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Green Co-Creation Strategies among Supply Chain Partners: A Value Co-Creation Perspective

Genzhu Li [1], Xianliang Shi [1], Yefei Yang [1,*] and Peter K. C. Lee [2]

[1] School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China; ligenzh@163.com (G.L.); xlshi@bjtu.edu.cn (X.S.)
[2] Faculty of Business, The Hong Kong Polytechnic University, Hong Kong, China; peter.kc.lee@polyu.edu.hk
* Correspondence: yangyefei@bjtu.edu.cn

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Abstract: In response to the global fight against environmental deterioration and resource shortage, many governments call on firms to implement green innovation strategies. However, for most small and medium-sized firms, the high cost of green innovation makes it difficult to achieve green goals, causing the need for a growing number of firms to cooperate with their supply chain partners on green innovations. Thus, this study explores, from a value co-creation perspective, how supply chain partners share the investment in, and benefits of, green innovation, assuring their long-term cooperation. Based on a three-level manufacturing supply chain, this paper proposes three different types of green co-creation strategies (i.e., the manufacturer and its supplier, the manufacturer and its competitor, the manufacturer and its retailer). We set the mechanism of co-creation to share the cost of green investment and consider the impact of co-creation on the sales of supply chain partners. Then, by constructing the value functions of three co-creation strategies and proving the concavity of these functions, the findings indicate that different co-creation strategies can indeed improve the firm's profit in a certain range and achieve a different maximum value in a certain green investment sharing point. This study enriches the literature on green co-creation in supply chains by combing green investment sharing strategies among supply chain partners with value co-creation. In addition, this study provides manufacturers with guidelines on how to share green costs and choose a green co-creation strategy in different operational environments.

Keywords: green supply chain; value co-creation; green investment sharing; green co-creation strategies

1. Introduction

Green sustainable development is one of the most important supply chain strategies and a rising global concern [1–3]. In China, with the rapid development of economy and society, the problems of resources and the environment are gradually magnified, such as the serious fog weather, the lack of groundwater and drinking water and soil pollution. Moreover, the waste of resources and the emission of pollutants are caused by the manufacturing industry [4]. Thus, the Chinese government and the ministry of environmental protection (MEP) issued and implemented stricter government regulatory requirements such as the "Green GDP" and "China RoHS" to force many firms to integrate sustainability into their supply chains [5]. Indeed, many manufacturers have started using different forms of green sustainable supply chain management, such as green procurement, green logistics, green design and reverse logistics [6,7], and they try to compel their suppliers to conduct environmental management practices.

However, despite such green/sustainable practices, the environmental performance has not achieved a satisfying outcome. For example, in terms of air quality, 64.2% of the cities at or above the prefecture level still exceeded the standard, and PM2.5 as the primary pollutant accounted for 60.0% of the days of severe pollution in 2018 [8]. The evidence indicates that manufacturers still make a limited contribution to environmental protection and management. There may be two reasons for this: (1) in the supply chain, considering the high cost of green technology investment, most partners are not willing to bear the expense of the implementation of green practices, although they need to adhere to environmental regulations; (2) manufacturers are ambiguous about whether they are benefited by these green practices. Therefore, the issues of how to reduce the investment cost of a green supply chain (GSC) and how to create value for manufacturers need to be important concerns in stimulating the enthusiasm of the main supply chain partners to implement sustainable practices.

In our study, based on the GSC strategy, we propose a cooperation strategy from a value co-creation perspective in order to improve the efficiency of the supply chain and encourage upstream/downstream entities to share green investment. Managing these green issues effectively requires an extended perspective, from an independent firm to the entire supply chain [1,9]. Value co-creation is the business cooperation strategy that the firms in the supply chain are beginning to attempt. On the one hand, value co-creation is conducive to deep collaborations between upstream and downstream firms in the supply chain [4]. Based on the relevant literature [10,11], value co-creation strategies include three categories, i.e., the manufacturer co-creates with its supplier, its competitor and its retailer [11]. Throughout the entire supply chain, manufacturers design and produce green products to satisfy the demands of environmentally concerned consumers, and suppliers and retailers use green marketing to promote their sales in their marketplaces [12]. For example, Walmart developed a green marketing plan for its suppliers and implemented an audit system called the balanced scorecard for the green management of its suppliers, thereby stimulating sales volumes. Moreover, Carbon Trust surveys indicate that manufacturers and retailers can achieve economic benefits when meeting environmental responsibilities in their production and operations, because the social and environmental resources involved in sustainable production and operations are difficult to imitate [6,13]. Furthermore, approximately 20% of customers prefer to buy green products even if they are more expensive than regular products, and this ratio is gradually rising [14]. Thus, we can consider the green cooperation strategy and benefit allocation among supply chain partners from a value co-creation perspective.

From the perspective of value co-creation, this paper proposes three categories of green co-creation strategies, verifies the superiority of value co-creation in the implementation of a green supply chain strategy and analyzes how to conduct green cost sharing, achieving the maximum co-creation value. This study not only extends the application of value-creation to green investment in the supply chain, but also fills the gap in the research on how to share green investment to achieve long-term green co-creation in collaboration with supply chain partners. In addition, it provides the basis for manufacturing enterprises to choose the appropriate strategy of value co-creation.

2. Literature Review

2.1. Cooperation in a Green Supply Chain

The ever-growing public green consciousness raises market demand for products with superior energy-saving performance, and hence stimulates manufacturers to go greener via innovation. Moreover, nations all over the globe have strengthened the power of greening support, which also leads manufacturers to carry out energy-saving activities such as technology development [15]. The government's control of the environment and the pressure of consumers and industry competition force enterprises to carry out green innovation and reform [16,17]. Especially for enterprises with a complex industrial chain, it is impossible to achieve an effective green supply chain management only by their own efforts [18], and the relationship between enterprises and other partners in the supply chain will also affect the performance of green innovation [19]. Thus, except for internal greening activities such as green innovation (process improvement, equipment renovation, etc.), supply chain members actively seek external research and development cooperation with their upstream/downstream partners to jointly improve the eco-saving performance of a product [20,21]. This behavior refers to the collaborative efforts of partners or competitors with the aim of achieving mutually beneficial results. In a business environment, cooperation often occurs when independent companies that exist in the same market work together in the exploration of knowledge, research and development and the technologies of new products, and when they cooperate simultaneously to increase their market-share and exploit the knowledge gained [22].

More recently, some scholars have found that cooperation in GSC can help enterprises reduce carbon emissions and improve firm/environment performance based on different forms of cooperation [23–25]. Firstly, some scholars explored the cooperation mode of upstream and downstream enterprises in supply chain from the perspective of game theory. For example, Sarkar et al. discussed the Nash equilibrium of green quality and non-green quality of products in a two-level supply chain with the goal of maximizing the overall profit [26]. Dai et al. applied a game-theoretical approach to examine two kinds of cooperative mechanisms on green development investment, i.e., Cartelization and a cost-sharing contract [15]. Second, many researches have confirmed that the cooperation in green development in supply chain has a positive effect on firm performance and environmental performance. Ji et al. investigated cooperation between a manufacturer and a retailer and considered online and offline shops. They also focused on how the cap-and-trade policy affects both economic performance and social welfare through simulating the emission reduction behavior of supply chain companies [27]. Zhan Yang et al. used an ISM model to confirm the positive impact of supply chain collaboration on the green innovation performance of the automotive industry chain [28]. The practice of green supply chain management plays a positive role in environmental performance and economic performance, thereby improving operational performance and promoting the sustainable development of enterprises [25,29]. In the clothing industry, the innovation practices and member cooperation of the green supply chain could have an impact on the overall profits of the supply chain [30]. In addition, Yenipazarli suggests that the collaboration in the carbon emissions reduction in their product/production process have an obvious influence on the environmental performance [31]. Third, some scholars indicate that power structure could affect the performance of the supply chain [32–34]. Chen et al. used game theory to analyze the impact of supply chain power relations on firm decision-making, as well as the economic and environmental performances of a two-echelon supply chain [35]. Based on their research, they found that supply chain relationships have a significant impact on economic and environmental performance.

Although there is literature that focuses on the cooperation forms and their effects, there is less exploring the mechanism and effect of cooperation from the perspective of value co- creation. This paper proposes different cooperation forms based on value co-creation in the three-stage supply chain, and verifies the superiority of value co-creation cooperation in green investment.

2.2. Value Co-Creation

Since the co-creation value was officially quoted by Prahalad and Ramaswamy, it has attracted the attention of various fields [36]. It is generally considered that the value of services is typically created together with suppliers and customers [37], as the exchange process of product/service typically requires an integration of knowledge-based and extensive information asymmetries [38–40]. Value co-creation process includes the joint efforts of participants [41], in which interaction is the key element of value co-creation [42]. Therefore, value co-creation influences different parties to collaborate and produce mutually valued outcomes as a deliberate and holistic management strategy [43]. According to Grönroos and Voima [44], value co-creation is a joint process that firms and customers jointly create value in interaction, and occurs specifically in "joint value spheres" between suppliers and customers [45]. One of the most prominent perspectives regarding co-creation is the service-dominant logic [46]. This view emphasizes the concept of the co-production of value and instead stresses the necessity of co-creation of value. Essentially, the fundamental unit of exchange is service rather than product, so providers create value together by exchanging services during interactions with customers [39]. Therefore, customers are regarded as active value creators, not passive value responders or recipients [47].

According to the views of stakeholders, a company is described as a group of relationships between individuals or groups that affect or are affected by its business operations, which is crucial to its operations [48]. These multiple stakeholders provide resources, influence the business environment, and influence firms' efficiency [49]. Therefore, from this perspective, the collective efforts of the stakeholder network are the core of value co-creation. It highlights mutual stakeholder relationships in which stakeholders are both recipients and creators or co-creators of value in joint value creation processes [50–54]. As the representative of the customer-oriented type, Prahalad proposes that the interaction between producers and consumers should be promoted by four aspects: dialogue, experience, risk assessment and transparency to achieve value co-creation [36]. Reviewing the literature of the business model, we concluded that the co-create value with customers is more important than other types of value co-creation, as it is fundamental to the concept of a business model [50,55]. Since customer co-creation value is a relatively new research area, most related studies have focused on developing measurement instruments to study customer co-creative value in various research contexts. Lusch et al. measured co-creation value from the perspectives of co-production and use value [56]. Similarly, Payne et al. focused on two means by which customers co-create value for organizations, namely customer ability and customer willingness [57]. Some of the literature also indicates that value co-creation should involve enterprises, customers and other roles in the field [16,58,59]. Therefore, this study applies value co-creation in the whole chain rather than an independent supply chain member.

3. The Model

In practice, the research and development of green technology and products often need to invest huge human and monetary capital, which is a big challenge for firms. Therefore, the sustainable value co-creation modes in this paper are based on the cost allocation and benefits sharing of green technology investment between value co-creators. Meanwhile, the feedback comments from consumers can also show the necessity of the suppliers and manufacturers developing green technologies and then reduce the cost of green technology investment. Therefore, we also considered the value co-creation option between manufacturers and retailers.

Scholars always use game theory to study the cooperation of the green supply chains [15,22–27], most of which are based on secondary-level supply chain. The models used in these studies rarely take into account investment cost, material cost, carbon tax, labor risk and other factors, nor can they explain the mechanisms and roles of cooperation from the perspective of value co-creation. In addition, most of the studies relevant to value co creation emphasize the importance of customers [36,38,43–46], while our research needs to consider suppliers, manufacturers and retailers. Thus, this study needs to develop a new model for the co-creation value of green practices implemented in a three-level supply chain with suppliers, manufacturers and retailers. This study assumed that the demand of products in the supply chain is uncertain. Firstly, it uses the knowledge of game theory to develop the expected profit model of suppliers, manufacturers and retailers in the three-level supply chain, then connect the supply chain partners through the proportion coefficient k of green investment cost sharing. Finally, based on the ratio, the final distribution results of co-creation value are obtained.

Here, we consider a three-level supply chain, including a manufacturer M and its supplier S, and a retailer R. We also consider the competitor in the same industry M' outside M's supply chain. Based on the consideration of carbon emission and green technology investment, the manufacturer is regarded as the leading entity in the supply chain system. This paper mainly focuses on the value co-creation between the manufacturer and its supplier, the manufacturer and its competitor in the same industry, and the manufacturer and its retailer (shown in Figure 1). The aim of this study is to explore the sustainable value co-creation mode in different situations, and the decision of green cost investment and allocation for each participant in the supply chain under different value co-creation strategies.

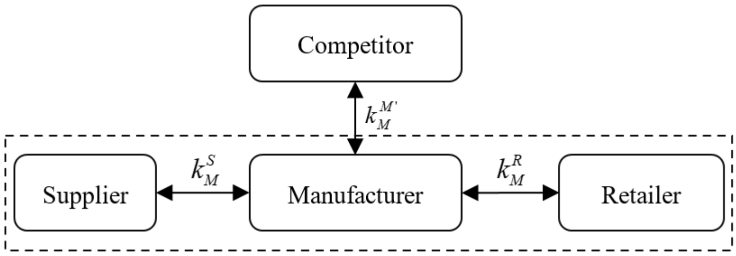

Figure 1. The implementation of co-creation strategy.

Let k ε [0,1] denote the cost allocation proportion of green technology investment. For example, as shown in Figure 1, when M and its supplier S co-create value together, it means that the M needs to undertake k_M^S while $(1-k_M^S)$ belongs to the S. The basic parameters include c, p, s, where c denotes the production/wholesale costs of M, M', S, R, p denotes the selling price of them, s denotes the product scrap value of them. This paper considers that green technology can improve the process of production, and then improve product quality and output. Thus, we define θ to denote the change index of sales volume. For example, after co-creation, the sales volume of M will change from q_M to $\theta_M q_M$.

Market demand is ever-changing, so we define D to represent the market demand satisfied by the supplier (S), manufacturers (M and M') and the retailer (R), where the demand distribution function is $D = F(x) = \int f(x)dx$. Considering the stable demand of the upstream supplier S, we assume that $D_s = q_s$. Except for the fixed production/purchase cost c, manufactures also need to undertake the green investment cost I, carbon tax cost T and the compensation cost for physical accidents of employees L.

The profit of Supplier S: The supplier's demand is stable. Moreover, they have simple production process and only produces raw materials. Thus, we don't consider the carbon tax T and accident compensation cost L. The supplier's profit is the sales revenue minus the production cost, as shown in Equation (1).

$$\prod(S) = p_S q_S - c_S q_S \tag{1}$$

The profit of manufacture M (M'): As the core entity of supply chain, the manufacturer needs to provide finished products to the retailer. The demands it faces are diverse and unstable. At the same time, due to the complex production process, it is easy to cause environmental pollution, so it is necessary to consider the carbon tax T and accident compensation cost L. The manufacture's profit is as shown in Equation (2).

$$\prod(M) = \int_0^{q_M} [p_M x + s_M(q_M - x)] f(x)\mathrm{d}x + \int_{q_M}^{+\infty} p_M q_M f(x)\mathrm{d}x - c_M q_M - L_M - T_M \tag{2}$$

Similarly, as the competitor of the core manufacture, the profit of M' is as shown in Equation (3).

$$\prod(M') = \int_0^{q_{M'}} [p_{M'} x + s_{M'}(q_{M'} - x)] f(x)\mathrm{d}x + \int_{q_{M'}}^{+\infty} p_{M'} q_{M'} f(x)\mathrm{d}x - c_{M'} q_{M'} - L_{M'} - T_{M'} \tag{3}$$

The profit of retailer R: The retailer faces customers directly, so their demand is more unstable and diversified. However, for retailers, they only need to undertake the purchase cost c, because they do not have any production processes. Thus, we do not consider the carbon tax T and accident compensation cost L. The retailer's profit is as shown in Equation (4).

$$\prod(R) = \int_0^{q_R} [p_R x + s_R(q_R - x)] f(x)\mathrm{d}x + \int_{q_R}^{+\infty} p_R q_R f(x)\mathrm{d}x - c_R q_R \tag{4}$$

In the above modeling, we have made several key assumptions, which are summarized as follows:

1. $p > c > s > 0$. This condition indicates that all participants in the supply chain (including suppliers, manufacturers, and retailers) have positive profit margins in the production of raw materials, the manufacture of products, and the final sale. In addition, the production cost is greater than the discounted price, which means that some losses will occur if the product is not sold at full price;
2. According to the purchase behavior of customers, the whole sales process is divided into two stages: normal sales stage and discount sales stage. Enterprises sell at regular prices in the normal sales stage and at discount prices in the discount sales stage. Assume that the remaining products that are not sold in the normal sales phase can always be sold in the discount sales phase;
3. The product shortage costs of suppliers, manufacturers and retailers are not considered in this study, and all of the suppliers, manufacturers and retailers are risk-neutral and completely rational;
4. This paper only considers the value co-creation under the carbon emission quota policy, and there is no carbon emission trading between enterprises in the supply chain;
5. This paper only considers the carbon emissions of manufacturers and suppliers in the production of raw materials and products, because the carbon emissions in the production process are the main source of carbon emissions;
6. This paper assumes that suppliers and manufacturers can reduce the carbon emission per unit product through investment in green technology, thus reducing the cost of carbon emission.

We summarize the notations used in the paper in Table 1.

Table 1. Summary of Notations.

D	the stochastic demand
q	the quantity of production/purchase
c	the production/wholesale costs
s	the product scrap value
I	the investment cost of green technology, while we assume that the investment cost of green technology is a quadratic function of emission reduction rate η, then $I(\eta) = 1/2t\eta^2$, t is the coefficient of green technology investment cost function
T	the carbon tax, while we assume that the carbon tax is a linear function of the carbon emission of unit product e, then $T = de$, d is the cost of unit carbon emission
L	the compensation cost for physical accidents of employees, while we assume that the compensation cost is a linear function of the probability of production accident λ, then $L(\lambda) = \lambda F_0$, F_0 is the average compensation cost for accidents of employees
Π	the profit of a firm, or the sum of the profits of the co-creators
k	the cost allocation proportion of green technology investment. For example, when M and its supplier S co-create value together, it means that the M needs to undertake k_M^S while $(1 - k_M^S)$ belongs to the S
θ	the change index of sales volume. For example, after co-creation, the sales volume of M will change from q_M to $\theta_M q_M$

4. Analysis

To investigate the positive effect of co-creation strategy among supply chain partners, we consider three potential options: (1) value co-creation between the manufacturer M and its supplier S, (2) value co-creation between the manufacturer M and its competitor M', and (3) value co-creation between the manufacturer M and its retailer R. First, we constructed the profit function after value co-creation between different firms. Then we proved the concavity of these profit functions, and then got the value range of k when the sum of the profits after co-creation is greater than the profits before co-creation. Finally, we figured out the value of the cost distribution ratio k when the profit after co-creation reaches the maximum.

4.1. Value Co-Creation between Manufacturers

4.1.1. The Profit Function after Value Co-Creation (S, M)

The basic assumption of the sustainable value co-creation model between the manufacturer and the supplier is as follows: in the supply chain system, the manufacturer and supplier share the cost of green technology investment. In this mode, we consider that the total cost of raw materials produced by the supplier is lower than the original cost, and the selling price of raw materials sold to the manufacturer will be lower. However, due to slight changes in the price allocated to each commodity, we perceive that the sales price will remain unchanged in this study. At the same time, due to the upgrading of green technologies, the carbon emissions of products have also been reduced. Considering the policy constraints and consumer preferences, the market demand for products will increase. Therefore, even if the manufacturer shares part of the green investment cost, their final profit may be higher than the original profit due to the increase in their sales volume. At the same time, due to the decrease in green investment cost and the increase in sales volume, the final profit of the manufacturer may be higher than the original profit.

Then, we build the profit function as Equation (5)

$$\begin{gathered}\prod(S,M) = \theta_S p_S q_S - \theta_S c_S q_S + \left\{\int_0^{\theta_M q_M} [p_M x + s_M(\theta_M q_M - x)] f(x)\mathrm{d}x + \right. \\ \left. \int_{\theta_M q_M}^{+\infty} \theta_M p_M q_M f(x)\mathrm{d}x - \theta_M c_M q_M - \theta_M \lambda_M F_M q_M - \theta_M de_M q_M \right\} - I(\eta)\end{gathered} \tag{5}$$

where θ_s, θ_M are the linear function of k_M^S, as such $\theta = ak + b$, a and b are constants.

The above Equation (5) can be simplified as Equation (6)

$$\prod(S,M) = \theta_S p_S q_S - \theta_S c_S q_S + (\mathrm{p_M} - \mathrm{s_M})[-\int_0^{\theta_M q_M} F(x)\mathrm{d}x] + \theta_M q_M(p_M - c_M - \lambda_M F_M - de_M) - I(\eta) \tag{6}$$

The process of proving the concavity of Equation (6) is as follows:

First, we get its first derivative,

$$\frac{\partial \Pi}{\partial k_M^S} = -q_S a_S(p_S - c_S) - (p_M - s_M) q_M a_M F(q_M a_M k_M^S + q_M b_M) + q_M a_M(p_M - c_M - \lambda_M F_M - de_M)$$

then, the second derivative is obtained as follows,

$$\frac{\partial^2 \Pi}{\partial {k_M^S}^2} = -(p_M - s_M) {q_M}^2 {a_M}^2 f(q_M a_M k_M^S + q_M b_M) < 0$$

Obviously, the second derivative function is less than zero constantly, so it is proved that the profit function of (S, M) is a concave function with a maximum value.

Theorem 1. *When the manufacturer and its supplier co-create value by sharing the cost of green investments, the sum of their profits exists the maximum value.*

4.1.2. Feasible Interval

When the total profit of manufacturer and supplier after value co-creation is greater than the sum of the profits of the manufacturer and supplier before value co-creation, this value co-creation mode is considered to be meaningful. If we set $\prod_S$ and $\prod_M$ as the profit of supplier and manufacturer before value co-creation, then $\prod_S + \prod_M > \prod_{(S,M)}$, which is:

$$\theta_S p_S q_S - \theta_S c_S q_S + \left\{\int_0^{\theta_M q_M} [p_M x + s_M(\theta_M q_M - x)] f(x)\mathrm{d}x + \int_{\theta_M q_M}^{+\infty} \theta_M p_M q_M f(x)\mathrm{d}x - \theta_M c_M q_M - \theta_M L_M - \theta_M T_M\right\}$$
$$-I(\eta) - (p_S q_S - c_S q_S) - \left\{\int_0^{q_M} [p_M x + s_M(q_M - x)] f(x)\mathrm{d}x + \int_{q_M}^{+\infty} p_M q_M f(x)\mathrm{d}x - c_M q_M - L_M - T_M\right\} > 0$$

After simplification, we can get that:

$$\theta_S p_S q_S - \theta_S c_S q_S + (\mathrm{p_M} - \mathrm{s_M})\left[-\int_0^{\theta_M q_M} F(x)\mathrm{d}x\right] + \theta_M q_M(p_M - c_M - \lambda_M F_M - de_M) - I(\eta)$$
$$-(p_S q_S - c_S q_S) - \left\{(\mathrm{p_M} - \mathrm{s_M})\left[-\int_0^{q_M} F(x)\mathrm{d}x\right] + q_M(p_M - c_M - \lambda_M F_M - de_M)\right\} > 0$$

Let g denotes the unit profit of each product without discount, G denotes the total profit of selling q products without discount, then, we can get the following expressions:

$$g_s = p_s - c_s \tag{7}$$

$$g_M = p_M - c_M - \lambda_M F_M - de_M \tag{8}$$

$$G_S = q_S g_S = q_S(p_S - c_S) \tag{9}$$

$$G_M = q_M g_M = q_M(p_M - c_M - \lambda_M F_M - de_M) \tag{10}$$

Let z be the unit discount amount for each product in the case of discount, and Z be the total discount amount for selling q products in the case of discount, then,

$$z = p - s \tag{11}$$

$$Z = qz = q(p - s) \tag{12}$$

In addition, set $F(x) = ax + b$ and take it into the above expressions, then, we can get the inequality as follows:

$$(a_S - a_S k_M^S + b_S)G_S - Z_M\left[\frac{a}{2}(a_M k_M^S + b_M)^2 q_M + b(a_M k_M^S + b_M)\right] + (a_M k_M^S + b_M)G_M - I(\eta)$$
$$-G_S + Z_M\left(\frac{a}{2} q_M + b\right) - G_M > 0$$

By solving the above inequality, the effective interval of value co-creation between manufacturer and supplier can be obtained.

Proposition 1a. *During the situation when the manufacturer and its supplier co-create value by sharing the cost of green investments, when $k_M^S \in (\varphi_1, \varphi_2)$, the sum of profits after co-creation is greater than before, which proves the positive effect of co-creation strategy, where φ_1, φ_2 are the two zero points of inequality.*

4.1.3. Feasible Interval

After proving the concavity of profit function, we will start to calculate the value of k, and the profit function will take the maximum value at that time. The calculation process is as follows.

When $\prod_{(S,M)}$ takes the extreme value, the first derivative must be equal to zero, then,

$$\frac{\partial \Pi}{\partial k_M^S} = -q_S a_S(p_S - c_S) - (p_M - s_M) q_M a_M F(q_M a_M k_M^S + q_M b_M) + q_M a_M(p_M - c_M - \lambda_M F_M - de_M) = 0$$

Similarly, according to Equations (7)–(12), and $\theta_M = a_M k_M^S + b_M$, $\theta_S = a_S(1 - k_M^S) + b_S$,then, we can get the first derivative function as follows,

$$\frac{\partial \Pi}{\partial k_M^S} = -G_S a_S - Z_M a_M F(q_M \theta_M) + G_M a_M = 0$$

Through substituting $F(x) = ax + b$ into the above first derivative function, then,

$$Z_M a_M (a q_M \theta_M + b) = G_M a_M - G_S a_S$$

Then, we can get the value of θ_M at present,

$$\theta_M = \frac{G_M a_M - G_S a_S - b Z_M a_M}{a Z_M a_M q_M}$$

On account of the linear relationship between θ_M and k_M^S, we can get that,

$$\begin{aligned} k_M^S &= \tfrac{1}{a_M}(\theta_M - b_M) \\ &= \tfrac{1}{a_M}\left\{\tfrac{G_M a_M - G_S a_S - b Z_M a_M}{a Z_M a_M q_M} - b_M\right\} \end{aligned}$$

Proposition 1b. *When the manufacturer and its supplier co-create value by sharing green investment cost,*

(1) *When the manufacturer's share* $k_M^S = \frac{1}{a_M}\left\{\frac{G_M a_M - G_S a_S - b Z_M a_M}{a Z_M a_M q_M} - b_M\right\}$*, the maximum of the sum of their profits after co-creation occurred;*
(2) *When the allocation proportion is less than this value of extreme point, if the manufacturer increases the proportion of investment, the sum of their profits will increase;*
(3) *When the allocation proportion is more than this value of extreme point, if the manufacturer increases the proportion of investment, the sum of their profits will decrease.*

4.2. Value Co-Creation between Manufacturers

4.2.1. The Profit Function after Value Co-Creation (M, M′)

The basic assumptions of sustainable value co-creation between manufacturers in the same industry are as follows: in the supply chain system, the manufacturers in the same industry share the cost of green technology investment, and they can develop more advanced green technologies. In this mode, we believe that the total cost of a single manufacturer is significantly lower than before, so the unit production cost of finished products will be reduced. However, due to slight changes in the price allocated to each product, we think that the sales price remains the same in this paper. At the same time, due to the upgrading of green technology, the carbon emissions of products have also been reduced. Considering the policy constraints and consumer preferences, the overall market demand for products will increase, so the manufacturer's will increase its output. Thus, the manufacturers are likely to earn more profits than before co-creation.

Then, we build the profit function as Equation (13)

$$\begin{aligned} &\prod(M, M') = \\ &\left\{\int_0^{\theta_M q_M} [p_M x + s_M(\theta_M q_M - x)] f(x) \mathrm{d}x + \int_{\theta_M q_M}^{+\infty} \theta_M p_M q_M f(x) \mathrm{d}x - \theta_M c_M q_M - \theta_M \lambda_M F_M q_M - \theta_M d e_M q_M\right\} + \\ &\left\{\int_0^{\theta_{M'} q_{M'}} [p_{M'} x + s_{M'}(\theta_{M'} q_{M'} - x)] f(x) \mathrm{d}x + \int_{\theta_{M'} q_{M'}}^{+\infty} \theta_{M'} p_{M'} q_{M'} f(x) \mathrm{d}x - \theta_{M'} c_{M'} q_{M'} - \theta_{M'} \lambda_{M'} F_{M'} q_{M'} - \theta_{M'} d e_{M'} q_{M'}\right\} \\ &-I(\eta) \end{aligned} \tag{13}$$

where $\theta_m, \varphi_{M'}$ are about the linear function of $k_M^{M'}$, as such $\theta = ax + b$, a and b are constants.

The above Equation (13) can be simplified as Equation (14):

$$\begin{aligned} \prod(M,M') = (p_M - s_M)[-\int_0^{\theta_M q_M} F(x)\mathrm{d}x] + \theta_M q_M (p_M - c_M - \lambda_M F_M - de_M) \\ (p_{M'} - s_{M'})[-\int_0^{\theta_{M'} q_{M'}} F(x)\mathrm{d}x] + \theta_{M'} q_{M'} (p_{M'} - c_{M'} - \lambda_{M'} F_{M'} - de_{M'}) - I(\eta) \end{aligned} \tag{14}$$

The process of proving the concavity of the Equation (14) is as follows.

First, we get its first derivative,

$$\begin{aligned} \frac{\partial \Pi}{\partial k_M^{M'}} = -(p_M - s_M) q_M a_M F(q_M a_M k_M^{M'} + q_M b_M) + q_M a_M (p_M - c_M - \lambda_M F_M - de_M) \\ + (p_{M'} - s_{M'}) q_{M'} a_{M'} F(q_{M'} a_{M'} + q_{M'} b_{M'} - q_{M'} a_{M'} k_M^{M'}) - q_{M'} a_{M'} (p_{M'} - c_{M'} - \lambda_{M'} F_{M'} - de_{M'}) \end{aligned}$$

then, the second derivative is obtained as follows,

$$\frac{\partial^2 \Pi}{\partial k_M^{M'2}} = -(p_M - s_M) {q_M}^2 {a_M}^2 f(q_M a_M k_M^{M'} + q_M b_M) - (p_{M'} - s_{M'}) {q_{M'}}^2 {a_{M'}}^2 f(q_{M'} a_{M'} + q_{M'} b_{M'} - q_{M'} a_{M'} k_M^{M'}) < 0$$

Obviously, the second derivative function is less than zero constant, so it is proved that the profit function of (M, M') is a concave function with a maximum value.

Theorem 2. *When the manufacturer and its competitor implement value by sharing green investment cost, the sum of their profits exists the maximum value.*

4.2.2. Feasible Interval

When the total profit of manufacturers after value co-creation is greater than the sum of the profits of two manufacturers before value co-creation, this value co-creation mode is considered to be meaningful. If we set $\prod_M$ and $\prod_{M'}$ as the profit of the two manufacturers before value co-creation, then $\prod_M + \prod_{M'} > \prod_{(M,M')}$, which is:

$$\begin{aligned} &\left\{\int_0^{\theta_M q_M} [p_M x + s_M(\theta_M q_M - x)] f(x)\mathrm{d}x + \int_{\theta_M q_M}^{+\infty} \theta_M p_M q_M f(x)\mathrm{d}x - \theta_M c_M q_M - \theta_M L_M - \theta_M T_M\right\} + \\ &\left\{\int_0^{\theta_{M'} q_{M'}} [p_{M'} x + s_{M'}(\theta_{M'} q_{M'} - x)] f(x)\mathrm{d}x + \int_{\theta_{M'} q_{M'}}^{+\infty} \theta_{M'} p_{M'} q_{M'} f(x)\mathrm{d}x - \theta_{M'} c_{M'} q_{M'} - \theta_{M'} L_{M'} - \theta_{M'} T_{M'}\right\} \\ &- I(\eta) - \left\{\int_0^{q_M} [p_M x + s_M(q_M - x)] f(x)\mathrm{d}x + \int_{q_M}^{+\infty} p_M q_M f(x)\mathrm{d}x - c_M q_M - L_M - T_M\right\} \\ &- \left\{\int_0^{q_{M'}} [p_{M'} x + s_{M'}(q_{M'} - x)] f(x)\mathrm{d}x + \int_{q_{M'}}^{+\infty} p_{M'} q_{M'} f(x)\mathrm{d}x - c_{M'} q_{M'} - L_{M'} - T_{M'}\right\} > 0 \end{aligned}$$

After simplification, we can get that:

$$\begin{aligned} &(p_M - s_M)[-\int_0^{\theta_M q_M} F(x)dx] + \theta_M q_M (p_M - c_M - \lambda_M F_M - de_M) \\ &+ (p_{M'} - s_{M'})[-\int_0^{\theta_{M'} q_{M'}} F(x)dx] + \theta_{M'} q_{M'} (p_{M'} - c_{M'} - \lambda_{M'} F_{M'} - de_{M'}) - I(\eta) \\ &- (p_M - s_M)[-\int_0^{q_M} F(x)dx] + q_M (p_M - c_M - \lambda_M F_M - de_M) \\ &+ (p_{M'} - s_{M'})[-\int_0^{q_{M'}} F(x)dx] + q_{M'} (p_{M'} - c_{M'} - \lambda_{M'} F_{M'} - de_{M'}) > 0 \end{aligned}$$

In addition, according to Equations (7)–(12), and $F(x) = ax + b$, we take them into the above expressions, then, we can get the inequality as follows:

$$\begin{aligned} &-Z_M\left[\tfrac{a}{2}(a_M k_M^{M'} + b_M)^2 q_M + b(a_M k_M^{M'} + b_M)\right] + (a_M k_M^{M'} + b_M) G_M \\ &-Z_{M'}\left[\tfrac{a}{2}(a_{m'} - a_{m'} k_M^{M'} + b_{m'})^2 q_{m'} + b(a_{m'} - a_{m'} k_M^{M'} + b_{m'})\right] + (a_{m'} - a_{m'} k_M^{M'} + b_{m'}) G_{M'} - I(\eta) \\ &+ Z_M(\tfrac{a}{2} q_M + b) - G_M + Z_{M'}(\tfrac{a}{2} q_{M'} + b) - G_{M'} > 0 \end{aligned}$$

By solving the above inequality, the effective interval of value co-creation between manufacturer and supplier can be obtained.

Proposition 2a. *During the situation when the manufacturer and its competitor co-create value by sharing the cost of green investments, when $k_M^{M'} \in (\varphi_3, \varphi_4)$, the sum of profits after co-creation is greater than before, which proves the positive effect of co-creation strategy, where φ_3, φ_4 are the two zero points of inequality.*

4.2.3. Extreme Point

After proving the concavity of profit function, we will start to calculate the value of k, and the profit function will take the maximum value at that time. The calculation process is as follows.

When $\prod_{(M, M')}$ takes the extreme value, the first derivative must be equal to zero, then,

$$\frac{\partial \Pi}{\partial k_M^{M'}} = -(p_M - s_M)q_M a_M F(q_M a_M k_M^{M'} + q_M b_M) + q_M a_M(p_M - c_M - \lambda_M F_M - de_M)$$
$$+(p_{M'} - s_{M'})q_{M'} a_{M'} F(q_{M'} a_{M'} + q_{M'} b_{M'} - q_{M'} a_{M'} k_M^{M'}) - q_{M'} a_{M'}(p_{M'} - c_{M'} - \lambda_{M'} F_{M'} - de_{M'}) = 0$$

Similarly, according to Equations (7)–(12), $\theta_M = a_M k_M^{M'} + b_M$ and $\theta_{M'} = a_{M'}(1 - k_M^{M'}) + b_{M'}$, then, we can get the first derivative function as follows,

$$\frac{\partial \Pi}{\partial k_M^{M'}} = -Z_M a_M F(q_M \theta_M) + G_M a_M + Z_{M'} a_{M'} F(q_{M'} - q_{M'} \theta_{M'}) - G_{M'} a_{M'} = 0$$

Through substituting $F(x) = ax + b$ into the above first derivative function, then,

$$Z_M a_M(a q_M \theta_M + b) - Z_{M'} a_{M'}(a q_{M'} - a q_{M'} \theta_{M'} + b) = G_M a_M - G_{M'} a_{M'}$$

Then, we can get the value of θ_M at the present,

$$\theta_M = \frac{G_M a_M - G_{M'} a_{M'} + a q_{M'} Z_{M'} a_{M'} - b[Z_M a_M - Z_{M'} a_{M'}]}{a[Z_M a_M q_M + Z_{M'} a_{M'} q_{M'}]}$$

On account of the linear relationship between θ_M and $k_M^{M'}$, we can get that,

$$k_M^{M'} = \frac{1}{a_M}(\theta_M - b_M)$$
$$= \frac{1}{a_M}\left\{\frac{G_M a_M - G_{M'} a_{M'} + a q_{M'} Z_{M'} a_{M'} - b[Z_M a_M - Z_{M'} a_{M'}]}{a[Z_M a_M q_M + Z_{M'} a_{M'} q_{M'}]} - b_M\right\}$$

Proposition 2b. *When the manufacturer and its competitor implement value by sharing green investment cost,*

(1) *When the manufacturer's share $k_M^{M'} =$*

$$\frac{1}{a_M}\left\{\frac{G_M a_M - G_{M'} a_{M'} + a q_{M'} Z_{M'} a_{M'} - b[Z_M a_M - Z_{M'} a_{M'}]}{a[Z_M a_M q_M + Z_{M'} a_{M'} q_{M'}]} - b_M\right\}$$

the maximum of the sum of their profits after co-creation occurred;

(2) *When the allocation proportion is less than this value of extreme point, if the manufacturer M increases the proportion of investment, the sum of their profits will increase;*

(3) *When the allocation proportion is more than this value of extreme point, if the manufacturer M increases the proportion of investment, the sum of their profits will decrease.*

4.3. Value Co-Creation between Manufacturer and Retailer

4.3.1. The Profit Function after Value Co-Creation (M, R)

$$\frac{1}{a_M}\left\{\frac{G_M a_M - G_{M'} a_{M'} + a q_{M'} Z_{M'} a_{M'} - b[Z_M a_M - Z_{M'} a_{M'}]}{a[Z_M a_M q_M + Z_{M'} a_{M'} q_{M'}]} - b_M\right\}$$

The basic assumptions of sustainable value co-creation between the manufacturer and the retailer as follows: the manufacturer and its retailer share the cost of green technology investment. The retailer provides the manufacturer with information about their customers' preferences, and points out the direction for their green technology research and development. The manufacturers can design products that meet their customers' needs based on their preferences, thus more customers will be attracted to purchase products and the sales volume of products will increase. We assume that the decrease in green technology investment cost has little effect on the wholesale price and sales price of products, so the relative value of the wholesale price and sales price will remain unchanged after value co-creation. In this context, due to the decrease in green technology investment cost and the increase in product sales, the profits of the manufacturer and the retailer are likely to rise relative to the pre-value co-creation.

Then, we build the profit function as Equation (15)

$$\begin{aligned}&\prod(M,R) = \\ &\left\{\int_0^{\theta_M q_M}[p_M x + s_M(\theta_M q_M - x)]f(x)\mathrm{d}x + \int_{\theta_M q_M}^{+\infty}\theta_M p_M q_M f(x)\mathrm{d}x - \theta_M c_M q_M - \theta_M \lambda_M F_M q_M - \theta_M d e_M q_M\right\} \\ &+\left\{\int_0^{\theta_R q_R}[p_R x + s_R(\theta_R q_R - x)]f(x)\mathrm{d}x + \int_{\theta_R q_R}^{+\infty}\theta_R p_R q_R f(x)\mathrm{d}x - \theta_R c_R q_R\right\} - I(\eta)\end{aligned} \quad (15)$$

where θ_M, θ_R are about the linear function of K_M^R, as such $\theta = ak + b$, a and b are constants.

The above Equation (15) can be simplified as Equation (16)

$$\begin{aligned}&\prod(M,R) = (\mathrm{p_M} - \mathrm{s_M})[-\int_0^{\theta_M q_M} F(x)\mathrm{d}x] + \theta_M q_M(p_M - c_M - \lambda_M F_M - d e_M) \\ &(\mathrm{p_R} - \mathrm{s_R})[-\int_0^{\theta_R q_R} F(x)\mathrm{d}x] + \theta_R q_R(p_R - c_R) - I(\eta)\end{aligned} \quad (16)$$

The process of proving the concavity of the Equation (16) is as follows.

First, we get its first derivative,

$$\begin{aligned}\frac{\partial \Pi}{\partial k_M^R} &= -(p_M - s_M) q_M a_M F(q_M a_M k_M^R + q_M b_M) + q_M a_M (p_M - c_M - \lambda_M F_M - d e_M) \\ &+ (p_R - s_R) q_R a_R F(q_R a_R + q_R b_R - q_R a_R k_M^R) - q_R a_R (p_R - c_R)\end{aligned}$$

then, the second derivative is obtained as follows,

$$\frac{\partial^2 \Pi}{\partial {k_M^R}^2} = -(p_M - s_M) {q_M}^2 {a_M}^2 f(q_M a_M k_M^R + q_M b_M) - (p_R - s_R) {q_R}^2 {a_R}^2 f(q_R a_R + q_R b_R - q_R a_R k_M^R) < 0$$

Obviously, the second derivative function is less than zero constant, so it is proved that the profit function of (M, R) is a concave function with a maximum value.

Theorem 3. *When the manufacturer and its retailer implement value by sharing green investment cost, the sum of their profits exists the maximum value.*

4.3.2. Feasible Interval

When the total profit of manufacturer and retailer after value co-creation is greater than the sum of the profits of the manufacturer and retailer before value co-creation, this value co-creation mode is considered to be meaningful. If we set $\prod_M$ and $\prod_R$ as the profit of the manufacturer and its retailer before value co-creation, then $\prod_M + \prod_R > \prod_{(M,R)}$, which is

$$\left\{\int_0^{\theta_M q_M}[p_M x + s_M(\theta_M q_M - x)]f(x)\mathrm{d}x + \int_{\theta_M q_M}^{+\infty}\theta_M p_M q_M f(x)\mathrm{d}x - \theta_M c_M q_M - \theta_M L_M - \theta_M T_M\right\} +$$
$$\left\{\int_0^{\theta_R q_R}[p_R x + s_R(\theta_R q_R - x)]f(x)\mathrm{d}x + \int_{\theta_R q_R}^{+\infty}\theta_R p_R q_R f(x)\mathrm{d}x - \theta_R c_R q_R\right\} - I(\eta)$$
$$-\left\{\int_0^{q_M}[p_M x + s_M(q_M - x)]f(x)\mathrm{d}x + \int_{q_M}^{+\infty} p_M q_M f(x)\mathrm{d}x - c_M q_M - L_M - T_M\right\}$$
$$-\left\{\int_0^{q_R}[p_R x + s_R(q_R - x)]f(x)\mathrm{d}x + \int_{q_R}^{+\infty} p_R q_R f(x)\mathrm{d}x - c_R q_R\right\} > 0$$

After simplification, we can get that

$$\begin{aligned}&(p_M - s_M)[-\int_0^{\theta_M q_M} F(x)dx] + \theta_M q_M(p_M - c_M - \lambda_M F_M - de_M)\\&+(p_R - s_R)[-\int_0^{\theta_R q_R} F(x)dx] + \theta_R q_R(p_R - c_R - \lambda_R F_R - de_R) - I(\eta)\\&-(p_M - s_M)[-\int_0^{q_M} F(x)dx] + q_M(p_M - c_M - \lambda_M F_M - de_M)\\&+(p_R - s_R)[-\int_0^{q_R} F(x)dx] + q_R(p_R - c_R) > 0\end{aligned}$$

In addition, according to Equations (7)–(12), and $F(x) = ax + b$, we take them into the above expressions, then we can get the inequality as follows

$$\begin{aligned}&-Z_M\left[\tfrac{a}{2}(a_M k_M^R + b_M)^2 q_M + b(a_M k_M^R + b_M)\right] + (a_M k_M^R + b_M)G_M\\&-Z_R\left[\tfrac{a}{2}(a_R - a_R k_M^R + b_R)^2 q_R + b(a_R - a_R k_M^R + b_R)\right] + (a_R - a_R k_M^R + b_R)G_R - I(\eta)\\&+Z_M(\tfrac{a}{2}q_M + b) - G_M + Z_R(\tfrac{a}{2}q_R + b) - G_R > 0\end{aligned}$$

By solving the above inequality, the effective interval of value co-creation between manufacturer and supplier can be obtained.

Proposition 3a. *During the situation when manufacturer and its retailer co-create value by sharing green investment cost, when $k_M^R \in (\varphi_5, \varphi_6)$, the sum of profits after co-creation is greater than before, which proves the positive effect of co-creation strategy, where φ_5, φ_6 are the two zero points of inequality.*

4.3.3. Extreme Point

After proving the concavity of profit function, we will start to calculate the value of k, and the profit function will take the maximum value at that time. The calculation process is as follows.

When $\prod_{(M,R)}$ takes the extreme value, the first derivative must be equal to zero, then,

$$\begin{aligned}&\tfrac{\partial \Pi}{\partial k_M^R} = -(p_M - s_M)q_M a_M F(q_M a_M k_M^R + q_M b_M) + q_M a_M(p_M - c_M - \lambda_M F_M - de_M)\\&+(p_R - s_R)q_R a_R F(q_R a_R + q_R b_R - q_R a_R k_M^R) - q_R a_R(p_R - c_R) = 0\end{aligned}$$

Similarly, according to Equations (7)–(12), $\theta_M = a_M k_M^R + b_M$ and $\theta_R = a_R(1 - k_M^R) + b_R$, then, we can get the first derivative function as follows,

$$\frac{\partial \Pi}{\partial k_M^R} = -Z_M a_M F(q_M\theta_M) + G_M a_M + Z_R a_R F(q_R - q_R\theta_R) - G_R a_R = 0$$

Through substituting $F(x) = ax + b$ into the above first derivative function, then,

$$Z_M a_M(a q_M\theta_M + b) - Z_R a_R(a q_R - a q_R\theta_R + b) = G_M a_M - G_R a_R$$

Then, we can get the value of θ_M at the present,

$$\theta_M = \frac{G_M a_M - G_R a_R + a q_R Z_R a_R - b[Z_M a_M - Z_R a_R]}{a[Z_M a_M q_M + Z_R a_R q_R]}$$

On account of the linear relationship between θ_M and k_M^R, we can get that,

$$\begin{aligned} k_M^R &= \frac{1}{a_M}(\theta_M - b_M) \\ &= \frac{1}{a_M}\left\{\frac{G_M a_M - G_R a_R + a q_R Z_R a_R - b[Z_M a_M - Z_R a_R]}{a[Z_M a_M q_M + Z_R a_R q_R]} - b_M\right\} \end{aligned}$$

Proposition 3b. *When the manufacturer and its retailer implement value by sharing green investment cost,*

(1) *When the manufacturer's share* $k_M^R =$

$$\frac{1}{a_M}\left\{\frac{G_M a_M - G_R a_R + a q_R Z_R a_R - b[Z_M a_M - Z_R a_R]}{a[Z_M a_M q_M + Z_R a_R q_R]} - b_M\right\}$$

the maximum of the sum of their profits after co-creation occurred;

(2) *When the allocation proportion is less than this value of extreme point, if the manufacturer M increases the proportion of investment, the sum of their profits will increase;*

(3) *When the allocation proportion is more than this value of extreme point, if the manufacturer M increases the proportion of investment, the sum of their profits will decrease.*

5. Numerical Study

5.1. Description of Scenario

China is the largest manufacturing country in the world. From 2014 to 2018, the added value of China's manufacturing industry grew steadily, and its contribution to GDP remained at about 30%. Manufacturing industry still played an important role in supporting China's economic growth. In 2016, China began to implement supply-side structural reform, and China's manufacturing industry entered a new stage of development [60]. However, as the manufacturing industry itself is an industry with great demand for natural resources, coupled with low utilization efficiency, it leads to excessive consumption of natural resources and environmental pollution at the same time in the process of economic development. At present, the indicators of chemical oxygen demand, nitrogen oxide, sulfur dioxide, ammonia nitrogen and carbon dioxide emissions in China all rank first in the world, so the implementation of the "green sustainable strategy" is imminent. The Chinese government has also promulgated various measures to promote firms to implement green changes, such as carbon tax policy and environmental subsidy policy. However, the high cost of change still makes many small and medium-sized enterprises face a dilemma. Therefore, China can be selected as a research environment with rich value co-creation strategies, because China's manufacturing industry has a high degree of experience relevance, and is currently striving to promote the green sustainable supply chain strategy.

5.2. Sample Selection

In this section, we choose the electronic parts industry with large carbon emissions as an example, because electronic accessories have a long demand cycle and relatively stable characteristics, and customer demand is random and less affected by other factors. This is consistent with the previous assumption (the assumption that the demand is uniformly distributed during the model building process).

The specific product selected for the numerical analysis is an electronic accessory U disk with a one-year calculation cycle. To simplify the supply chain, the members of the supply chain are a supplier, two competing manufacturers and a retailer. Then rationally allocate the parameters and bring them into the calculation formula in the previous chapter to calculate the profits and investment ratio of the supply chain members before and after the value co-creation, and illustrate the effect of the value co-creation on the profit of the supply chain members.

The data in this part comes from U disk industry statistical reports, e-commerce platform data and news reports, etc. We collected the six brands, six different storage capacity and their official prices respectively from e-commerce platform (i.e., J.D.Com) to calculate the average retailing prices. The manufacturing price and supplier materials' price are calculated from the overall profit margin of the U disk industry in the U disk industry statistical reports. The sum of the annual sales volume of the six U disk brands serves as the demand of retailers and suppliers. The obtained data relevant to price and quantities are shown in Table 2.

Table 2. Parameter replication without value co-creation.

	p(RMB)	c(RMB)	s(RMB)	q(10^7 units)
S	36	31	27	45
M	50	40	32	25
M′	52	40	32	20
R	75	60	53	45

As it is known that the electronic parts industry has certain pollution to the environment, the existence of carbon tax should be considered in the cost calculation. According to [61,62], set the price elasticity of energy and capital supply, and set other related elasticity according to economic principles. According to the “"China Carbon Tax Framework Design”, 1.9 tons of carbon dioxide will be generated per ton of raw coal consumed, and 3 tons of carbon dioxide will be generated per ton of crude oil consumed. According to the recommendations of the research group of the Ministry of Finance and the Planning Institute of the Ministry of Environmental Protection, China will levy a 50 yuan tax on carbon dioxide emissions per ton. Then, according to the consumption of coal and crude oil in the 2018 version of China Statistical Yearbook, the above data can be obtained, so that the carbon tax rate is 5%. Among the members of the supply chain, only manufacturers should consider carbon tax t, because the production process is easy to cause environmental pollution, so assume that the carbon tax of manufacturers M and M′ is T = 0.05.

After value co-creation among members of the supply chain, they will jointly invest in green technology. It can be seen from the above chapters that the formula of investment cost is: $I(\eta) = 1/2t\ \eta 2$, referring to the parameter assignment of other papers, η = 0.2, t = 1000.

Due to the high degree of automation, mechanization and air-tightness in the U-disk and other electronic accessories industries, production mainly relies on automated assembly lines. During the manufacturing process, less dust and harmful gases are produced so the industry has high production safety and the probability of personal accidents is very small. Therefore, the employee compensation L is not considered in the numerical analysis.

Through value co-creation among different members of the supply chain, although green investment costs increase, product emissions reduce. Taking into account policies and consumer preferences, market demand for products will increase. Taking the above data into the formula, we can get the sales growth θ under the different value co-creation strategies shown in Table 3.

Table 3. The change index of sales volume.

	θ_1	θ_2
(S, M)	1.0124	1.0153
(M, M′)	1.026	1.0175
(M, R)	1.0348	1.003

Therefore, even if the manufacturer shares part of the green investment cost, due to the increase in sales, its final profit may be higher than the original profit. Finally, the profit comparison results and investment ratios of the three supply chain green value co-creation strategies can be calculated. The results are shown in Table 4.

Table 4. Results.

	Π	$\prod'$	k
(S, M)	560	687.7	$K_M^S = 0.31$
(M, M')	693.4	769.7	$K_M^{M'} = 0.65$
(M, R)	586	980.5	$K_M^R = 0.87$

5.3. Results and Analysis

This section takes the domestic electronic parts industry in China as an example for numerical analysis, aiming to prove that value co-creation strategy can reduce the costs of all supply chain partners, improve their sales volume and increase their profits. Electronic parts, such as U disk, have the characteristics of long product cycle and stable demand, which are in line with the assumptions of the model in this study.

Numerical analysis shows that electronic parts manufacturing enterprises can achieve different degrees of profit growth by creating value with different firms in the upstream and downstream of the supply chain. For example, we found that when the co-creation coefficient K_M^S of manufacturer M and its upstream supplier S is 0.31, and the profit of M increases by 22.8%. M and its competitor M' co-create value, when the sum of profits is the best, the co-creation coefficient $K_M^{M'}$ is 0.65, and the profit of M increases by 11.0%. Similarly, when M and its retailer R co-create, the co-creation coefficient is 0.87, and M's profit increases by 67.3%.

Through numerical analysis, we found that the value co-creation coefficient of the manufacturer and its retailer is the largest, while the profit growth is the largest, which means that the co-creation degree of manufacturers and retailers is relatively deep, and manufacturers need to strongly support retailers to carry out green transformation so as to achieve their own profit growth. This phenomenon can be explained by the fact that in the era of increasing consumption capacity, the supply chain structure is changing from pushing to pulling. Therefore, customer preferences and satisfaction are particularly important for the entities in the supply chain to cultivate competitiveness. For the three value co creation strategies, co-creation with retailers is the most important.

6. Discussions and Conclusions

6.1. Summary and Discussion

Green supply chain (GSC) has become a hot topic in the field of supply chain. In China, the government has issued a series of guiding policies on the green development, proposing that green development is imperative to reduce the burden on the environment or to reduce the cost and promote the operational efficiency. Moreover, an increasing number of firms begin to cooperate with supply chain partners to develop green technologies and realize green production. Green development of the supply chain is a general trend around the world.

Green sustainability is an important development strategy of supply chain, but a single supply chain member often cannot bear all the costs of green investment, which requires cooperation between supply chain partners [2,3]. We believe that the cooperation mode of value co-creation can guide supply chain partners to invest in green technology and distribute benefits. Through the literature review, we have sorted out three modes of value co-creation: the manufacturer co-creates with its supplier, its competitor and its retailer. Such co-creation in the supply chain still involves operational or technological investment, for example, the manufacturer needs to change the production process, thus producing a huge green investment cost. Therefore, there is still a question that puzzles us: can this cooperation mode achieve real benefits?

Considering this problem, based on the three-level manufacturing supply chain, this paper proposes three co-creation cooperation selections from the perspective of the value co-creation, which can reduce the pressure of firms in the supply chain by sharing the cost of green investment and realize the whole supply chain green and sustainable. This article considered the uncertainty of demand, used the expectation formula of probability theory to establish a mathematical model, and discussed the total profit of the three co-creation models, respectively. In the process of analysis, we proved the concavity of three kinds of value functions and found the maximum value points. The results indicate that the impact factors are mainly stochastic product demand, production/purchase quantity, production/wholesale costs, green technology investment cost, carbon tax and compensation cost for physical accidents of employees and find that different co-creation strategies can indeed improve the firm profit in a certain range and achieve different maximum value in a certain green investment sharing point.

The technological upgrade and other costs in the process of green production are regarded as green investment costs. The value co-creation among supply chain partners shares these costs and reduces the pressure of a single supply chain member. At the same time, the use of green technologies makes products more popular, and the demand for products in the supply chain increases, resulting in an increase in total sales revenue. Through the model calculation, the increased income can offset the green investment cost in a certain range, and the numerical calculation also supports this result:

1. Value co-creation between the manufacture and its supplier Combined with the actual operational, we assume that when the manufacturer M and its supplier S implement value co-creation, it may affect the output, price and carbon tax of both parties. They can share the green investment with a certain proportion of k (i.e., the function of the change index of sales volume θ_M) to achieve the maximum value. In addition, we confirm that when k belongs to a certain range (i.e., determining by the total profit of selling q products without discount, the unit discount amount for each product in the case of discount, the total discount amount for selling q products in the case of discount and the fixed coefficients of M and S), value co-creation strategy has a positive impact on the interests of the supplier and the manufacturer;
2. Value co-creation between the manufacture and its competitor In addition to cooperation with upstream suppliers, it can also carry out technical cooperation with firms in the same industry to improve their competitive advantages. Therefore, we consider the situation that the manufacturer M and its competitor M' co-create to share the green investment. Similarly, through value co-creation, the sales price, output and green investment cost of both firms could be affected. If the allocation ratio k (i.e., the function of the change index of sales volume θ_M) is controlled within a reasonable range (i.e., determining by the total profit of selling q products without discount, the unit discount amount for each product in the case of discount, the total discount amount for selling q products in the case of discount and the fixed coefficients of M and M'), it can give full play to the advantages of value co-creation;
3. Value co-creation between the manufacture and its retailer The retailer is the company closest to the customer. The value co-creation between the manufacturer M and its retailer R can not only obtain consumer information, but also share the green cost with retailers, so as to meet the needs of customers to the greatest extent with minimum cost. Through mathematical derivation,

we confirm the positive effect of value co-creation on the profits of manufacturers and retailers (i.e., the function of the change index of sales volume θ_M).

6.2. Implications

The conclusions of this study also have theoretical and practical significance for the research on value co-creation under the GSC strategy. From the theoretical perspective, this paper studied the implementation of GSC strategy from the perspective of co-creation, which provides a new perspective of supply chain co-creation. Moreover, this paper considered the co-creation behavior between the manufacture and its upstream/downstream entities, as well as competitors, while most other studies only focus on the co-creation between firms and their customers. Thus, this paper improves the application of co-creation theory in supply chain. In the practical perspective, this paper provided three co-creation options, and gave a reasonable range of cost sharing proportion. It provides confidence for firm managers to co-create value with their partners, and promotes the effective implementation of GSC strategy. When the manufacturer maintains a good relationship with its supplier, it can choose the strategy of value co-creation with supplier to improve its safety of production environment and increase the output. Similarly, the manufacturer can implement the strategy of co-creation with its retailer if there is a good cooperation between them. Moreover, in the same industry, cooperation should be more important than competition among manufacturers. Therefore, manufacturers can co-create value with their competitors and share the cost of green investment, so as to produce higher quality products and improve industry standards.

6.3. Limitations and Future Researches

This study has several limitations, and opportunities exist to extend this research in the future. First, this paper only considers the co-creation of two entities in the supply chain, but in practice, the implementation of the supply chain strategy involves multiple members upstream and downstream. Thus, future research can consider the value co-creation of multi-bodies in the supply chain. Second, this paper only considers the increase in product sales after the cost-sharing of green investment, but there are other impacts brought on by the value co-creation, such as the decrease in risk and the increase in consumer expectation price. Thus, future research can continue to explore and confirm other advantages caused by co-creation. Third, this paper only verifies the benefits of cost sharing of green investment through mathematical reasoning, rather than obtaining real data for actual example verification. Thus, future research can make further case study based on this paper to get more practical conclusions.

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