The remaining assumptions remain unchanged. Based on this, the profit functions of the green retailer and green manufacturer can be respectively expressed as:

$$R_g^S = q_{1g}\left(p_{1g} - w_1\right) + \left(p_{2g} - w_1\right)q_{2g} \tag{9}$$

$$M_g^S = \left(q_{1g} + q_{2g}\right)w_1 - \frac{\beta r^2}{2} \tag{10}$$

In this model, at the beginning of the first stage, the manufacturer first selects the wholesale price w_1 and the greenness level r of the product, incurring green research and development costs ε_i. Using backward induction, we can determine the order of solving this model. First, we solve for the optimal decisions in the second stage. During the second stage, the decisions of the first stage have already been made, so the relevant decision variables are known values. When $\beta > \frac{(k+1)2b^2}{-k^2+4k+4}$, the Hessian matrix of the green manufacturer's objective function is strictly positive definite. Obviously, $\frac{2(k+1)}{-k^2+4k+4} > \frac{1}{4}$, that is to say, when the optimality of this model is satisfied, the optimality of Model 1 will also be satisfied. In fact, in this reach, it is easy to prove that $\frac{2(k+1)}{-k^2+4k+4} \in (0.5, 0.5714)$. That is to say, $\beta > \frac{b^2}{2}$. At this point, the optimal decisions of each participant in the supply chain can be obtained, and the optimal pricing and optimal level of green innovation for the product are specifically described as follows:

$$r^S = \frac{2b(k+1)\left(a_g c^2 + a_t oc - 4a_g \alpha\right)}{(-c^2+4\alpha)(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)} \tag{11}$$

$$p_{1g}^S = \frac{\beta(-k^2+7k+6)\left(a_g c^2 + a_t oc - 4a_g \alpha\right)}{2(4\alpha - c^2)(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)} \tag{12}$$

$$p_{2g}^S = \frac{\beta(-k^2+5k+6)\left(a_g c^2 + a_t oc - 4a_g \alpha\right)}{2(4\alpha - c^2)(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)} \tag{13}$$

5. Mathematical analysis

5.1. Subsection optimal promotional strategy

Theorem 1. *Optimal marketing strategy* *a)* $p_{1g}^{NS} - p_{2g}^{NS} = \frac{3\beta(a_g c^2 + a_t oc - 4a_g\alpha)}{(-c^2+4\alpha)(b^2-4\beta)} \cdot \frac{k}{4(k+1)} > 0$, *when* $k = 0, p_{1g}^{NS} - p_{2g}^{NS} = 0$

b) $p_{1g}^{S} - p_{2g}^{S} = \frac{k\beta(a_g c^2 + a_t oc - 4a_g\alpha)}{(-c^2+4\alpha)(-4\beta k - 4\beta + 42b^2k + \beta k^2 + 2b^2)} > 0$ *when* $k = 0, p_{1g}^{S} - p_{2g}^{S} = 0$

c) $\frac{\partial M_g^{NS}}{\partial k} = \frac{\beta(a_g c^2 + a_t oc - 4a_g\alpha)^2}{(4\alpha - c^2)^2} \cdot \frac{(\beta(9k^2+18k+8))}{(8(4\beta-b^2)^2(k+1)^2)} > 0$, $\frac{\partial M_g^{S}}{\partial k} = \frac{\beta(a_g c^2 + a_t oc - 4a_g\alpha)^2}{(4\alpha - c^2)^2} \cdot \frac{\beta k(k+2)}{(-4\beta - 4\beta k + 2b^2k + \beta k^2 + 2b^2)^2} > 0$

d) $\frac{\partial R_g^{NS}}{\partial k} = \frac{\beta^2(-a_g c^2 - a_t oc + 4a_g\alpha)^2}{2(4\alpha - c^2)^2} \cdot \frac{9k^2+18k+8}{8(4\beta-b^2)^2(k+1)^2} > 0$, $\frac{\partial R_g^{S}}{\partial k} = \frac{\beta^2(-a_g c^2 - a_t oc + 4a_g\alpha)^2}{2(4\alpha - c^2)^2} \cdot \frac{k(k+2)(2b^2k + 2b^2 - \beta k^2 + 4\beta k + 4\beta)}{(4\beta + 4\beta k - 2b^2k - \beta k^2 - 2b^2)^3} > 0$

e) $\frac{\partial p_{1g}^{NS}}{\partial k} = 0, \frac{\partial p_{2g}^{NS}}{\partial k} < 0$

f) $\frac{\partial p_{1g}^{S}}{\partial k} = \frac{\beta(-a_g c^2 - a_t oc + 4a_g\alpha)}{2(4\alpha - c^2)} \cdot \frac{2b^2k^2 + 4b^2k - 2b^2 + 3\beta k^2 + 4\beta k + 4\beta}{(-4\beta - 4\beta k + 2b^2k + \beta k^2 + 2b^2)^2} > 0$

g) $\frac{\partial p_{2g}^{S}}{\partial k} = \frac{\beta(-a_g c^2 - a_t oc + 4a_g\alpha)}{2(4\alpha - c^2)} \cdot \frac{2b^2k^2 + 4b^2k + 2b^2 + \beta k^2 + 4\beta k - 4\beta}{(-4\beta - 4\beta k + 2b^2k + \beta k^2 + 2b^2)^2}$, $\frac{\partial p_{2g}^{S}}{\partial k} > 0$ *when* $\beta < -(2b^2k^2 + 4b^2k + 2b^2)/(k^2 + 4k - 4)$, $\frac{\partial p_{2g}^{S}}{\partial k} < 0$ *when* $\beta > -(2b^2k^2 + 4b^2k + 2b^2)/(k^2 + 4k - 4)$.

Theorem 1 indicates that when price-cutting strategies promote consumers' purchasing behavior, retailers always tend to adopt this operational strategy. This is probably because discounts have a far greater effect on promoting consumption than the losses caused by price reductions. As for situations where discounts have a smaller stimulating effect on demand, retailers only need to adjust the magnitude of the price reduction. In other words, retailers can always choose the most suitable discount rate based on the external environment. In addition, since the scenario of $k = 0$ also represents the case where the retailer does not adopt a price-cutting strategy, Theorem 1(c) and Theorem 1(d) also indicate that when consumers are interested in discounts, the price-cutting strategy is always beneficial for the green supply chain to improve its profitability. Moreover, as consumers become more sensitive to price changes, the ability of price-cutting strategies to improve the profitability of the supply chain also increases. This perhaps suggests that achieving price reduction is not just the responsibility of retailers. Manufacturers also have sufficient incentives to help retailers achieve price reduction, as long as this behavior can attract consumers. Interestingly, in Model 2, strategic retailers will cater to consumers' preference for promotions by raising product prices in the first stage in advance, rather than truly cutting prices.

In production, enterprises should actively adopt pricing strategies and set different prices at different stages to maintain their profits. Meanwhile, it is also necessary for consumer groups to be aware of the real reasons behind the changes in product prices in order to maximize consumer utility.

5.2. Impact of traditional supply chains

Theorem 2. *Impact of traditional supply chains* *a)* $\frac{\partial r^{NS}}{\partial a_2}=\frac{-boc}{(-c^2+4\alpha)(-b^2+4\beta)}<0,\frac{\partial r^{S}}{\partial a_2}=\frac{-2b(k+1)oc}{(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0,\frac{\partial r^{NS}}{\partial o}=\frac{-ba_2c}{(-c^2+4\alpha)(-b^2+4\beta)}<0,\frac{\partial r^{S}}{\partial o}=\frac{-2b(k+1)a_2c}{(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0$

b) $\frac{\partial r^{NS}}{\partial c}=\frac{-ba_2o}{(-c^2+4\alpha)(-b^2+4\beta)}<0,\frac{\partial r^{S}}{\partial o}=\frac{-2b(k+1)a_2o}{(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0$

c) $\frac{\partial r^{NS}}{\partial \alpha}=\frac{4ba_2oc}{(-c^2+4\alpha)^2(-b^2+4\beta)}>0,\frac{\partial r^{S}}{\partial \alpha}=\frac{8b(k+1)a_2oc}{(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}>0.$

Theorems 2(a) to (c) indicate that as the market size of traditional products expands, consumer sensitivity to product services increases, and cross-sensitivity rises, the degree of energy-saving and environmental innovation in green products will decrease accordingly. It is not difficult to observe that under any scenario, the degree of green innovation exhibits an opposite trend to the development of traditional products. This is because traditional products and green products share certain similarities, and the development of traditional products to some extent weakens consumers' willingness to purchase. Therefore, when traditional products gain momentum, the development of green products will be hindered. Conversely, when the development of traditional products is impeded, green products can enjoy further growth. The development of the two types of products exhibits a contradictory nature.

Theorem 3. *Impact of traditional supply chains on pricing*

a) $\frac{\partial p_{1g}^{NS}}{\partial a_2}=\frac{-3\beta oc}{(-c^2+4\alpha)(-b^2+4\beta)}<0,\frac{\partial p_{2g}^{NS}}{\partial a_2}=\frac{-3\beta(3k+4)oc}{(-c^2+4\alpha)(k+1)(-b^2+4\beta)}<0,\frac{\partial p_{1g}^{S}}{\partial a_2}=\frac{-\beta\left(-k^2+7k+6\right)oc}{2(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0,\frac{\partial p_{2g}^{S}}{\partial a_2}=\frac{-\beta\left(-k^2+5k+6\right)oc}{2(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0$

b) $\frac{\partial p_{1g}^{NS}}{\partial o}=\frac{-3\beta a_tc}{(-c^2+4\alpha)(-b^2+4\beta)}<0,\frac{\partial p_{2g}^{NS}}{\partial o}=\frac{-3\beta(3k+4)a_tc}{(-c^2+4\alpha)(k+1)(-b^2+4\beta)}<0,\frac{\partial p_{1g}^{S}}{\partial o}=\frac{-\beta\left(-k^2+7k+6\right)a_tc}{2(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0,\frac{\partial p_{2g}^{S}}{\partial o}=\frac{-\beta\left(-k^2+5k+6\right)a_tc}{2(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0$

c) $\frac{\partial p_{1g}^{NS}}{\partial c}=\frac{-3\beta a_to}{(-c^2+4\alpha)(-b^2+4\beta)}<0,\frac{\partial p_{2g}^{NS}}{\partial c}=\frac{-3\beta(3k+4)a_to}{(-c^2+4\alpha)(k+1)(-b^2+4\beta)}<0,\frac{\partial p_{1g}^{S}}{\partial c}=\frac{-\beta\left(-k^2+7k+6\right)a_to}{2(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0,\frac{\partial p_{2g}^{S}}{\partial c}=\frac{-\beta\left(-k^2+5k+6\right)a_to}{2(-c^2+4\alpha)(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}<0$

d) $\frac{\partial p_{1g}^{N}}{\partial \alpha}=\frac{3\beta a_toc}{(-c^2+4\alpha)^2(-b^2+4\beta)}>0,\frac{\partial p_{2g}^{N}}{\partial \alpha}=\frac{3\beta(3k+4)a_toc}{(-c^2+4\alpha)^2(k+1)(-b^2+4\beta)}>0,\frac{\partial p_{1g}^{S}}{\partial \alpha}=\frac{\beta\left(-k^2+7k+6\right)a_toc}{2(-c^2+4\alpha)^2(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}>0,\frac{\partial p_{2g}^{S}}{\partial \alpha}=\frac{\beta\left(-k^2+5k+6\right)a_toc}{2(-c^2+4\alpha)^2(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}>0.$

Theorems 3(a) to (d) suggest that as the market size of traditional products expands, consumer sensitivity to product services increases, and cross-sensitivity rises, the prices of green supply chain products will be forced to decline. This may be because the expansion of the traditional market and consumers' increasing focus on services enhance the competitive advantages of traditional products, thus forcing green products to maintain their competitiveness through price cuts. On the other hand, as the cost coefficient for service innovation in traditional products increases, indicating a greater difficulty in innovating traditional product services, the prices of green products exhibit an upward trend. This may also be a manifestation of the development bottleneck faced by traditional products.

5.3. Impact of pre-stocking strategy

Theorem 4. *Impact of promotional strategy on optimal innovation*

a) $r^{SR} - r^{NR} > 0$.

Proof of Theorem 4. $r^{S} - r^{NS} = \frac{b\beta(k+2)^2(a_g c^2 + a_t oc - 4a_g\alpha)}{(-c^2+4\alpha)(-b^2+4\beta)(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)}$

where $-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2 < 0$, $-b^2 + 4\beta > 0$. So $r^{SR} - r^{NR} > 0$. □

Theorem 4 states that when retailers adopt the pre-stocking strategy, manufacturers always tend to increase the green research and development level of their products. This may be because retailers concentrate their ordering behavior in the first stage of the game, when product green innovation occurs. At this point, for manufacturers, the market demand has greatly expanded, so they have more incentive to engage in green innovation, even though they are not aware that retailers will no longer purchase their products in the second stage of the game.

Theorem 5. *Impact of promotional strategy on pricing*

a) $p_{1g}^{S} - p_{1g}^{NS} > 0$

b) $p_{2g}^{S} - p_{2g}^{NS} > 0$.

Proof of Theorem 5.

$$p_{1g}^{S} - p_{1g}^{NS} = \frac{\beta(-k^2+7k+6)(a_g c^2 + a_t oc - 4a_g\alpha)}{2(4\alpha - c^2)(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)} - \frac{3\beta(a_g c^2 + a_t oc - 4a_g\alpha)}{(-c^2+4\alpha)(b^2-4\beta)} = \beta\frac{(a_g c^2 + a_t oc - 4a_g\alpha)}{(4\alpha - c^2)}\left(\frac{(-k^2+7k+6)}{2((k+1)2b^2 - (4+4k-k^2)\beta)} - \frac{3}{(b^2-4\beta)}\right)$$ where:

$$\frac{(-k^2+7k+6)}{2((k+1)2b^2 - (4+4k-k^2)\beta)} - \frac{3}{(b^2-4\beta)} = \frac{(-k^2+7k+6)(b^2-4\beta) - 12(k+1)b^2 + 6(4+4k-k^2)\beta}{2((k+1)2b^2 - (4+4k-k^2)\beta)(b^2-4\beta)}$$

And $(-k^2+7k+6)(b^2-4\beta) - (12(k+1)b^2 - 6(4+4k-k^2)\beta) = ((-k^2+7k+6) - 12(k+1))b^2 - (4(-k^2+7k+6) - 6(4+4k-k^2))\beta = (-k^2-5k-6)b^2 - \beta(2k^2+4k) < 0$

$$p_{21}^{S} - p_{21}^{NS} = \frac{\beta(-k^2+5k+6)(a_g c^2 + a_t oc - 4a_g\alpha)}{2(4\alpha - c^2)(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)} - \frac{3\beta(3k+4)(a_g c^2 + a_t oc - 4a_g\alpha)}{4(k+1)(-c^2+4\alpha)(b^2-4\beta)} = \frac{\beta(a_g c^2 + a_t oc - 4a_g\alpha)}{2(4\alpha - c^2)}\left(\frac{(-k^2+5k+6)}{(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)} - \frac{3(3k+4)}{2(k+1)(b^2-4\beta)}\right)$$

where $\frac{(-k^2+5k+6)}{(-4\beta k-4\beta+2b^2k+\beta k^2+2b^2)}-\frac{3(3k+4)}{2(k+1)(b^2-4\beta)}=\frac{2(k+1)(b^2-4\beta)(-k^2+5k+6)-3(3k+4)\left((k+1)2b^2-(4+4k-k^2)\beta\right)}{4(k+1)(b^2-4\beta)\left((k+1)2b^2-(4+4k-k^2)\beta\right)}$, and $2(k+1)(b^2-4\beta)(-k^2+5k+6)-6(3k+4)(k+1)b^2+3(3k+4)(4+4k-k^2)\beta=\left(2(k+1)(-k^2+5k+6)-6(3k+4)(k+1)\right)b^2-\left(8(k+1)(-k^2+5k+6)-3(3k+4)(4+4k-k^2)\right)\beta=(-2k^3-10k^2-20k-12)b^2-k(k^2+8k+4)\,\beta<0$. □

Theorem 5 points out that the early order strategy always leads to an increase in the retail price of the product. This may be because the early order strategy greatly stimulates manufacturers' investment in research and development, which in turn raises the cost of the product, causing consumers to pay more for the retailer's behavior. However, from another perspective, the increase in product greenness also greatly stimulates market demand, making consumers more willing to pay for the product.

Theorem 6. *The impact of green innovation costs on pre-stocking strategy*

a) $\frac{\partial(R^{S*}-R^{NS*})}{\partial\beta}<0$

b) $\frac{\partial(M^{S*}-M^{NS*})}{\partial\beta}<0$.

Proof of Theorem 6. $\frac{\partial(R^{S*}-R^{NS*})}{\partial\beta}=\frac{(a_gc^2+a_toc-4a_g\alpha)^2}{2(4\alpha-c^2)^2}\left(\frac{2\beta(-k^3+3k^2+8k+4)(-4\beta-4\beta k+2b^2k+\beta k^2+2b^2)^2-\beta^2 2(-4\beta-4\beta k+2b^2k+\beta k^2+2b^2)V}{(-4\beta-4\beta k+2b^2k+\beta k^2+2b^2)^4}-\frac{16\beta(9k^2+40k+32)(4\beta-b^2)^2(k+1)-\beta^2 64(4\beta-b^2)(k+1)}{64(4\beta-b^2)^4(k+1)^2}\right)$

where $V=(-4-4k+2\beta k)$

and $\frac{2\beta(-k^3+3k^2+8k+4)}{(-4\beta-4\beta k+2b^2k+\beta k^2+2b^2)^2}-\frac{\beta^2V}{(-4\beta-4\beta k+2b^2k+\beta k^2+2b^2)^3}+\frac{\beta^2}{(4\beta-b^2)^3(k+1)}-\frac{2\beta(9k^2+40k+32)}{8(4\beta-b^2)^2(k+1)}<+\frac{\beta^2-\beta^2(-4-4k+2\beta k)(k+1)}{(4\beta-b^2)^3(k+1)}+\frac{16\beta(-k^3+3k^2+8k+4)(k+1)}{8(4\beta-b^2)^2(k+1)}-\frac{2\beta(9k^2+40k+32)}{8(4\beta-b^2)^2(k+1)}=\frac{\beta^2-\beta^2(-4-4k+2\beta k)(k+1)}{(4\beta-b^2)^3(k+1)}+\frac{16\beta(-k^3+3k^2+8k+4)(k+1)(4\beta-b^2)}{8(4\beta-b^2)^3(k+1)}-\frac{2\beta(9k^2+40k+32)(4\beta-b^2)}{8(4\beta-b^2)^2(k+1)}$. □

It is easy to know that there exists a β^* that when $\beta<\beta^*$, the above formula is bigger than zero, when $\beta>\beta^*$, the above formula is smaller than zero, so when $\beta>\beta^*$, $\frac{\partial(R^{S*}-R^{NS*})}{\partial\beta}<0$.

Besides, it is easy to know, $\beta^*<\frac{(k+1)2b^2}{-k^2+4k+4}$, so, $\frac{\partial(R^{S*}-R^{NS*})}{\partial\beta}<0$

$$M^{S*}-M^{NS*}=\frac{\beta(a_gc^2+a_toc-4a_g\alpha)^2}{(4\alpha-c^2)^2}\left(\frac{k+1}{-2b^2k-2b^2-\beta k^2+4\beta k+4\beta}-\frac{-4b^2k-4b^2+9\beta k^2+40\beta k+32\beta}{8(4\beta-b^2)^2(k+1)}\right)$$

$$\frac{\partial(M^{S*}-M^{NS*})}{\partial\beta}=\frac{(a_gc^2+a_toc-4a_g\alpha)^2}{(4\alpha-c^2)^2}\left(\frac{(k+1)}{(-2b^2k-2b^2-\beta k^2+4\beta k+4\beta)}-\frac{\beta(k+1)(-k^2+4k+4)}{(-2b^2k-2b^2-\beta k^2+4\beta k+4\beta)^2}+\frac{(-4b^2k-4b^2+9\beta k^2+40\beta k+32\beta)}{(4\beta-b^2)^3(k+1)}-\frac{(-4b^2k-4b^2+18\beta k^2+80\beta k+64\beta)}{8(4\beta-b^2)^2(k+1)}\right)$$

where $\frac{(k+1)}{(-2b^2k-2b^2-\beta k^2+4\beta k+4\beta)}-\frac{\beta(k+1)(-k^2+4k+4)}{(-2b^2k-2b^2-\beta k^2+4\beta k+4\beta)^2}-\frac{(-9k^2+40k+32)}{8(4\beta-b^2)^2(k+1)}+\frac{(-4b^2k-4b^2+9\beta k^2+40\beta k+32\beta)64}{8(4\beta-b^2)^3(k+1)}<\frac{(k+1)}{(4\beta-b^2)}-\frac{\beta(k+1)(-k^2+4k+4)}{(-2b^2k-2b^2-\beta k^2+4\beta k+4\beta)^2}-\frac{(-9k^2+40k+32)}{8(4\beta-b^2)^2(k+1)}+\frac{(-4b^2k-4b^2+9\beta k^2+40\beta k+32\beta)64}{8(4\beta-b^2)^3(k+1)}<0$.

Theorem 7. *The impact of green awareness on pre-stocking strategy*

a) $\frac{\partial(M^{S*}-M^{NS*})}{\partial b}>0$,

b) $\frac{\partial(R^{S*}-R^{NS*})}{\partial b}>0$.

Proof of Theorem 7.

$M^{S*}-M^{NS*}=\frac{\beta(a_gc^2+a_toc-4a_g\alpha)^2}{(4\alpha-c^2)^2}\left(\frac{k+1}{-2b^2k-2b^2-\beta k^2+4\beta k+4\beta}-\frac{-4b^2k-4b^2+9\beta k^2+40\beta k+32\beta}{8(4\beta-b^2)^2(k+1)}\right)$, where $\frac{k+1}{-2b^2k-2b^2-\beta k^2+4\beta k+4\beta}-\frac{-4b^2k-4b^2+9\beta k^2+40\beta k+32\beta}{8(4\beta-b^2)^2(k+1)}$ it is easy to know $\frac{\partial\frac{k+1}{-2b^2k-2b^2-\beta k^2+4\beta k+4\beta}}{\partial b}>0$, $\frac{\partial\frac{-4b^2k-4b^2+9\beta k^2+40\beta k+32\beta}{8(4\beta-b^2)^2(k+1)}}{\partial b}<0$, so $\frac{\partial(M^{S*}-M^{NS*})}{\partial b}>0$. □

Theorem 8. *The impact of sensitivity to price changes on pre-stocking strategy*

a) $\frac{\partial(M^{S*}-M^{NS*})}{\partial k}<0$

b) $\frac{\partial(R^{S*}-R^{NS*})}{\partial k}<0$.

Proof of Theorem 8.

$\frac{\partial(M^{S*}-M^{NS*})}{\partial k}=\frac{\beta(a_gc^2+a_toc-4a_g\alpha)^2}{(4\alpha-c^2)^2}\left(\frac{2\beta k-3\beta k^2}{(-2b^2k-2b^2-\beta k^2+4\beta k+4\beta)^2}-\frac{\beta(9k^2+18k+8)}{8(4\beta-b^2)^2(k+1)^2}\right)<0$. □

Theorem 9. *The impact of pre-stocking strategy on profits*

a) $R^{S*}-R^{NS*}>0$, *when* $\beta<\beta^S$, $R^{S*}-R^{NS*}<0$ *when* $\beta>\beta^S$

b) $M^{S*}-M^{NS*}<0$ *when* $b<b^S$, $M^{S*}-M^{NS*}>0$ *when* $b>b^S$.

Proof of Theorem 9.

$$R^{S*}-R^{NS*}=\frac{\beta^2(a_gc^2+a_toc-4a_g\alpha)^2(-k^3+3k^2+8k+4)}{2(4\alpha-c^2)^2(-4\beta-4\beta k+2b^2\mathrm{k}+\beta k^2+2b^2)^2}-\frac{\beta^2(9k^2+40k+32)(a_gc^2+a_toc-4a_g\alpha)^2}{16(4\beta-b^2)^2(4\alpha-c^2)^2(k+1)}$$

$=\frac{\beta^2(-a_gc^2-a_toc+4a_g\alpha)^2}{2(4\alpha-c^2)^2}\left(\frac{-k^3+3k^2+8k+4}{(4\beta+4\beta k-2b^2\mathrm{k}-\beta k^2-2b^2)^2}-\frac{9k^2+40k+32}{8(4\beta-b^2)^2(k+1)}\right)$. □

Because $R^{S*} - R^{NS*}$ decreases as β increases, increases as b increases, and decreases as k increases. When $b = 0$ and $k = 1$, there exists a β that makes $R^{S*} - R^{NS*} < 0$. When $b = 1$ and $k = 0$, there exists a beta that makes $R^{S*} - R^{NS*} > 0$. Therefore, there exists a β^S that makes $R^{S*} - R^{NS*} = 0$. The same with $M^{S*} - M^{NS*}$.

Theorems 6 to 9 point out the influence of the external market environment on the early order strategy and when it should be adopted. The study found that contrary to intuition, arranging sales plans ahead of time through reasonable expectations for the future does not always improve profitability. A reasonable order strategy should be chosen based on changes in the external market environment. When consumers have a high awareness of greenness, the early order strategy helps improve the profitability of all participants in the green supply chain. This may be because the early order strategy greatly increases the market demand faced by manufacturers in the first stage, although at this point manufacturers are not aware of the retailer's true intentions. Stimulated by this external condition, manufacturers greatly increase the green innovation level of green products. And consumers who pay more attention to the environmental attributes of goods are obviously more willing to pay for it.

At the same time, the increase in green research and development costs and consumers' increased sensitivity to price changes will be unfavorable for retailers to continue adopting the early order strategy. It is not difficult to find that because the early order strategy will lead to blind investment in green research and development by manufacturers in the first stage, the increase in green research and development costs greatly increases the cost of the product, which in turn limits the retailer's profitability and ultimately leads the retailer to abandon this strategy. For retailers, consumers paying more attention to price changes should have helped them adopt the early order strategy. Unfortunately, however, because retailers lose the opportunity to renegotiate with manufacturers in the second stage, their ability to adopt a price-cutting strategy in the second stage is also reduced. As a result, retailers may be better off giving up market prediction and renegotiating with manufacturers in the second stage rather than adopting the early order strategy. Or, as consumers become more sensitive to price changes, the ability of price-cutting strategies to increase profits gradually surpasses the early order strategy. At this point, retailers should retain the bargaining power in the second stage to gain more pricing flexibility to implement price-cutting strategies, rather than losing more opportunities for price cuts by adopting the early order strategy.

In summary, enterprises should scientifically choose operational strategies based on the external market environment, and no strategy is necessarily superior to another. The use of one strategy may also indirectly deprive the enterprise of the opportunity to use another strategy, leading to suboptimal profitability. At the same time, the profitability of the supply chain also exhibits significant negative externalities. The environmentally optimal production method for enterprises may not necessarily be the most profitable production method for them. Therefore, it is also necessary for the government to strengthen its guidance to enterprises and help them adopt appropriate business strategies to achieve a win-win situation.

6. Model 3—An extended model, advance purchase strategy considering market fluctuation risks

In this section, we will continue to explore the situation of uncertain market size in the second stage. Similar to Model 2, the retailer chooses to order goods in advance in the first stage. However, in this section, we assume that the market size a' in the second stage is uncertain and follows a uniform distribution of $(a - \Delta a, a + \Delta a)$.

At the beginning of the first stage, the retailer believes that the potential market size for the next two stages is a_g. After deciding on the retail prices p_{1g} and p_{2g} for the products in the next two stages, the retailer will purchase all the goods from the manufacturer at the wholesale price w_{1g} in a one-time deal. When the second stage begins, the market size changes to a', and the retailer reselects the retail price p_{2g} of the products in the second stage with the goal of maximizing profits and sells the remaining goods. The other assumptions are the same as those in Model 2. For the convenience of discussion, this study does not consider storage costs and replenishment issues in the second stage, which may be a direction for future research expansion.

When $\beta > \frac{(k+1)2b^2}{-k^2+4k+4}$, the Hessian matrix of the green manufacturer's objective function is strictly positive definite. At this point, the optimal decisions of each decision-maker can be obtained through backward induction. Among them, the optimal green innovation level of the manufacturer and the optimal green product pricing in the first stage are the same as those in Model 2, as shown below:

$$r^V = \frac{2b(k+1)\left(a_g c^2 + a_t oc - 4a_g \alpha\right)}{(-c^2+4\alpha)(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)} \tag{14}$$

$$p_{1g}^V = \frac{\beta(-k^2+7k+6)\left(a_g c^2 + a_t oc - 4a_g \alpha\right)}{2(4\alpha - c^2)(-4\beta k - 4\beta + 2b^2 k + \beta k^2 + 2b^2)} \tag{15}$$

7. Numerical experiment

To further explore additional management insights and verify the authenticity of the model, we conduct numerical experiments in this section. Following Zhang et al. (2021) and Khorshidvand (1999) we set $k = c = 0.5, \alpha = \beta = 2$. Referring to He (2022), we assign $a_g = a_t = 60$ (unit/year), $b = 0.5, o = 0.15$. For simplify, we assume that Δa = 15. Using these parameters, we can obtain the optimal decisions and profit comparisons for the supply chain, as summarized in **Table 1**.

Table 1. The optimal decisions and profit comparisons for the supply chain.

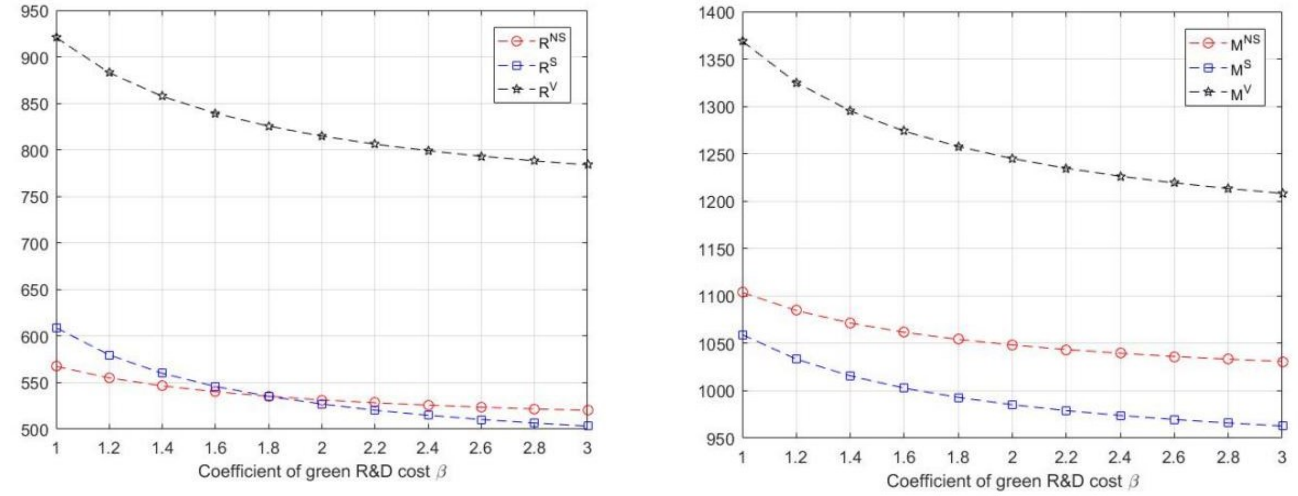
	Non-Strategic	Strategic	Risk
r	3.83	8.29	8.29
p_{1g}	46.00	51.28	51.28
p_{2g}	42.17	45.61	34.71
M_g	1048.29	985.30	1244.91
R_g	531.50	527.02	814.78

As can be seen from **Table 1**, just as previously demonstrated, the early order strategy can help promote green innovation behavior in the green supply chain, but it does not necessarily contribute to profitability, and this behavior will increase the product's selling price to a certain extent. Perhaps neither consumers nor businesses want to see this. This is probably because when retailers adopt the strategy of purchasing in advance, the first-stage order quantity faced by manufacturers increases. Therefore, this behavior will inevitably lead to more investment in green product research and development by manufacturers. However, under given conditions, the green R&D cost coefficient is high, and consumers' preference for product greenness is low. The blind investment behavior of manufacturers weakens the profitability of the supply chain in the second stage, which leads to a decline in the total profits of participants in the green supply chain in both stages. Therefore, in actual production, retailers should actively choose operational strategies based on the external market environment. When the external environment is friendly, retailers can maximize profits by purchasing large quantities in advance, which also helps the supply chain develop in a more energy-saving and environmentally friendly direction. However, when the external environment is less friendly, retailers should also give up purchasing in advance to avoid sending wrong market signals to the upstream supply chain. However, to some extent, governments that adhere to environmental protection responsibilities may hope that retailers adopt more early order strategies.

In addition, in this study, the expected revenue of Model 3 is much higher than that of Model 1 and Model 2. This may be because the revenue brought by the expansion of the market size is much higher than the loss caused by the shrinkage of the market size. This also means that when the market prospects are bright, enterprises should be more active in estimating future demand and preparing for it accordingly. Since the first stage of Model 3 is the same as Model 2, the pricing and green innovation level in the first stage of Model 3 are identical to Model 2. However, due to the impact of market uncertainty, the product pricing in the second stage of Model 3 is significantly lower than Model 2.

7.1. The impact of green innovation costs on profits

Figure 1 points out that, as previously demonstrated, when research and development costs are low, retailers will be more inclined to adopt the early order strategy. However, as the difficulty of green innovation continues to increase, the extra revenue generated by the early order strategy continues to decrease and ultimately falls below the base model. This may be because manufacturers make decisions solely with the aim of maximizing profits in the current stage, and when the retailer's one-time order volume expands, the manufacturer mistakenly believes that the market demand in the current stage has expanded and blindly increases the green innovation level of the product. When the research and development cost coefficient is too large, the negative impact of this behavior is further expanded.

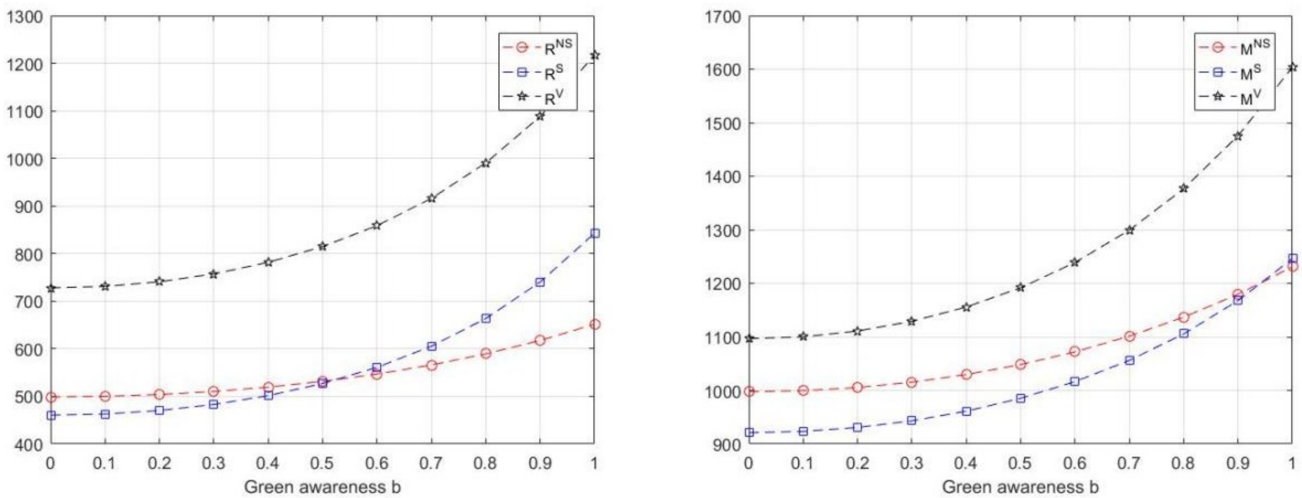


(a) **(b)**

Figure 1. Impact of green innovation costs on profits.

7.2. The influence of consumers' green awareness

Figure 2 indicates that as consumers' green awareness increases, both retailers and manufacturers experience improved profitability. Furthermore, the enhancement of consumers' green awareness further propels the performance of the early order strategy to exceed that of the base model, whether it's for retailers or manufacturers. This may be due to the fact that early ordering significantly enhances the manufacturer's green research and development efforts, and environmentally-conscious consumers clearly prefer to purchase more energy-efficient products. As consumers' green awareness continues to rise, this effect outweighs the increased costs associated with early ordering, ultimately improving the profitability of the green supply chain. As many previous studies have confirmed, consumer attention to environmental protection may be the optimal solution to promote environmental improvement.

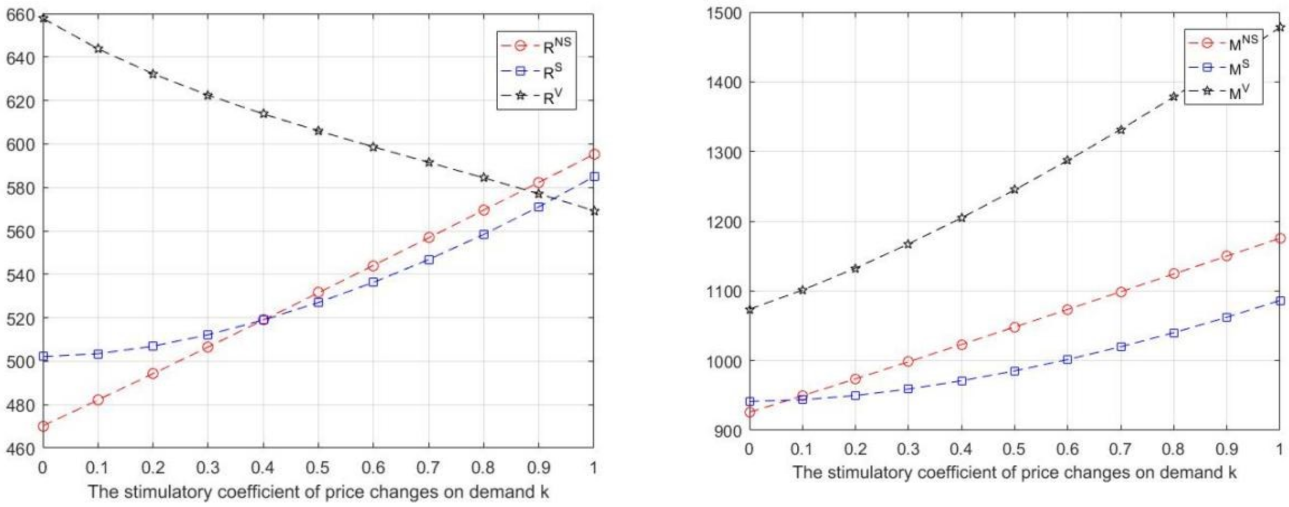


(a) **(b)**

Figure 2. The influence of consumers' green awareness.

7.3. The impact of consumer sensitivity to price changes

Figure 3 indicates that as the stimulatory effect of price cuts on consumption continues to increase, the profitability of the supply chain will also continue to improve. However, at the same time, the performance of the early order strategy may be slightly worse than the base model. In addition, it is worth noting that the profitability of retailers in Model 3 decreases significantly as *k* increases. This may be because when retailers are unable to accurately estimate future market conditions, excessive ordering can limit their pricing flexibility.



(a) **(b)**

Figure 3. The impact of consumer sensitivity to price changes.

8. Conclusion

8.1. Main conclusions

This study explores a green supply chain system composed of a green supply chain and a traditional supply chain, which is influenced by the service innovation level of traditional products. To help retailers who are at a disadvantage in the game improve their profitability, we explored two possible operational strategies, namely price-cutting strategy and early replenishment strategy.

The study found that when price cuts can promote consumers' desire to purchase, retailers always tend to lower product prices in the second game stage, and this strategy can indeed improve the profitability of retailers while increasing the green level of the product. As consumers pay more attention to changes in product prices, the profitability of all participants in the supply chain will gradually increase, and manufacturers will therefore have more incentive to invest in green innovation of products. This is obviously the result that all sectors of society prefer to see. However, it should be noted that strategic retailers do not necessarily reduce prices, but will first raise the retail prices of the products in the first stage to have more room for price cuts in the second stage. Obviously, this behavior will ultimately damage the interests of consumers.

In addition, this article explores the impact of retailers adopting an early replenishment strategy. The study found that, contrary to intuition, although the early replenishment strategy can enhance the green level of the product, predicting future demand in advance does not necessarily improve the profitability of the supply chain, depending on the external market environment, even if we do not consider the negative impact of storage costs and market fluctuations. This is likely because early replenishment means that retailers lose the opportunity to negotiate prices in the second stage, and bulk purchases lead manufacturers to blindly increase the level of green innovation of their products. Therefore, this operational strategy does not always achieve its desired effect, and can only improve the profitability of the supply chain when the cost of green innovation is low, or when consumers have a high awareness of green issues, or when consumers are not so concerned about changes in product prices.

Finally, this study analyzes the impact of the expanding market size of traditional products on green products. As the market expands, consumer sensitivity to product services increases, and cross-sensitivity rises, leading to a decline in the level of energy-saving and environmental innovation in green products. This is primarily because traditional products and green products share certain similarities, and the development of traditional products to some extent diminishes consumers' willingness to purchase green products. Consequently, when the traditional product market thrives, the development of green products may be hindered. Conversely, when the traditional product market faces obstacles, green products may enjoy greater growth opportunities.

8.2. Limitations of the research

There are many limitations in this study. Firstly, it only discusses the scenario where consumers focus on price cuts, while in actual production, price cuts do not necessarily stimulate demand. Secondly, this study fails to incorporate the costs associated with retailers' estimation of future demand into the modeling process. In reality, demand is difficult to predict, and this behavior can significantly increase costs. The circumstances under which retailers can advance their purchases might be a direction for further discussion in future research.

Conflict of interest: The author declares no conflict of interest

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