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A Model of Waste Price in a Symbiotic Supply Chain Based on Stackelberg Algorithm

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Abstract: By establishing a two-level symbiotic supply chain system consisting of one supplier and one manufacturer, we use Stackelberg method to analyze the optimal price and revenue model of supplier and manufacturer in the symbiotic supply chain under two power structures in which the supplier and manufacturer are dominant respectively, and analyze the influence of the degree of symbiosis and power structure on the model. Through comparative analysis, we find that: There is a relationship between the income level and the degree of symbiosis in the symbiotic supply chain. The change of power structure will affect the relative benefits of suppliers and manufacturers in the symbiotic supply chain. The manufacturer's expected unit product revenue will affect the supply chain revenue when the manufacturer is dominant. Finally, the sensitivity analysis of relevant parameters is carried out through an example analysis, and the validity of the conclusion is verified. This paper has a guiding significance for the behavior of enterprises in the cogeneration supply chain.

Keywords: symbiotic supply chain; power structure; recycling of waste; Stackelberg; the degree of symbiosis



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1. Introduction

In recent years, with the attention of the international community to the environmental pollution caused by economic development, green development or sustainable development has gradually become the common consensus of all countries. Current initiatives and subsidies for greener production and less wasteful resources have led companies to become more active. However, when enterprises carry out a series of activities, the extra energy and cost of environmental governance will occupy the capital of enterprises used for production activities, resulting in low enthusiasm of enterprises to carry out carbon emission reduction. Therefore, enterprises are constantly looking for new ways of green development so that they can make their own contribution to green development without damaging their own profits. On this basis, in the context of sharing economy, the formation and development of the symbiotic supply chain for the purpose of realizing waste sharing has made an important contribution to helping enterprises achieve green development [1,2].

The emergence and development of symbiotic supply chain has a great relationship with sharing economy and industrial symbiosis. The sharing economy was first developed by Marcus Felson and Joe L. Spaeth was proposed with the concept of Collaborative Consumption [3]. Later, Rachel Botsman proposed three development stages of sharing economy: code sharing, life or content sharing, and offline resource sharing [4]. The sharing economy is gradually extending from online to offline entities. The types of sharing economy can be product and service system, redistributive market, and collaborative lifestyle [4].

Industrial symbiosis was first used to describe the organic relationship between different industries, including the waste of one industry as the input of another industry [5]. In the research related to supply chain, industrial symbiosis is an important research topic,

and symbiosis supply chain is also based on the concept of industrial symbiosis [6,7]. In the context of sharing economy, industrial symbiosis within the symbiotic supply chain is conducive to the win-win situation of economy and environment within the supply chain [8] and the realization of green and sustainable development [9,10]. In the symbiotic supply chain, the waste produced by one enterprise can be used by another enterprise as raw materials for production, so that the idle resources can be used reasonably. In the context of sharing economy, resource sharing within the supply chain is already being done by many enterprises. In the supply chain, the wastes generated by enterprises in the production process can be transformed into certain resources, which can be imported into the downstream enterprises for further processing and production to form products that can flow to the market, thus replacing raw materials and reducing enterprises' costs.

The stable symbiotic relationship formed among enterprises in the symbiotic supply chain can help the upstream enterprises to reduce the cost of waste non-polluting treatment, and help the downstream enterprises to obtain resources to replace raw materials, so as to realize the recycling process of waste and realize the sharing of waste resources. However, the power between enterprises that form a symbiotic relationship is not necessarily balanced. When different enterprises have advantages, will the income and cost of supply chain enterprises change? In addition, what is the degree of symbiosis among the enterprises that form symbiosis, and will it affect the symbiosis supply chain? The above problems are of great value to be discussed.

Therefore, this paper will study the internal problems of the symbiotic supply chain by means of waste sharing. In particular, it will study the supplier and the manufacturer of the secondary symbiotic supply chain as the study subject by constructing a dynamic game model of the supplier and the manufacturer to explore the supplier and the manufacturer that are dominant under the two kinds of power structure of symbiosis in the supply chain suppliers and manufacturers that have the most superior price and profit model. The study analyzes the influence of the degree of symbiosis and the power structure of the model. Finally, it is verified by numerical simulation.

The research content of this paper is new compared with the existing research. Specifically, there are few researches on the concept of symbiotic supply chain, and most researches are on the concept of symbiotic supply chain itself. Secondly, when studying the symbiotic supply chain, this paper adds the consideration of the power structure, and comprehensively considers the benefits of the symbiotic supply chain from the situation that the supplier and the manufacturer are respectively dominant.

Based on the Stackelberg game and the numerical simulation analysis, we draw the following conclusion: the yield of the symbiotic supply chain is related to the degree of symbiosis. The change of power structure will affect the relative benefits of suppliers and manufacturers in a symbiotic supply chain. A manufacturer's expected revenue per unit product will influence supply chain revenue when the manufacturer is dominant.

2. Literature Review

In this section, we will make a detailed review of the literature related to this study, respectively from two aspects: related studies on symbiotic supply chain and the influence of power structure on supply chain. Studies on symbiotic supply chain are used to describe the source of symbiotic supply chain and what contribution symbiotic supply chain makes to green development compared with ordinary supply chain. Sorting out the literature related to power structure can help us understand its important role in the supply chain and understand the essential differences between different power structures. It helps us to analyze its role in the symbiotic supply chain.

2.1. Discussion on Symbiotic Supply Chain

Symbiotic supply chain comes from the study of industrial symbiosis. The earliest definition of industrial symbiosis comes from Frosh: waste from one process can be used as raw material for another, thereby reducing the impact of industry on the environment [11].

Symbiotic supply chain is produced by the symbiosis of traditional industries, but it is different from the symbiosis of traditional industries. In the symbiotic supply chain, waste is mainly exchanged between suppliers and manufacturers, and the products produced by suppliers are not necessarily provided to enterprises in the middle and lower reaches of the supply chain [12]. Therefore, symbiotic supply chain is considered as a network composed of suppliers, manufacturers, distributors, and customers to realize efficient resource utilization by providing products, by-products, and wastes [12]. The lack of scientific and effective waste management mechanism in the supply chain leads to the accumulation of waste and the failure of effective utilization. Industrial symbiosis can be used as an effective way to realize waste recycling among enterprises [13,14] and help enterprises to effectively circulate waste, so as to realize rational utilization and sharing of resources. Through the analysis of large distributors in the UK, industrial symbiosis is integrated into the supply chain, which is believed to be able to help realize the exchange of wastes in the supply chain, thus greatly reducing the damage of wastes to the environment [15]. Industrial symbiosis in the supply chain can realize supply chain network cooperation and improve regional competitiveness through the recycling and utilization of enterprise by-products and wastes [16]. Through the establishment of a mathematical model, the study shows that the cooperation among members in the supply chain is conducive to helping enterprises obtain higher retail prices and more profits [17]. In a Stackelberg game to study the park's waste, the skill of establishing a price model shows that when the marginal cost of recycling waste between enterprises is lower than the cost of purchasing raw materials, enterprises are more inclined to establish a symbiotic relationship, and the increase of the degree of symbiosis also increases the enterprise's income [18,19].

In the study of waste, industrial symbiosis has become an important perspective, which can help coordinate the relationship between different subjects in the supply chain, realize the flow and integration of resources in the supply chain, and thus promote the green economic development [20]. In a closed-loop supply chain consisting of a single manufacturer and a single retailer, waste exchange between the manufacturer and the retailer can guarantee the profits of both manufacturers and retailers under decentralized decision-making through an improved two-step pricing contract [21]. In a three-level supply chain consisting of collectors, recyclers, and manufacturers, the collector is responsible for collecting wastes, the recycler is responsible for recycling, and the manufacturer is responsible for processing and reproducing the wastes collected from collectors and recyclers. When collectors and recyclers have the same power structure, the competitive cooperative relationship between them does not influence the decisions of members in the supply chain. When the two have different power structures, the manufacturer will choose to buy wastes from the collector, and the profit obtained by the manufacturer is lower than that under the same power structure [22]. In the urban supply chain, various symbiotic relationships for the purpose of waste resource form a symbiotic network, which can realize efficient recycling and utilization of waste [13,23]. Some researchers use PDIPBB method (primal-dual interior-point and branch-and-bound methods) to solve the problem of multi-objective optimization, so as to obtain a solution to maximize the use of waste and minimize the cost in the supply chain [24,25]. A symbiotic supply chain can help enterprises to gain higher ability to resist interruption risk. Simple interruption will only affect directly related enterprises and not the whole supply chain. However, complex changes such as the change of waste disposal cost will affect the income of multiple enterprises in the supply chain [26]. Studies on closed-loop supply chain in the food industry have shown that resource reprocessing activities can be reduced by treating the inevitable wastes generated in the production process and making them return to the supply chain cycle as production materials [27].

2.2. The Influence of Different Power Structures on Supply Chain

The different power structure of the members in the supply chain will influence the supply chain. Existing scholars have conducted a large number of different rights structures on the impact of traditional supply chain and other supply chains. Earlier studies explored the source and influence of power of members, including power source, conflict, satisfaction, performance, etc. [28]. Ghosh and Shan respectively analyzed three conditions: in a two-level supply chain, each member is the dominant Stackelberg equilibrium and two members have the same position Nash equilibrium, and compared these three conditions [29]. Song and Gao showed through the revenue sharing contract and the research that the use of revenue sharing contract can achieve partial coordination of the supply chain, but it is difficult to achieve the optimal profit under the centralized decision [30]. In the supply chain consisting of two manufacturers and one retailer at the same time, in the context of three power structures of fee cooperation game, the manufacturer has the incentive to adopt exclusive distribution, while the retailer is more willing to conduct transactions with multiple manufacturers [31]. In the centralized and decentralized closed-loop supply chain including manufacturers and retailers, when the retailer has higher power, the retailer's profit will increase gradually with the increase of power, and the manufacturer's profit will decrease with the reduction of the retailer's demand for receiving waste. At the same time, the optimal power structure will change with the change of waste receiving demand [32]. The expected demand in the supply chain determines whether an enterprise can benefit from the supply chain, and the reduction of demand uncertainty will lead to the increase of manufacturer's earnings and the decrease of retailer's earnings [33]. Under three different power structures, price discount and pricing scheme will influence the supply chain. In the case that retailers are in the ascendant, price discount can increase the income of suppliers and retailers, and no price discount will bring more income to retailers [34,35]. In a two-channel supply chain consisting of manufacturer and retailer, when the cross-price elasticity of demand is 0, there is no difference in the equilibrium solution of supply chain competition between manufacturer and retailer. However, when the cross-price elasticity is not 0, the traditional channel price reaches the highest in the case dominated by retailers and the lowest in the case dominated by manufacturers [36].

In a supply chain consisting of a single manufacturer and a single retailer with both offline and online channels, by establishing a Stackelberg game between manufacturer and retailer and Nash game in which both parties have the same position, the profit and price of both manufacturers and retailers will decrease with the decrease of their dominant position [37]. In a second-level dual-channel supply chain decision making with different authority using Stackelberg game method, a manufacturer can always achieve the optimal situation in a retailer-dominated situation, and the optimal situation of a second-level retailer depends on the change of the manufacturer's effort cost coefficient and the consumer's heterogeneous preference structure [38,39]. In the single-channel secondary supply chain consisting of a single manufacturer and a single retailer, the expected profit of the sales enterprise in the leading position when taking decentralized decisions in clearance sale is decreasing, while the profit of the manufacturing enterprise is increasing. When centralized collaborative decision-making is adopted, the profits of both manufacturing and sales enterprises are increasing [40].

To sum up, previous studies have made great contributions to the research on industrial symbiosis and supply chain. However, the research is based on complete symbiosis. When incomplete symbiosis exists in the supply chain, it is still a question worth studying whether the above research can be established. Based on the above analysis, this paper established a secondary symbiosis of waste material supplier and the manufacturer supply chain system, using Stackelberg game method, research in supply chain completely symbiosis symbiotic symbiosis with incomplete state, the supplier and the manufacturer under the condition of each own, the price of each enterprise, profit model, and carries on the analysis.

3. Model Description and Assumptions

Before the formal analysis begins, we will first give a brief overview of the process of using Stackelberg game to analyze the parties within a symbiotic supply chain.

First, we will describe the symbiotic supply chain mentioned above. Second, on this basis, make assumptions about the conditions of use. Third, summarize and define the meanings of the variables that appear in the article. Fourthly, based on assumptions, we use known variables to solve the optimal return and price functions. Fifth, considering the influence of different power structures, this paper will discuss the revenue and price functions in the two cases of supplier dominance and manufacturer dominance respectively, and draw several inferences. Sixth, numerical simulation is used to analyze the internal revenue of the symbiotic supply chain under the condition of given partial parameter values. Finally, based on all the above analysis, several conclusions are drawn. The specific process is shown in Figure 1.

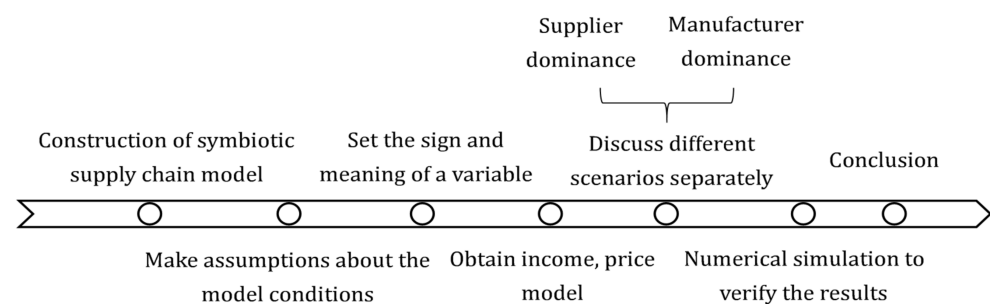


Figure 1. Steps of Stackelberg game.

3.1. Model Description

In this paper, a two-level single-channel symbiotic supply chain system composed of suppliers and manufacturers is established. Suppliers and manufacturers represent waste suppliers and manufacturers, and waste flow exists between them, but there is not necessarily flow of raw materials and products. By processing waste from suppliers and converting it into raw materials needed for commodity production, manufacturers enter into a new cycle, which brings benefits to suppliers and manufacturers in the symbiotic supply chain and reduces the damage caused by waste to the environment.

The symbiotic supply chain model is shown in Figure 2. The symbiotic supply chain is different from the traditional supply chain. In the symbiotic supply chain, waste suppliers and manufacturers may come from different locations in different supply chains, but they form a new symbiotic supply chain due to the supply and demand relationship of waste, and waste is exchanged between them instead of products. In the symbiotic supply chain, the raw materials required by the manufacturer for production are all from waste suppliers in the complete symbiotic state, and in the incomplete symbiotic state, they are partly from waste suppliers and partly from raw material suppliers in the supply chain where the manufacturer is located.

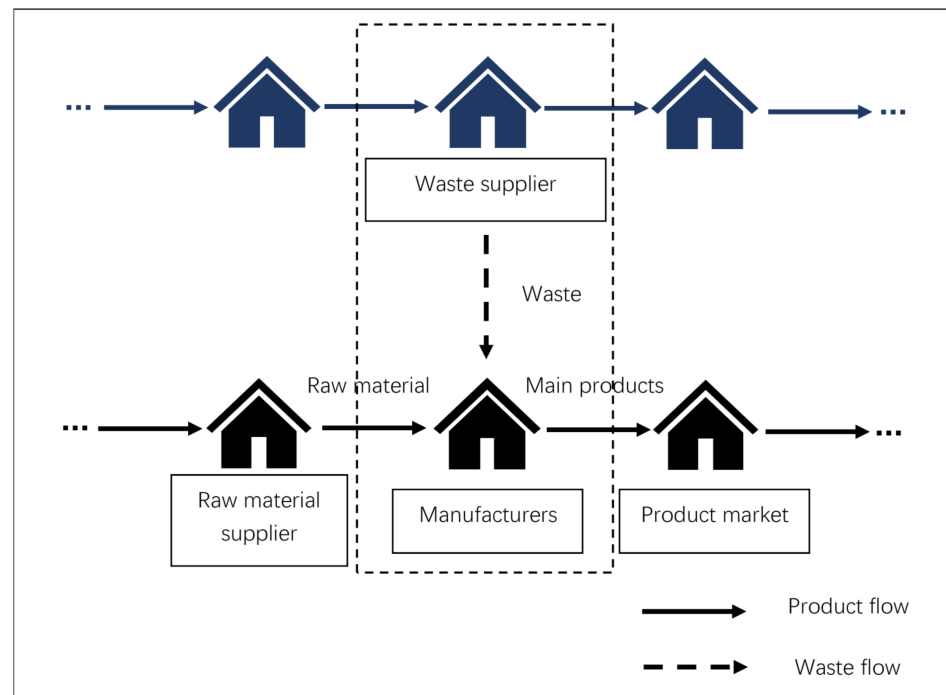


Figure 2. Symbiotic supply chain diagram.

3.2. Assumptions

The model established in this paper is based on the states under ideal conditions. In real life, the income of symbiotic supply chain receives the joint action of many factors. However, in order to highlight the main research factors in the study. Therefore, based on the assumptions made by existing studies on environmental conditions in supply chain analysis using Stackelberg game [37,41], this paper first makes the following assumptions for the model:

Hypothesis 1. *Both the supplier and the manufacturer take profit maximization as the decision criterion.*

Hypothesis 2. *The preference of the market for the main product produced from raw materials and the main product produced from waste is the same, and there will be no change of preference due to the change of materials.*

Hypothesis 3. *The supplier's cost is less than the exchange price of the waste and the manufacturer's cost is less than the selling price of the main product.*

4. Model Establishment and Solution

According to the assumptions of the model mentioned above, the model of supplier and manufacturer's price and earnings in the symbiotic supply chain is analyzed by Stackelberg game.

First, the symbols used in this article and their meanings are shown in Table 1.

Table 1. Income solution table of enterprise A in supply chain.

Symbolic	Meaning
P_s	The exchange price of waste produced by the supplier
P_m	The selling price of the main product produced by the manufacturer
P_0	The price of raw materials consumed by the manufacturer for each unit of the main product produced
D_m	The amount of waste exchanged between suppliers and manufacturers
D	The total amount of the main product produced by the manufacturer
C_1	Unit cost of waste disposal by supplier
C_2	The unit cost of recycling waste by a manufacturer
C_3	Unit cost for a manufacturer to produce the main product
π_s	Total revenue generated by suppliers
π_m	The total revenue generated by the manufacturer
π	Total revenue in a symbiotic supply chain
n	The degree of symbiosis of the supply chain
a	The largest market demand for the main product produced by the manufacturer

The products produced by the manufacturer flow to the final market and are traded at the market price P_m . The maximum market demand is a . We assume that the demand produced by the manufacturer is a linear function of the market price, and the price elasticity coefficient is 1, then the market demand function of the products produced by the manufacturer can be expressed as:

$$D = a - P_m \quad (1)$$

In the symbiotic supply chain, in the state of complete symbiosis, all raw materials needed by the manufacturer for production are provided by the supplier. Then, the demand for waste is equal to the market demand for the main product. In the incomplete symbiosis state, only part of the raw materials needed by the manufacturer come from the supplier. Then, the demand function of waste can be expressed as:

$$D_m = n \cdot D \quad (2)$$

where n is the degree of symbiosis, which represents the part of the raw materials converted from waste by the supplier.

In a two-stage symbiotic supply chain consisting of supplier and manufacturer, the corresponding cost structure of supplier and manufacturer will change after the symbiotic relationship is formed.

For suppliers, in the symbiotic state, waste sales revenue will be obtained and waste disposal cost will be saved. For manufacturers, the formation of symbiosis will bring waste procurement costs. The benefits and costs of establishing a symbiotic relationship between supplier and manufacturer are shown in Figure 3.

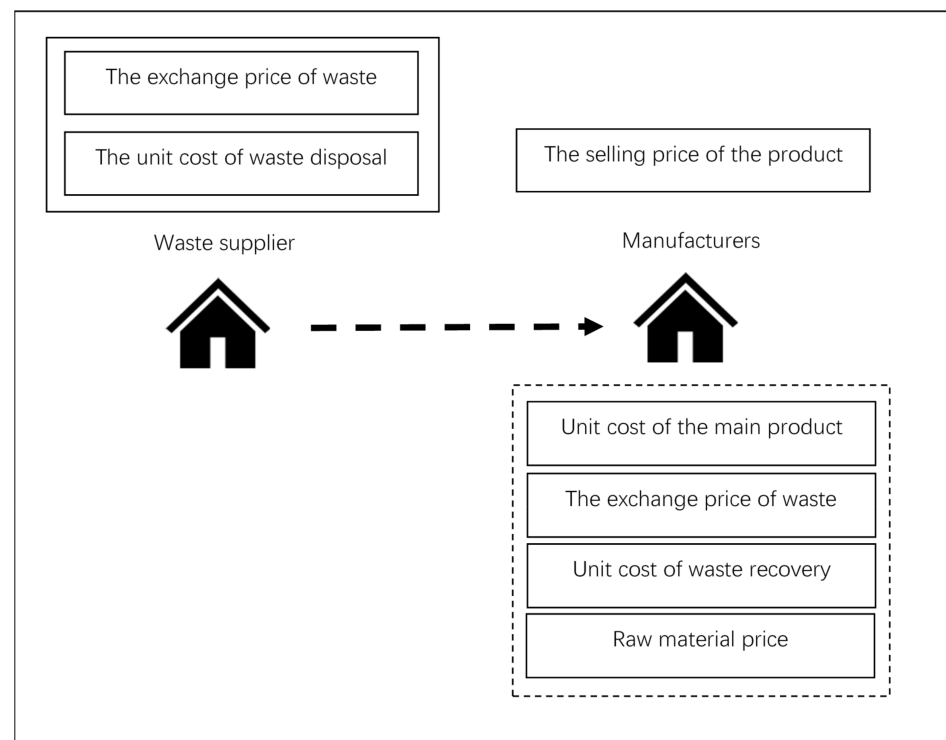


Figure 3. The supplier and manufacturer benefit cost in the symbiotic relationship.

Therefore, in the symbiotic supply chain, the supplier, manufacturer, and supply chain revenue models are respectively:

$$\pi_s = (P_s + C_1)D = (P_s + C_1)n(a - P_m) \quad (3)$$

$$\pi_m = (P_m - C_3)D - n(P_s + C_2)D - (1 - n)P_0D \quad (4)$$

$$\pi_m = a - P_m[(P_m - C_3) - n(P_s + C_2) - (1 - n)P_0] \quad (5)$$

$$\pi = \pi_s + \pi_m$$

where π_s represents the income of suppliers, π_m represents the income of manufacturers, and π represents the income of the whole symbiotic supply chain.

According to the definition of each variable, the following relationships can be obtained:

$$a > P_m, P_m > P_s + C_1, P_m > P_0 + C_3.$$

In the incomplete symbiosis, $0 < n < 1$. In the complete symbiosis, $n = 1$.

Due to the different forms of price functions under different power structures, the situation of supplier dominance and manufacturer dominance are discussed in the following part.

After the assignment and expression of variables in the symbiotic supply chain, the optimal price and revenue of suppliers and manufacturers as well as the revenue of the whole symbiotic supply chain will be analyzed respectively in terms of supplier dominance and manufacturer dominance.

In the case of supplier dominance, the supplier occupies the leading position in the price decision. First, the manufacturer determines the optimal price according to its own optimal revenue, and then the manufacturer determines its own price based on the price determined by the supplier. So, when we're doing this, we're going to do it backwards. First, take the derivative of the manufacturer's revenue to get a price. Secondly, the optimal price is brought into the supplier revenue model, and the derivative of the optimal price is obtained. Then, according to the relationship between the supplier and the manufacturer's

optimal price, the manufacturer's optimal price is obtained. Finally, according to the optimal price of suppliers and manufacturers, the benefits of suppliers, manufacturers, and the whole supply chain are obtained.

Similarly, in the case of manufacturer dominance, the manufacturer occupies the leading position in price decision and first determines the optimal price according to its own optimal revenue. Then, the supplier determines its own price based on the manufacturer's price determination. So, when we are doing this, we are going to do it backwards. In this case, the manufacturer will first determine a unit product earnings value, so we need to adjust the supplier and manufacturer's price and revenue model on this basis. Secondly, the derivative of supplier revenue is obtained to obtain the supplier's optimal price. Next, the optimal price is brought into the manufacturer's revenue model, and the derivative is taken to obtain the manufacturer's optimal price. Finally, according to the optimal price of suppliers and manufacturers, the benefits of suppliers, manufacturers, and the whole supply chain are obtained.

4.1. Stackelberg Model of Supplier Dominance

In the state of supplier dominance, the supplier is in the leading position and the manufacturer is in the following position. The supplier makes the price decision first. The specific order is as follows: the supplier first determines the optimal price, and the manufacturer selects the optimal price according to the supplier's price.

Therefore, according to the reverse solution process of game theory, the manufacturer will select the optimal price P_m based on the price P_s determined by the supplier. We obtain the derivative of Equation (4) with respect to P_m , and make it equal to 0, and get:

$$P_m = \frac{a+P_0+C_3+n(P_s+C_2-P_0)}{2} \quad (6)$$

Then, put the solved P_m into Equation (3) to get the profit value of the supplier:

$$\pi_s = \frac{n(P_s+C_1)[a-(1-n)P_0-nP_s-C_3-nC_2]}{2} \quad (7)$$

Then, the derivative of Equation (7) with respect to P_s is calculated and set to be equal to 0 to get the supplier's optimal price:

$$P_s^* = \frac{a-(1-n)P_0+nC_1-nC_2-C_3}{2n} \quad (8)$$

Then put P_s into Equation (6) to get the supplier's optimal price:

$$P_m^* = \frac{3a+(1-n)P_0+nC_1+nC_2+C_3}{4} \quad (9)$$

So far, we have obtained the optimal price model P_s^* and P_m^* of suppliers and manufacturers under the condition of supplier dominance, and then put it into Equations (1) and (2) to obtain the demand model under the state of supplier possession:

$$D = a - P_m = \frac{a-(1-n)P_0+nC_1-nC_2-C_3}{4} \quad (10)$$

$$D_m = n \cdot D = \frac{n[a-(1-n)P_0+nC_1-nC_2-C_3]}{4} \quad (11)$$

P_s^* and P_m^* are substituted into Equations (4) and (5) to obtain the total revenue model of suppliers, manufacturers, and symbiotic supply chain under the state of supplier dominance:

$$\pi_s = \frac{[a-(1-n)P_0+nC_1-nC_2-C_3]^2}{8} \quad (12)$$

$$\pi_m = \frac{[a-(1-n)P_0+nC_1-nC_2-C_3]^2}{16} \quad (13)$$

$$\pi = \frac{3[a-(1-n)P_0+nC_1-nC_2-C_3]^2}{16} \quad (14)$$

4.2. Stackelberg Model of Manufacturer Dominance

When the manufacturer is in the dominant position, the manufacturer is in the leading position and the supplier is in the following position. The manufacturer makes the price decision first. The specific order is as follows: the manufacturer first determines the optimal price, and the supplier selects the optimal price according to the supplier's price.

Therefore, according to the reverse solution process of game theory, the supplier will choose the optimal price P_s based on the manufacturer's price P_m . Let's assume that the manufacturer first determines the unit profit value of m :

$$P_m = n(P_s + C_2) + (1 - n)P_0 + C_3 + m \quad (15)$$

Then, the profit value of the supplier can be expressed as:

$$\pi_s = (P_s + C_1)D = (P_s + C_1)n[a - n(P_s + C_2) + (1 - n)P_0 + C_3 + m] \quad (16)$$

We take the derivative of Equation (16) with respect to P_s and make it equal to 0, and get:

$$P_s^* = \frac{a - (1 - n)P_0 - m - nC_1 - nC_2 - C_3}{2n} \quad (17)$$

Substituting Equation (17) into Equation (4) can obtain the manufacturer's profit value represented by P_m :

$$\pi_m = a - P_m \left\{ (P_m - C_3) - n \left[\frac{a - (1 - n)P_0 - m - nC_1 - nC_2 - C_3}{2n} + C_2 \right] - (1 - n)P_0 \right\} \quad (18)$$

Take the derivative of Equation (18) with respect to P_m and make it equal to 0, then the manufacturer's optimal price model can be obtained:

$$P_m^* = \frac{3a + (1 - n)P_0 - m - nC_1 + nC_2 + C_3}{4} \quad (19)$$

So far, we have obtained the optimal price model P_s^* and P_m^* of suppliers and manufacturers under the condition of supplier dominance, and then put it into Equations (1) and (2) to obtain the demand model under the state of supplier possession:

$$D = a - P_m = \frac{a - (1 - n)P_0 + m + nC_1 - nC_2 - C_3}{4} \quad (20)$$

$$D_m = n \cdot D = \frac{n[a - (1 - n)P_0 + m + nC_1 - nC_2 - C_3]}{4} \quad (21)$$

P_s^* and P_m^* are substituted into Equations (4) and (16) to obtain the total revenue model of suppliers, manufacturers, and symbiotic supply chain under the state of supplier dominance:

$$\pi_m = \frac{[a - (1 - n)P_0 + m + nC_1 - nC_2 - C_3]^2}{16} \quad (22)$$

$$\pi_s = \frac{[a - (1 - n)P_0 - m + nC_1 - nC_2 - C_3]^2}{8} \quad (23)$$

$$\pi = \frac{[a - (1 - n)P_0 + m + nC_1 - nC_2 - C_3]^2}{16} + 2 \frac{[a - (1 - n)P_0 - m + nC_1 - nC_2 - C_3]^2}{16} \quad (24)$$

To sum up, the price, income, and demand models of suppliers and manufacturers are obtained under the two conditions of supplier dominance and manufacturer dominance, as shown in Table 2:

Table 2. Price, revenue, and demand model summary under different states.

	Partial Symbiosis	Complete Symbiosis
Supplier dominance	$P_s^{11} = \frac{a-(1-n)P_0+nC_1-nC_2-C_3}{2n}$	$P_s^{12} = \frac{a+C_1-C_2-C_3}{2}$
	$P_m^{11} = \frac{3a+(1-n)P_0+nC_1+nC_2+C_3}{4}$	$P_m^{12} = \frac{3a+C_1+C_2+C_3}{4}$
	$D^{11} = \frac{a-(1-n)P_0-nC_1-nC_2-C_3}{4}$	$D^{12} = \frac{a-C_1-C_2-C_3}{4}$
	$D_m^{11} = \frac{n[a-(1-n)P_0-nC_1-nC_2-C_3]}{4}$	$D_m^{12} = \frac{a-C_1-C_2-C_3}{4}$
	$\pi_s^{11} = \frac{[a-(1-n)P_0+nC_1-nC_2-C_3]^2}{8}$	$\pi_s^{12} = \frac{[a+C_1-C_2-C_3]^2}{8}$
	$\pi_m^{11} = \frac{[a-(1-n)P_0+nC_1-nC_2-C_3]^2}{16}$	$\pi_m^{12} = \frac{[a+C_1-C_2-C_3]^2}{16}$
Manufacturer dominance	$P_s^{21} = \frac{a-(1-n)P_0-m-nC_1-nC_2-C_3}{2n}$	$P_s^{22} = \frac{a-m-C_1-C_2-C_3}{2}$
	$P_m^{21} = \frac{3a+(1-n)P_0-m-nC_1+nC_2+C_3}{4}$	$P_m^{22} = \frac{3a-m-C_1+C_2+C_3}{4}$
	$D^{21} = \frac{a-(1-n)P_0+m+nC_1-nC_2-C_3}{4}$	$D^{22} = \frac{a+m+C_1-C_2-C_3}{4}$
	$D_m^{21} = \frac{n[a-(1-n)P_0+m+nC_1-nC_2-C_3]}{4}$	$D_m^{22} = \frac{a+m+C_1-C_2-C_3}{4}$
	$\pi_s^{21} = \frac{[a-(1-n)P_0+m+nC_1-nC_2-C_3]^2}{16}$	$\pi_s^{22} = \frac{[a+m+C_1-C_2-C_3]^2}{16}$
	$\pi_m^{21} = \frac{[a-(1-n)P_0-m+nC_1-nC_2-C_3]^2}{8}$	$\pi_m^{22} = \frac{[a-m+C_1-C_2-C_3]^2}{8}$

4.3. Comparative Analysis

In this part, according to the above analysis and summary of price, income, and demand of suppliers and manufacturers under the two power structures, the results are analyzed to explore the influence of different authority and different degree of symbiosis on enterprises in the symbiotic supply chain.

Corollary 1. *In a supplier-led two-stage symbiosis supply chain, the benefits of suppliers under complete and partial symbiosis are greater than those of manufacturers.*

The proof can be easily seen from Table 2:

$$\pi_s^{11} - \pi_m^{11} = \frac{[a - (1 - n)P_0 + nC_1 - nC_2 - C_3]^2}{16}$$

According to the definitions of a , P_0 , C_1 , C_2 , and C_3 ,

$$\pi_s^{11} - \pi_m^{11} > 0$$

$$\pi_s^{12} - \pi_m^{12} = \frac{[a + C_1 - C_2 - C_3]^2}{16}$$

According to the definition of a , C_1 , C_2 and C_3 ,

$$\pi_s^{12} - \pi_m^{12} > 0$$

In short, that is to say, the partial symbiotic and complete symbiotic earnings of suppliers are greater than those of manufacturers.

Corollary 2. *In a two-stage symbiotic supply chain dominated by manufacturer, the value of profit of supplier and manufacturer depends on m value.*

Proof. In the partial symbiosis state dominated by the manufacturer, \square

$$\pi_s^{21} - \pi_m^{21} = \frac{2[a - (1 - n)P_0 - m + nC_1 - nC_2 - C_3]^2 - [a - (1 - n)P_0 + m + nC_1 - nC_2 - C_3]^2}{16}$$

The first derivative of m is obtained as follows:

$$\frac{df}{dm} = \frac{3C_3 + 3nC_2 - 3nC_1 + 3(1-n)P_0 + m - 3a}{8}$$

The second derivative with respect to m is:

$$\frac{d^2f}{dm^2} = \frac{1}{8}$$

This indicates that the difference of earnings between suppliers and manufacturers presents a trend of decreasing first and then increasing. It is not going to have a definite sign, depending on the value of m .

When $m = (3 - 2\sqrt{2})[a - (1-n)P_0 + nC_1 - nC_2 - C_3]$ or $m = (3 + 2\sqrt{2})[a - (1-n)P_0 + nC_1 - nC_2 - C_3]$, $\pi_s^{21} - \pi_m^{21} = 0$, and the supplier and the manufacturer's earnings are the same.

When $m = (3 - 2\sqrt{2})[a - (1-n)P_0 + nC_1 - nC_2 - C_3] < m < (3 + 2\sqrt{2})[a - (1-n)P_0 + nC_1 - nC_2 - C_3]$, $\pi_s^{21} - \pi_m^{21} < 0$, in which case the profit of the supplier is less than the profit of the manufacturer.

When $m < (3 - 2\sqrt{2})[a - (1-n)P_0 + nC_1 - nC_2 - C_3]$ or $m > (3 + 2\sqrt{2})[a - (1-n)P_0 + nC_1 - nC_2 - C_3]$, $\pi_s^{21} - \pi_m^{21} < 0$, in which case the profit of the supplier is greater than the profit of the manufacturer.

Similarly, it can be obtained in a state of complete symbiosis:

When $m = (3 - 2\sqrt{2})[a + C_1 - C_2 - C_3]$ or $m = (3 + 2\sqrt{2})[a + C_1 - C_2 - C_3]$, $\pi_s^{22} - \pi_m^{22} = 0$, and the supplier and the manufacturer's earnings are the same.

When $(3 - 2\sqrt{2})[a + C_1 - C_2 - C_3] < m < (3 + 2\sqrt{2})[a + C_1 - C_2 - C_3]$, $\pi_s^{22} - \pi_m^{22} < 0$, in which case the profit of the supplier is less than the profit of the manufacturer.

When $m < (3 - 2\sqrt{2})[a + C_1 - C_2 - C_3]$ and $m > (3 + 2\sqrt{2})[a + C_1 - C_2 - C_3]$, $\pi_s^{22} - \pi_m^{22} > 0$, in which case the profit of the supplier is greater than the profit of the manufacturer.

It can be seen from Corollary 2 that the determination of the manufacturer's m value is related to the earnings of both the supplier and the manufacturer in the symbiotic supply chain. At the same time, the change of m value will lead to the change of relative value of the difference between supplier and manufacturer.

Corollary 3. Under the complete symbiosis led by the supplier, the supplier's optimal waste exchange price is lower than the manufacturer's optimal product selling price.

Proof. Under the two states dominated by suppliers, the difference between the optimal price of manufacturer and supplier is: $\Delta P_1 = \frac{a - C_1 + 3C_2 + 3C_3}{4}$. According to the definition of each variable, $\Delta P_1 > 0$, therefore, the manufacturer's optimal product price is higher than the waste price.

Corollary 4. In a completely symbiotic state dominated by the manufacturer, the supplier's optimal waste exchange price is lower than the manufacturer's optimal product sale price.

Proof. Under the two states dominated by manufacturer, the difference between the optimal price of manufacturer and supplier is: $\Delta P_2 = \frac{a + m + C_1 + 3C_2 + 3C_3}{4}$. According to the definition of each variable, $\Delta P_2 > 0$, therefore, the manufacturer's optimal product price is higher than the waste price. \square

It can be seen from Corollary 3 and Corollary 4 that under complete symbiosis, the selling price of the manufacturer's products is always higher than the exchange price of the supplier's wastes, no matter in the supplier's dominant state or the manufacturer's dominant state. However, the difference between the two prices in the case of supplier

dominance is less than the difference between the two prices in the case of manufacturer dominance. Under the condition that C_1 , or unit cost of waste disposal, remains unchanged, the larger m is, the greater the difference between supplier and manufacturer's optimal price under two different power structures.

Corollary 5. *In the incomplete symbiosis state of supplier dominance, the relationship between manufacturer and supplier optimal price depends on the value of the symbiosis coefficient n and the relative size of P_0 , C_1 , and C_2 .*

Proof. Under the incomplete symbiosis state of supplier dominance, the optimal price difference between supplier and manufacturer is:

$$\Delta P_3 = P_s - P_m = \frac{(2 - 3n)a - (n + 2)(1 - n)P_0 + n(2 - n)C_1 - n(n + 2)C_2 - (n + 2)C_3}{4n}$$

As a function of n , it can be expressed as:

$$\Delta P_3 = P_s - P_m = \frac{(P_0 - C_1 - C_2)n^2 + (P_0 + 2C_1 - 2C_2 - C_3 - 3a)n + (2a - 2P_0 - 2C_3)}{4n}$$

Take the derivative of ΔP_3 with respect to n , to see what happens to ΔP_3 .

The first derivative is: $\frac{d\Delta P_3}{dn} = \frac{2C_3 - n^2C_2 - n^2C_1 + (n^2 + 2)P_0 - 2a}{4n^2}$ The second derivative is: $\frac{d^2\Delta P_3}{dn^2} = \frac{a - P_0 - C_3}{n^3}$ According to the definitions of a , P_0 , and C_3 , it can be seen that $a - P_0 - C_3 > 0$, so the second derivative $\frac{d^2\Delta P_3}{dn^2} > 0$ indicates that the difference between suppliers and manufacturers presents a trend of first decreasing and then increasing with the increase of n . When $n = \sqrt{\frac{2a - 2P_0 - 2C_3}{P_0 - C_1 - C_2}}$ ($P_0 \neq C_1 + C_2$), the difference between the two reaches its minimum value.

From Corollary 3 and Corollary 5, it can be seen that the gap between the optimal price of the manufacturer and the supplier is different in the incomplete symbiosis state and complete symbiosis state where the supplier is dominant. In the symbiotic state, the difference between the two is fixed; in the incomplete symbiotic state, the difference between the two is not only affected by the degree of symbiosis, but also by the price and cost of raw materials.

Corollary 6. *In the incomplete symbiosis state where the manufacturer is dominant, the relationship between the optimal price of the manufacturer and the supplier depends on the relative values of the symbiosis coefficients n and m as well as P_0 , C_1 , and C_2 .*

Proof. Under the incomplete symbiosis in which the manufacturer is dominant, the optimal price difference between the manufacturer and the supplier is: \square

$$\Delta P_4 = P_s - P_m = \frac{2 - 3na - (n + 2)(1 - n)P_0 - (2 - n)m - n(2 - n)C_1 - n(n + 2)C_2 - (n + 2)C_3}{4n}$$

As a function of n , it can be expressed as:

$$\Delta P_4 = P_s - P_m = \frac{(P_0 + C_1 - C_2)n^2 - (3a - P_0 - m + 2C_1 + 2C_2 + C_3)n + 2a - 2P_0 - 2m - 2C_3}{4n}$$

Take the derivative of ΔP_4 with respect to n , to see what happens to ΔP_4 .

The first derivative is: $\frac{d\Delta P_4}{dn} = \frac{2C_3 - n^2C_2 - n^2C_1 + (n^2 + 2)P_0 - 2a}{4n^2}$ The second derivative is: $\frac{d^2\Delta P_4}{dn^2} = \frac{a - P_0 - C_3}{n^3}$ According to the definitions of a , P_0 , and C_3 , it can be seen that $a - P_0 - C_3 > 0$, so the second derivative $\frac{d^2\Delta P_4}{dn^2} > 0$ indicates that the difference between suppliers and manufacturers presents a trend of first decreasing and then increasing with the increase of

n. When $n = \sqrt{\frac{2a-2m-2P_0-2C_3}{P_0+C_1-C_2}}$ ($P_0 \neq C_1 + C_2$), the difference between the two reaches its minimum value.

It can be seen from Corollary 4 and Corollary 6 that in the complete and incomplete symbiosis state owned by the manufacturer, the gap between the optimal price between the manufacturer and the supplier is also different. The optimal price difference between the two is determined under complete symbiosis. In the incomplete symbiosis state, the price gap between the two is not only affected by the symbiosis coefficient, partial price, and cost, but also affected by the expected unit income m .

5. Numerical Example

Based on the above analysis of the prices and incomes of suppliers and manufacturers in the symbiotic supply chain, this part visually observes the influence of power structure and symbiotic coefficient on the prices and incomes of each enterprise in the symbiotic supply chain through the given and determined variable values.

This section considers a two-level symbiotic supply chain system involving suppliers and manufacturers. We assume the following symbiotic supply chain structure. To reduce waste, environmental pollution, and raw material costs, a brewery entered into a partnership with a feed factory. The residue produced by the brewery during the brewing process can be sold to the feed factory as a product. In this process, the brewery and the feed factory themselves are not in the same supply chain, but because the waste of one party can be used as the raw materials of the other party, they choose to cooperate for their own interests and form a symbiotic supply chain. In this symbiotic supply chain, breweries are suppliers who produce waste and when they sell it to feed mills, they not only get income but also reduce the cost of waste disposal. For the feed factory, the price is lower than raw materials, but the same effect of waste, can reduce their own production costs. Next, we will analyze this symbiotic supply chain.

References to the assignment of variables in [42,43] and the assumptions in this article about the relationships between variables, we will assign values to the important variables above. The symbiosis coefficient n is an independent variable, which does not need to be assigned. According to basic hypothesis 3, Equation (1), and the relationship between variables, variables that need to be given a value include:

For supplier: Unit disposal cost of waste $C_1 = 10$.

For manufacturer: unit cost of reclaimed waste $C_2 = 10$, unit production cost $C_3 = 5$, unit market price $P_0 = 50$ of raw materials, maximum market demand of products $a = 80$, and expected unit income $m = 15$ when the manufacturer takes the lead.

According to the price and income model of supplier and manufacturer obtained above, and by taking into account the specific values of the relevant variables, we can obtain the function of the symbiosis coefficient between supplier and manufacturer under different rights structures.

In the case of supplier dominance, the price and revenue function of supplier and manufacturer and the total revenue of the symbiotic supply chain are respectively:

$$P_s^{11} = \frac{50n + 25}{2n}$$

$$P_m^{11} = -\frac{30n - 295}{4}$$

$$\pi_s^{11} = \frac{2500n^2 + 2500n + 625}{8}$$

$$D_m^{11} = \frac{2500n^2 + 2500n + 625}{16}$$

In the case of manufacturer dominance, the price and revenue function of supplier and manufacturer and the total revenue of the symbiotic supply chain are respectively:

$$P_s^{21} = \frac{15n + 5}{n}$$

$$P_m^{21} = -\frac{25n - 140}{2}$$

$$\pi_s^{21} = \frac{625n^2 + 250n + 25}{2}$$

$$D_m^{21} = \frac{625n^2 + 1000n + 400}{4}$$

Therefore, in the case that suppliers and manufacturers are dominant respectively, the optimal price and income of suppliers and manufacturers corresponding to different degrees of symbiosis are shown in Tables 3 and 4 and Figures 4–7.

Table 3. Price, revenue, and demand under supplier dominance.

n	P_s^{11}	P_m^{11}	D^{11}	D_m^{11}	π_s^{11}	π_m^{11}	π
0.1	575.00	271.75	28.25	2.83	1653.13	826.56	2479.69
0.2	337.50	267.25	32.75	6.55	2278.13	1139.06	3417.19
0.3	258.33	262.75	37.25	11.18	3003.13	1501.56	4504.69
0.4	218.75	258.25	41.75	16.70	3828.13	1914.06	5742.19
0.5	195.00	253.75	46.25	23.13	4753.13	2376.56	7129.69
0.6	179.17	249.25	50.75	30.45	5778.13	2889.06	8667.19
0.7	167.86	244.75	55.25	38.68	6903.13	3451.56	10354.69
0.8	159.38	240.25	59.75	47.80	8128.13	4064.06	12192.19
0.9	152.78	235.75	64.25	57.83	9453.13	4726.56	14179.69
1	147.50	231.25	68.75	68.75	10878.13	5439.06	16317.19

Table 4. Price, revenue, and demand of the manufacturer in the dominant state.

n	P_s^{11}	P_m^{11}	D^{11}	D_m^{11}	π_s^{11}	π_m^{11}	π
0.1	115.00	71.25	8.75	0.88	78.13	76.56	154.69
0.2	65.00	70.00	10.00	2.00	112.50	100.00	212.50
0.3	48.33	68.75	11.25	3.38	153.13	126.56	279.69
0.4	40.00	67.50	12.50	5.00	200.00	156.25	356.25
0.5	35.00	66.25	13.75	6.88	253.13	189.06	442.19
0.6	31.67	65.00	15.00	9.00	312.50	225.00	537.50
0.7	29.29	63.75	16.25	11.38	378.13	264.06	642.19
0.8	27.50	62.50	17.50	14.00	450.00	306.25	756.25
0.9	26.11	61.25	18.75	16.88	528.13	351.56	879.69
1	25.00	60.00	20.00	20.00	612.50	400.00	1012.50

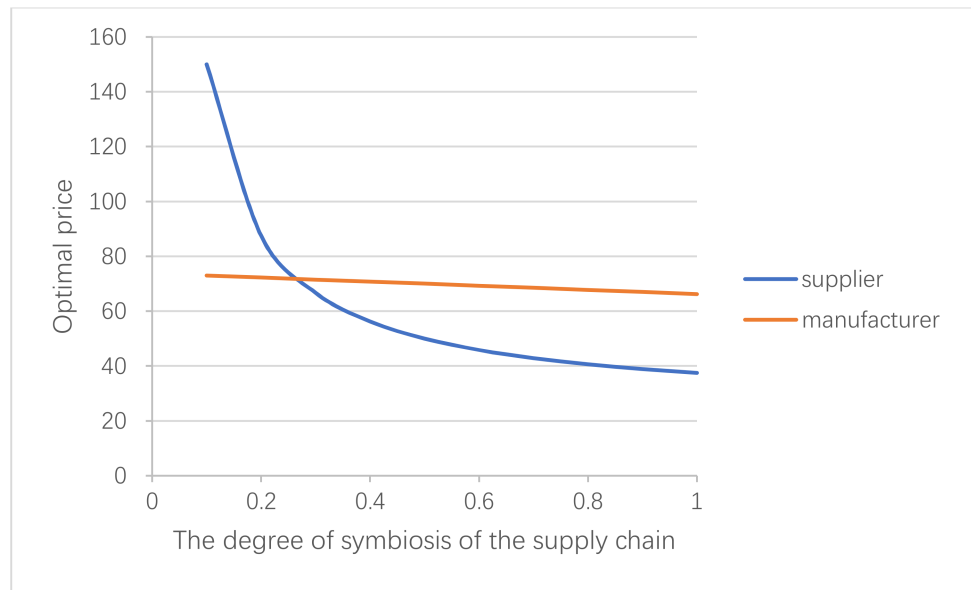


Figure 4. Optimal price comparison diagram under supplier dominance.

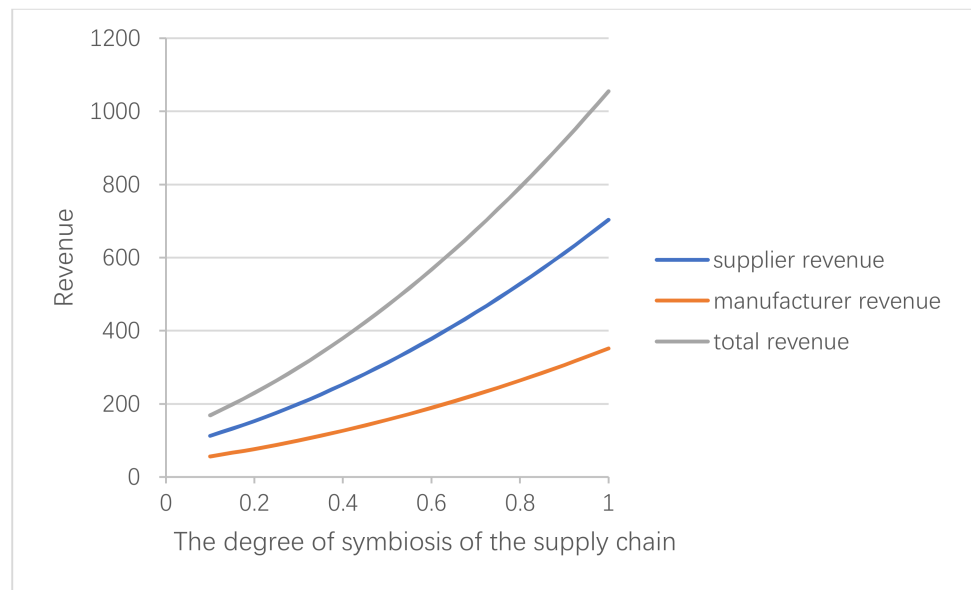


Figure 5. Revenue comparison diagram under supplier dominance.

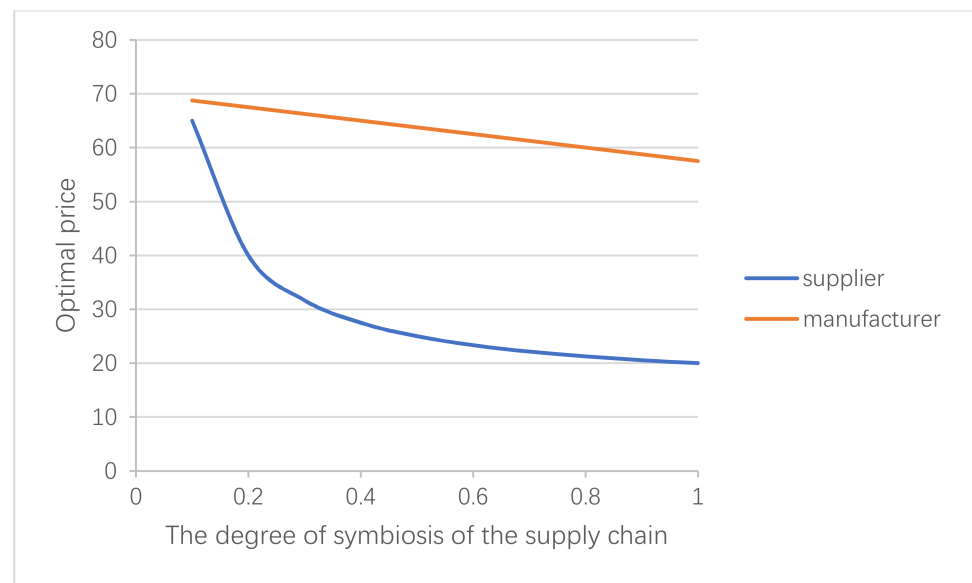


Figure 6. Optimal price comparison under manufacturer dominance.

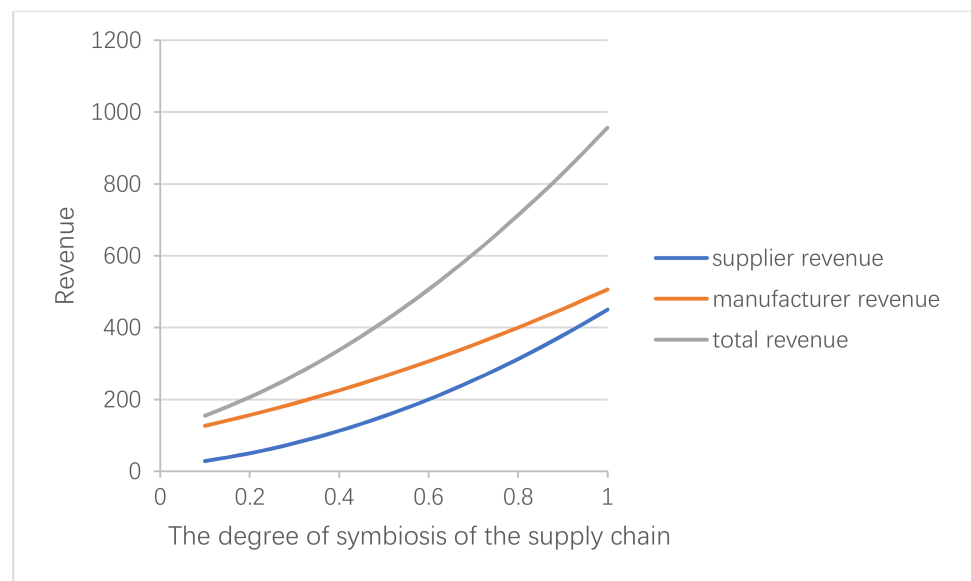


Figure 7. Revenue comparison under manufacturer dominance.

In both cases, the optimal prices of suppliers and manufacturers show a decreasing trend. However, the supplier's optimal price presents a nonlinear trend, and the range of change gradually decreases. However, the manufacturer's optimal price shows a linear change trend and changes at a certain rate. In the two cases, with the increasing degree of symbiosis, the income of suppliers and manufacturers presents a gradually increasing trend, and the suppliers and manufacturers obtain relatively higher income with their respective advantages.

In the research hypothesis of this paper, since suppliers' symbiosis can always reduce waste disposal costs, suppliers in the symbiosis state can obtain higher earnings than in the non-symbiosis state. For manufacturers, waste exchange will bring two parts: income and cost. Manufacturers will judge whether to conduct industrial symbiosis according to whether the final profit value is greater than the profit value without symbiosis. Based on the values of each variable assumed in this paper, the results shown in Figure 8 are

obtained. Manufacturers have an incentive to exchange wastes only if the benefits are greater than if they were not symbiotic.

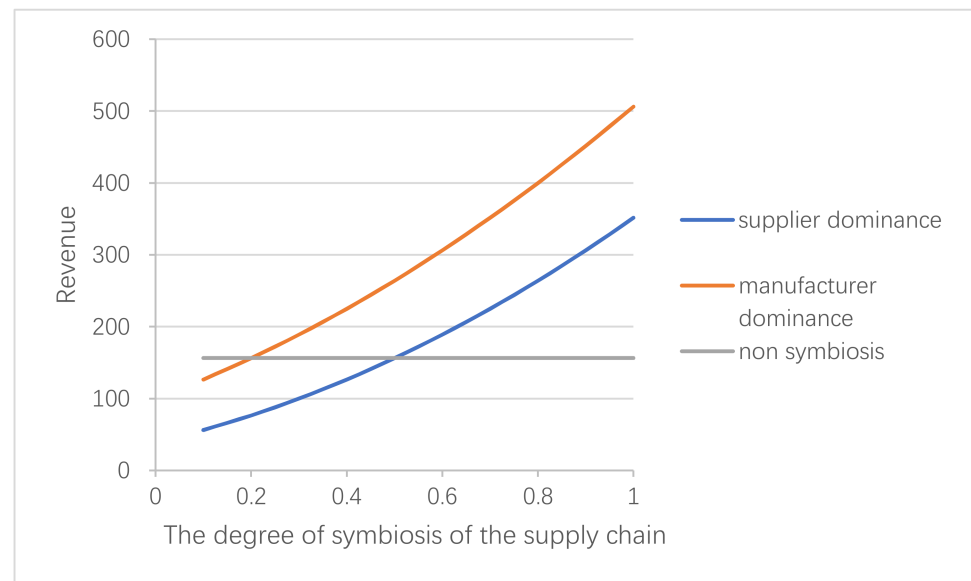


Figure 8. Comparison of manufacturer's earnings in three states.

In the absence of symbiosis, no waste is exchanged between the supplier and the manufacturer. Suppliers generate waste disposal costs, and manufacturers generate revenue from product sales, raw material purchase prices, and production costs. Therefore, in the non-symbiotic state, the benefits of suppliers and manufacturers can be expressed as:

$$\pi_s^0 = -C_1 D_s \quad (25)$$

$$\pi_m^0 = (P_m - P_s - C_3)D = (P_m - P_s - C_3)(a - P_m) \quad (26)$$

By taking the first derivative of Equation (26) and making it equal to 0, we can get:

$$a - 2P_m + P_0 + C_3 = 0$$

Therefore, the optimal price of the manufacturer is obtained as follows:

$$P_m = \frac{a + P_0 + C_3}{2}$$

Because the second derivative is $-2 < 0$, the manufacturer's income has a maximum value:

$$\pi_m^0 = (P_m - P_s - C_3)(a - P_m) = \frac{(a - P_0 - C_3)^2}{4}$$

Therefore, in the non-symbiotic state, the manufacturer's optimal price is 156.25. Then, under the conditions assumed in this paper, when the revenue of the supplier in the two scenarios is greater than 156.25, additional revenue will be generated. In both cases, manufacturers are motivated to exchange wastes when the symbiosis coefficient is greater than 0.2 and 0.5, respectively. The details are shown in Figure 8.

In the above analysis, we assume that the manufacturer's expected profit per unit product is 15, but according to the previous discussion, the change in m value affects the supplier's and manufacturer's earnings. Therefore, we decided to compare the changes of suppliers' and manufacturers' earnings under different values of m .

Firstly, according to the principle that the manufacturer's income is greater than 156.25, the value range of m when the manufacturer carries out industrial symbiosis is calculated.

$$\pi_m^{21} = \frac{[a-(1-n)P_0+m+nC_1-nC_2-C_3]^2}{16} > 156.25$$

Therefore, the value range of m is: $0 \leq m \leq 25$. Figures 9 and 10 show the changes of supplier and manufacturer's earnings under different values of m . The results show that: with the increase of the manufacturer's expected unit product income, the supplier's income decreases gradually, and the manufacturer's income increases gradually. With the increase of symbiosis degree, the revenue of both supplier and manufacturer will increase gradually when the expected revenue of unit product of supplier is unchanged.

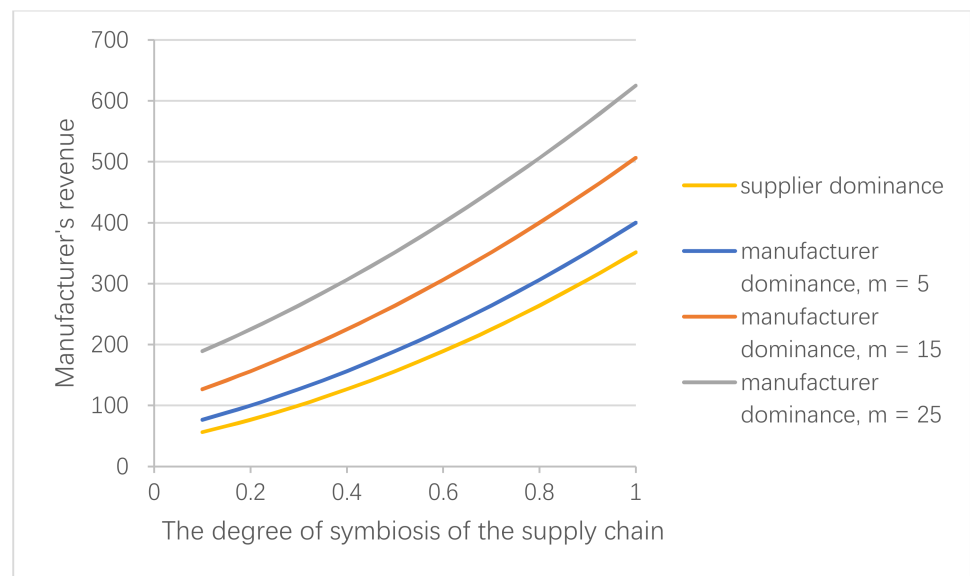


Figure 9. Relationship between m and manufacturer's revenue.

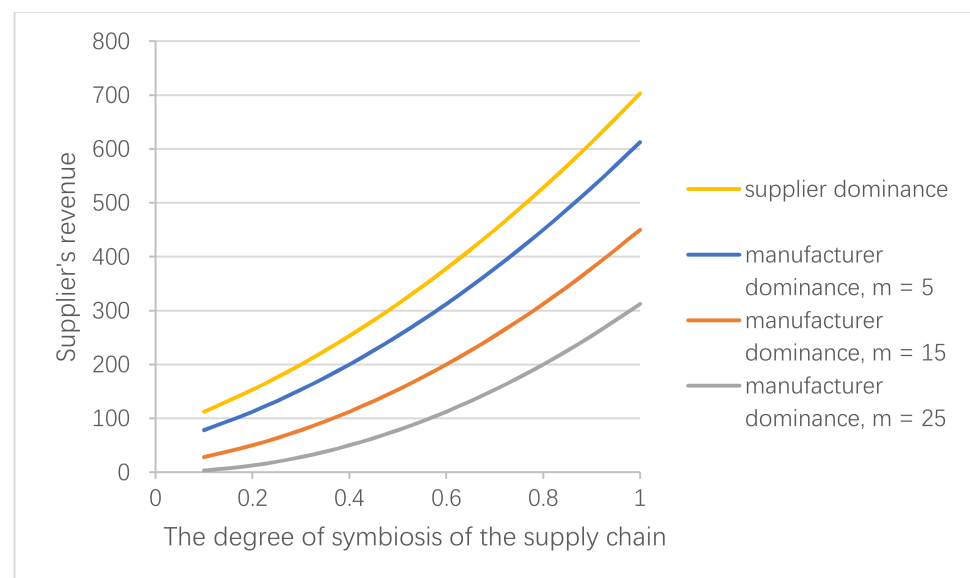


Figure 10. Relationship between m and supplier's revenue.

As can be seen from Figure 11, under the two power structures of supplier dominance and manufacturer dominance, supplier revenue, manufacturer revenue, and the overall

revenue of the symbiotic supply chain will all increase with the increase of the maximum market demand for products. The overall revenue of the symbiotic supply chain under supplier ownership is greater than that under manufacturer dominance. As can be seen from Figure 12, in the manufacturer dominant state, the manufacturer's revenue increases with the increase of the manufacturer's expected unit revenue, while the supplier's revenue decreases with the increase of the manufacturer's expected unit revenue. The overall revenue of the symbiotic supply chain decreases first and then increases slowly with the increase of the expected unit revenue of the manufacturer.

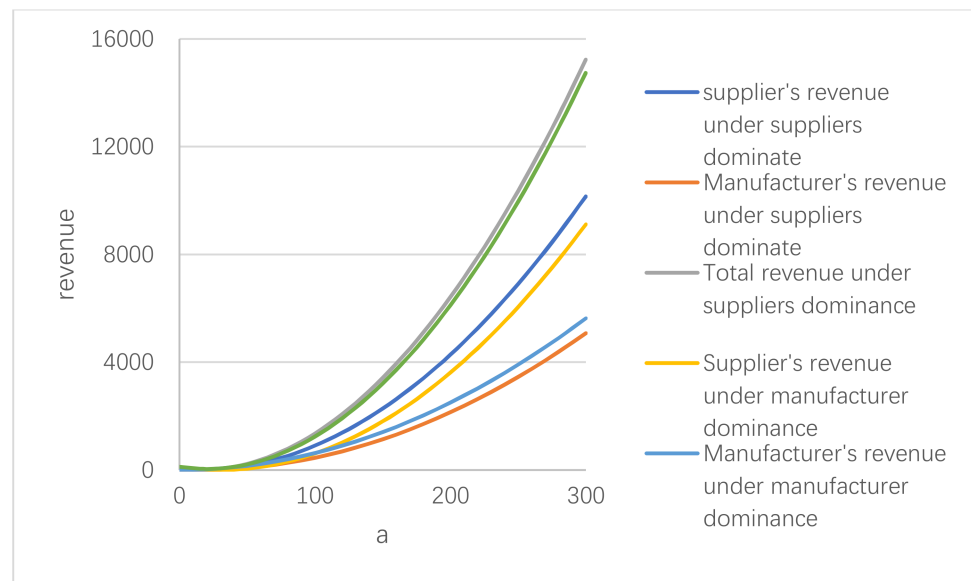


Figure 11. Relationship between a and internal revenue.

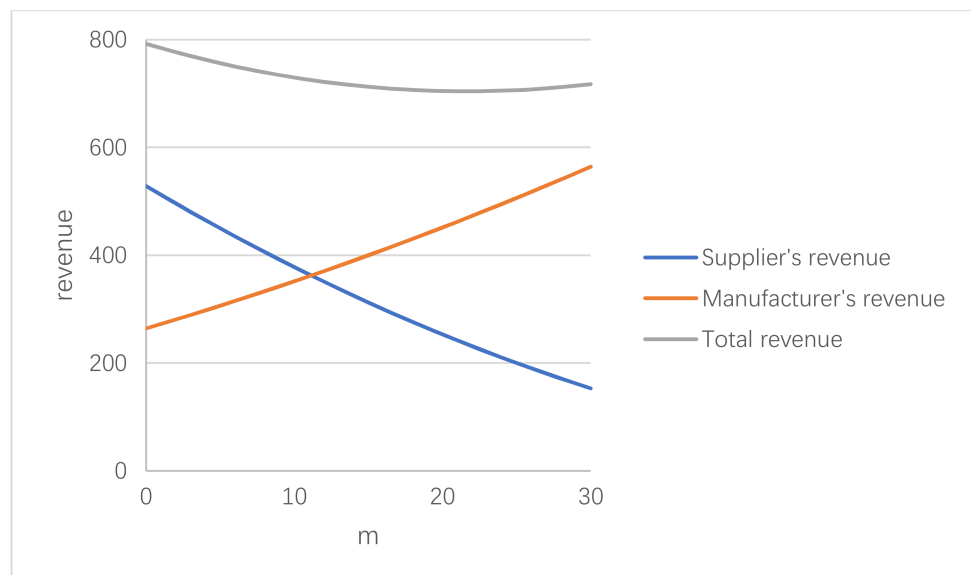


Figure 12. Relationship between m and internal revenue.

Next, we will perform sensitivity analysis on several variables. In the variables of Stackelberg model, product price and output, and waste exchange price and exchange amount are all determined by the internal members of the symbiotic supply chain. Therefore, the sensitivity analysis of this part is the maximum market demand of product a and the manufacturer's expected unit product revenue m . Figures 13 and 14 respectively

show the influences of the maximum product market demand a and the manufacturer's expected unit product revenue m on the internal supplier revenue, manufacturer revenue, and overall revenue of the symbiotic supply chain under different power structures. The values of other variables are the same as the above analysis.

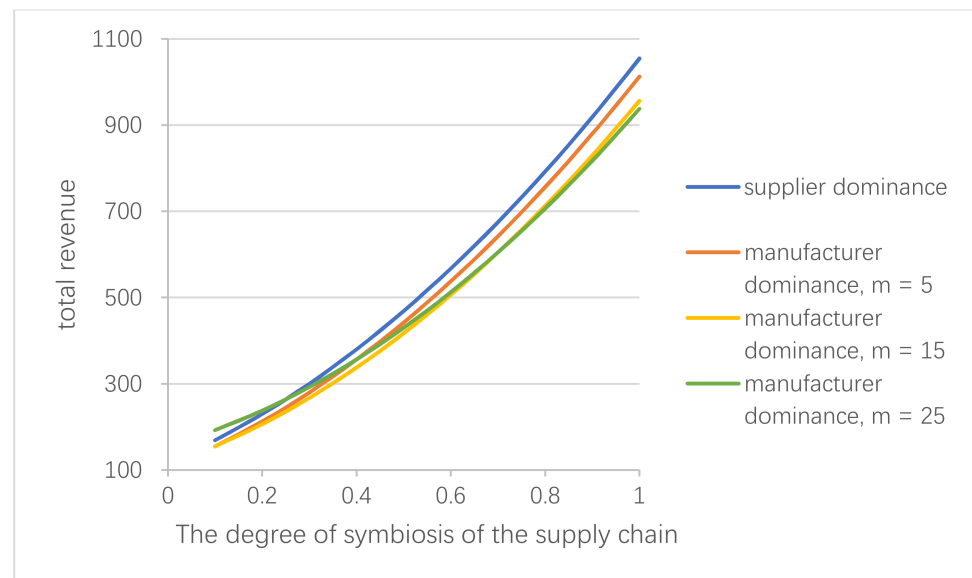


Figure 13. Robust analysis—different values of m .

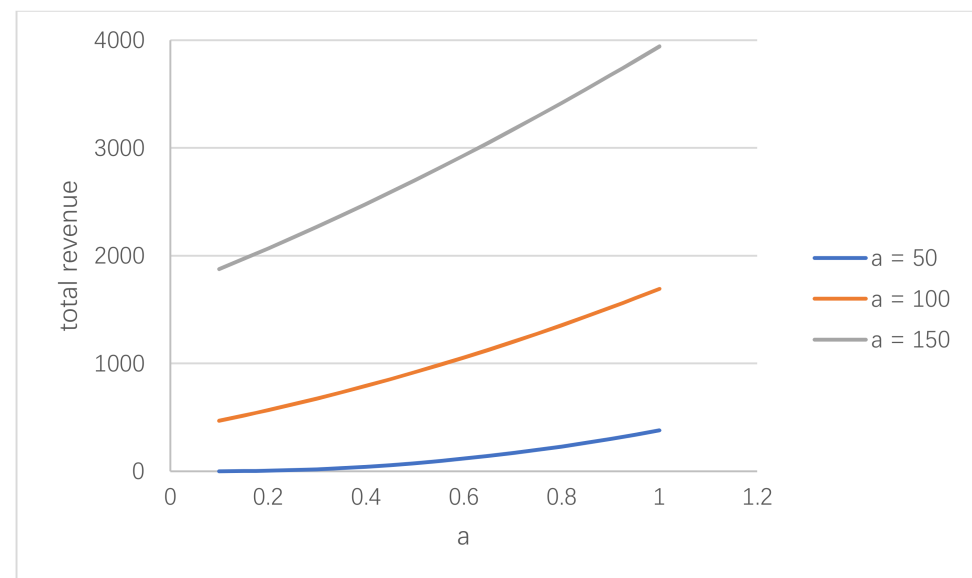


Figure 14. Robust analysis—different values of a .

As can be seen from Figure 13, within the reasonable value range of m , no matter what value m is in the manufacturer's dominant state, the profit value of the symbiotic supply chain will increase with the increase of n . As can be seen from Figure 14, in different values of a , the revenue of the symbiotic supply chain will also increase with the increase of n . The change of m and a in the two figures will not cause the influence of the symbiosis coefficient in the symbiosis supply chain. It is shown that this result has good robustness.

6. Discussion

By constructing symbiotic supply chain models under different rights structures, this paper has enlightenment on the practice of waste recycling and waste sharing in the symbiotic supply chain. In today's increasingly scarce resources, it is particularly important to improve the efficiency of resource utilization and reduce idle resources. However, enterprises will be interfered by many aspects in practice, which requires the joint efforts of the government and enterprises. On the one hand, the government can help establish an information management platform for waste recycling, help enterprises circulate information, avoid idle resources caused by incomplete information, and enable waste resources to be effectively shared among enterprises. On the other hand, enterprises can establish a supply chain with a reasonable degree of symbiosis, establish a waste resource sharing mechanism, and determine a reasonable authority, so as to achieve the optimal income of enterprises in the symbiosis supply chain.

The Stackelberg game method used in this paper has strong practicability in practical operation. In a symbiosis in the supply chain, you just need to get the supplier and the manufacturer produces in the process of game between the two sides each cost, expected return and the market value of the products or raw materials, waste exchange prices, the market demand of products, such as variables, can be obtained according to the Stackelberg game symbiosis supply chain in the process, the parties can obtain the optimal price and the final benefits and the income of the symbiosis of the supply chain. All the variables mentioned above can be easily obtained within the enterprise or through market research, so this model has a good possibility of implementation.

Although this paper analyzes the price setting and income among the members of the symbiotic supply chain through Stackelberg game, it is concluded that the improvement of symbiotic degree is beneficial to the suppliers, manufacturers, and the whole symbiotic supply chain. However, one thing we find in Figure 8 is that industrial symbiosis cannot always make each member of the supply chain gain more benefits than non-symbiosis. In the two cases of supplier dominance and manufacturer dominance, the total revenue of the symbiotic supply chain is lower than that of the non-symbiotic state, and a very high degree of symbiosis is needed to obtain the same revenue in the supplier dominance case. In other words, members of the symbiotic supply chain are not motivated to carry out industrial symbiosis in all states.

As mentioned, in the past, a lot of research with the improvement of symbiotic degree of corporate earnings increases gradually, but it does not conflict with the above phenomenon; it also reminds us that the attention degree of symbiosis of important role at the same time should also pay attention to under the degree of this kind of symbiosis, the enterprise will gain more profit than when not symbiosis, in which companies have power to industrial symbiosis. Secondly, there are a variety of methods used in relevant researches, including Stackelberg game, Nash equilibrium, two-stage pricing analysis, differential game, evolutionary game, etc. Different literatures have adopted the most appropriate methods in different situations. The results of this paper are consistent with the results of most literatures in terms of the effect of symbiosis degree on returns. However, based on the combination of symbiosis degree, power structure, and manufacturer's expected revenue per unit product, this study presents complex research results, and thus enriches the research results in the field to some extent.

7. Conclusions

In this paper, a Stackelberg game is adopted to study the price decision model of symbiosis supply chain under different rights structures, and to discuss the optimal price, revenue, and comparison of enterprises in complete and incomplete symbiosis supply chain under the condition that the supplier and the manufacturer are respectively dominant.

The results show that:

- (1) The income in the symbiotic supply chain is related to the degree of symbiosis.

In the symbiotic supply chain model of supplier and manufacturer, supplier revenue, manufacturer revenue, and total profit will increase with the increase of symbiosis degree.

(2) The change of power structure will affect the relative benefits of suppliers and manufacturers in the symbiotic supply chain.

Compared with the manufacturer-led power structure, the supplier gains more and the manufacturer gains less under the supplier led power structure, and the relative size of the total gains of the symbiotic supply chain will change with the change of symbiosis degree. The profit of the supply chain dominated by the manufacturer is greater than that of the supply chain dominated by the supplier.

(3) The manufacturer's expected unit product revenue will affect the supply chain revenue when the manufacturer is dominant.

The change of the manufacturer's expected revenue per unit product has no effect on the symbiotic supply chain led by the supplier. However, it has an important impact on the manufacturer-led symbiotic supply chain. In the manufacturer-led symbiotic supply chain, with the increase of the expected profit of the manufacturer, the final profit of the manufacturer increases, which is greater than the profit of the supplier. The final revenue obtained by the supplier decreases and is all less than that obtained by the supplier when the supplier is dominant.

To sum up, the difference between the two power structures of supplier dominance and manufacturer dominance leads to the difference in the price decision-making process, so there is a gap between the optimal price and the optimal income of the final supplier and manufacturer. The degree of symbiosis will influence the optimal decision between supplier and manufacturer. However, the expected unit income of the manufacturer will only influence the decision of the manufacturer in the favorable situation.

Therefore, the management implications of this paper are as follows: firstly, the degree of symbiosis of the symbiosis supply chain has an absolutely important impact on the members of the supply chain, and all parties in the symbiosis supply chain should try their best to help the symbiosis supply chain achieve maximum symbiosis. Secondly, according to the research results, in the symbiotic supply chain, no matter who occupies the dominant position, the supplier and the manufacturer will take the leading position in the price decision and income. Therefore, enterprises should strive to obtain their own competitive advantages and obtain the absolute dominant position. Suppliers and manufacturers should adjust their pricing strategies flexibly according to the change of their dominant position in order to achieve more profits.

The existing problems in this paper include: only considering the symbiotic supply chain system including a supplier and a manufacturer and ignoring the situation of waste sharing between suppliers and manufacturers. The cost allocation of enterprises in the supply chain is not taken into account. Therefore, further research on these two aspects can be carried out in the future.

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