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Research Article

Pricing Decision and Financing Approach Selection of Fund-Deficient Closed-Loop Supply Chain under Distributor's Risk Aversion

Xiaodong Xia [1] and Yongqing Nan [2]

[1]School of Economics and Management, Southeast University, Nanjing 211189, China
[2]School of Government Audit, Nanjing Audit University, Nanjing 211815, China

Correspondence should be addressed to Xiaodong Xia; xxd@seu.edu.cn

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The study aims at an issue of the rational financing approach selection on the fund-deficient remanufacturing closed-loop supply chain (CLSC), which is composed of one fund-deficient manufacturer and a risk-adverse distributor. The pricing decision under the cases of manufacturer is with sufficient fund, with limited fund, via debt financing and via equity financing are solved on the CLSC game model. Moreover, the equilibrium solution in different cases is solved using backward induction, analyzing the impact of risk-averse parameters on the equilibrium solution in different cases and obtaining the critical conditions for the manufacturer to execute the optimal financing approach. The conclusion shows that the wholesale price and the retailing price of the new product in debt financing are both greater, while the retailing prices of the remanufacturing product are equal in the two financing approaches. Only when the manufacturer's self-owned fund is constrained and the executable dividend proportion is lower than a critical value, the manufacturer will execute equity financing. However, if the self-owned fund is exceedingly deficient and the executable profit-sharing proportion is adequately large, the manufacturer will prefer debt financing. When executing financing, the consumer surplus declines, while the risk-averse parameter goes up. Debt financing is far eco-friendlier, while equity financing enables both parties and the total revenues of CLSC to attain a multibenefit status in specific circumstances.

1. Introduction

In our modern life, factories have produced a good variety of products to satisfy customers' heterogeneous demands. They have brought about a series of environmental problems, such as carbon emissions, resource waste, and energy shortage. The climate warming and sea-level rise caused by these problems have aroused widespread concern from the public and the government. To solve these urgent troubles on eco-pollution and energy deficiency, the adoption of closed-loop supply chain (CLSC) operations and management has gradually become a crucial step to recycle natural resources and realize green innovation development in the long run. Savaskan et al. [1] announced that CLSC activities not only reduce the producing costs and promote business revenue for companies but also increase the ecological benefits. Ding et al. [2] have claimed that the remanufacturing business of automobile components can cut down on nearly 50% of processing costs and more than 60% of energy compared with producing a new product. As known to us all, recycling and remanufacturing not only save resources but also help companies reduce costs and carbon emissions, which has attracted widespread attention all over the world. Atasu and Souza [3] have found that some countries, such as the United States, Germany, and the United Kingdom, have incorporated remanufacturing activities into their corporate production regulations to improve their operational efficiency.

In the contemporary manufacturing activity, the original manufacturer is unable to engage in broad-scale remanufacturing business on account of the magnanimous discarding of products. Hence, the original manufacturer licenses a third-party remanufacturer to go in for recycling and remanufacturing issues. In the light of the high profits on the remanufacturing activities, an increasing number of well-known enterprises, such as Apple [4], Xerox [5], and Dell [6], commenced to carry out CLSC operations by recycling wasted products and adopting advance remanufacturing crafts. Thus, it is of great significance to adopt CLSC management to achieve sustainable development and a circular economy.

Nowadays, with the expansion of the production scale, the manufacturing investment and operating costs of the enterprise will increase, which may bring about the restriction of the manufacturer's capital flow and production capacity. The report data from The World Bank [7] found that there were almost more than 60% of them that were small and medium-sized enterprises (SMEs), of which 54.4% had to secure the operation capital from financing. As a matter of fact, the company that is under capital constraint will secure the necessary funds by debt financing or propagating the excellent features of new products to attract social investors' funds [8]. In the real world, Hewlett-Packard China Co., Ltd. responded to the national call for low-carbon and energy savings actively, making full use of environmental-friendly materials to manufacture products. It attracted the close attention of Hua Xia Bank and gave its bank loans to support the high-efficiency operations of Hewlett-Packard. Furthermore, the Coronavirus disease affected the capital flow of Nio, which made Nio seek funds from external financing. Nio Auto enterprise released its first mass-produced model ES8 for publicizing its excellent characteristics in low carbon and operation durability. It sought funds from the Tencent company in the form of equity financing. Thus, for the capital-constrained companies, their financing capital mainly came from the two major financing approaches, one is debt financing, another is equity financing.

Moreover, in the light of the survey of Mckinsey & Company, Feng et al. [9] claimed that more than two-fifths of the enterprise directors reach a consensus that the companies will tend to be risk-averse when they face the uncertainty of actual operation and management in the CLSC operations.

As we all know, the remanufacturing process is quite complicated. Chen et al. [10] found that it mainly included major steps, such as collecting, dissembling, cleaning, detecting, sorting, and assembling. The remanufacturing process was influenced by uncertain factors, such as the number of recovered products, the cost of remanufacturing, and the quality of the cores. Therefore, since the uncertainty of the remanufacturing cost led to the fluctuations in corporate profits, companies are more likely to take their own risk preference into consideration when pursuing the maximization of their own profits in CLSC operations.

A majority of the existing research is conducted in a stable state. It may neglect the impacts of fluctuation on the remanufacturing cost, optimal decisions, and CLSC, which consists of a capital-constrained manufacturer and a risk-averse distributor. However, in real life, since the downstream of the CLSC player distributor recycled the waste products and remanufactured them, the uncertainties in remanufacturing costs derived from the sudden issues will make the distributor generate risk aversion behavior. It may affect the decision-making process of CLSC members in capital-constrained circumstances. Thus, it is instructive for us to make interesting and meaningful research work on the influence of distributor's risk aversion behavior on the pricing decision and financing approach selection of the CLSC operations and management on the condition of limited capital.

From the specific analysis above, to supply the scientific reference for the pricing decisions on the CLSC players in the distributor-remanufacturing mode, this paper focused on solving an important issue on the pricing decisions in CLSC, which is composed of a single capital-constraint manufacturer and one risk-averse distributor. Moreover, it is clear for us to obtain the optimal pricing decision by backward induction when the manufacturer is under the debt financing case and equity financing case. Furthermore, we will compare the equilibrium solutions of the manufacturer's revenue, distributor's utility value, environmental impacts, and consumer surplus (CS) in the two financing approaches to derive more enlightenment. As a result, we are committed to solving the following issues:

(1) How do these financial approaches impact the manufacturer's pricing decisions and distributor's pricing decisions, respectively?
(2) What is the influence of the risk averse factor on the OEM's wholesale price and revenue, distributor's sales volumes, expected profit, utility value, CS, and environmental impact in the two financing approaches?
(3) What is the specific impact of the manufacturer's initial capital on the CLSC player's pricing decision, sales volumes, and financing strategy selections?
(4) How does the initial capital and risk-averse factor jointly affect acceptable dividend proportion?

The remainder of this paper is set as follows: part 2 gives a review of literature streams. Part 3 demonstrates the specific assumptions and illustrations of model settings, part 4 and part 5 construct the Stackelberg game models for the specific four cases and make a comprehensive contrast on the equilibrium solutions about these two financing approaches. Moreover, the numerical analysis of all the corollaries and the management insights was shown in part 6. At last, part 7 gives article conclusions, research limitations, and the later investigative themes.

2. Literature Review

Three groups of the existing research are related with this study, which are as follows: (1) distributor-remanufacturing mode in the CLSC operations, (2) the financing approach selection in the capital-limited CLSC management, and (3) risk aversion in the behavior operational management on CLSC.

2.1. Distributor Remanufacturing Operations Management in CLSC. A large amount of literature studied the distributor-remanufacturing mode in CLSC. Long et al. [11] aimed at the issue of optimal pricing decisions on the two-period CLSC operations under different recycling modes, such as OEM recycling, authorized distributor recycling, authorized third-party recycling, and hybrid recycling, jumping to a conclusion that when the WTP factor is high enough, OEM's revenue in the hybrid recycling mode became the highest upon comparing the equilibrium solutions among all the recycling scenarios. Huang and Wang [12] focused on the operation decisions on a single period CLSC under three remanufacturing scenarios, namely manufacturer in-house remanufacturing (case M), licensing the distributor to remanufacture (case MD), and licensing the third party to remanufacture (case MT). The result indicated that the carbon emissions of the licensing remanufacturing models were less than the manufacturer's in-house remanufacturing models. The cases of MD, MT, and M bring the biggest revenues to distributors, third parties, and manufacturers, successively. Taleizadeh et al. [13] compared two remanufacturing scenarios, which are distributor-remanufacturing and third-party remanufacturing, when taking the environmental impact, return policy, and quality improvement effort into consideration on CLSC management. They found that, under all remanufacturing rates investigated, the entire supply chain profit under the distributor-remanufacturing scenario was more than that of third-party remanufacturing. Yang et al. [14] were devoted to the research of differential pricing decisions on the two-period CLSC system composed of one manufacturer and a warrant distributor, observing that the manufacturer can take advantage of the licensing fee mechanism to increase the revenues of the whole CLSC members and enhance the implementation of sustainable development. In the light of the pricing decisions on the green supply chain, which consists of a single manufacturer and one distributor, Alizadeh-Basban and Taleizadeh [15] proposed three-game approaches, namely the Nash game (N), the manufacturer-Stackelberg game (SM), and the distributor-Stackelberg game (SR), to solve the problem. They were employed according to different power structures. The result showed that the SM game led by the manufacturer was the best game power structure from the perspective of maximizing the profits of the entire green supply chain by comparison and analysis.

However, all the previous studies focused only on the optimal operation decision under the distributor-remanufacturing pattern with ample producing funds, ignoring the influence of restricted and self-owned manufacturing capital on operational management in CLSC. In addition, capital, as a kind of significant resource in enterprises, is always constrained, which results in nonideal pricing decisions. Thus, it is vital for us to concentrate on the optimal pricing decisions under different financing approaches in a capital-deficient supply chain.

2.2. Optimal Selection of Financial Methods in CLSC. Another group of literature introduced the optimal pricing decisions and CLSC decisions, considering limited capital. There were some scientific achievements in the optimal financing method selection on the interface of CLSC operations and supply chain financing. Zhang and Chen [16] aimed at the optimal production decision on a dyadic CLSC composed of one supplier and a single capital-constrained manufacturer in the amended newsvendor model, obtaining the conclusion that full trade credit with a bank loan is the best financing method compared to any other financing approach in the view of whole supply chain revenue through numerical contrast and analysis. Zhang et al. [17] focused on a piece of research about the optimal pricing decision on a dyadic supply chain that consists of a single retailer and one capital-constrained manufacturer, where the manufacturer can obtain capital fractional through the retailer or fractional through the bank. Reaching the result that the new and remanufactured products sales prices in the retailer's credit financing approach was lower, higher wholesale price is higher than that of the bank financing approach through comparing the equilibrium solutions in the game model. Zheng et al. [18] aimed at a meaningful issue of the optimal pricing decisions on CLSC composed of one capital constraint remanufacturer and a single manufacturer in the bank financing and equity financing strategy under the Nash game, arriving at the conclusion that the bank financing rate and equity ratio have converse impacts on the sales prices of the new and remanufactured products. The revenue of the remanufacturer is concave with the equity ratio. With regards to the optimal pricing decisions on the dual-channel supply chain, which are comprised of one capital-constrained manufacturer and a single dominant supplier, Li et al. [19] compared the equilibrium set of the optimal decisions among the trade credit financing, bank loan financing, and portfolio financing. The outcome of the research indicated that the equity dividend ratio and bank loan interest rate together affect the equilibrium sales volumes and the supplier's revenue. The supplier and manufacturer tend to select a trade credit financing strategy when the equity dividend ratio is relatively small.

However, as we all know, remanufacturing progress is a complex production activity because of the uncertain quality of recycled cores, the uncertain producing cost of remanufacturing products, the uncertain returnable rate, and so on. In this way, the remanufacturer, who is downstream of CLSC, has the tendency to be risk-averse. At this time, the premise of being risk-neutral on the CLSC operation decision is not completely applicable. The CLSC players usually maximize their utility functions, which are composed of the expectations and variances about the profit function, to make the optimal pricing decision. Thus, we ought to introduce risk aversion into the decision-making of CLSC players to achieve the optimal pricing decision in accordance with the actual operation situations.

2.3. Risk Averse Behavior Management in CLSC. The third group of literature focused on the optimal pricing decision of supply chain members with risk aversion behavior preference in behavior operations management. Zhang and Zhu [20] aimed at the issue of optimal pricing decisions and coordination of the two-tier supply chain made of one risk-averse remanufacturer and a single retailer during the stochastic market demand scenario. The whole of profits in the coordinated contract on maximum utility in the risk aversion case was bigger than that of the risk-neutral case when the variance of the uncertain demand is over a certain threshold. Ke et al. [21] focused on the issue of the optimal pricing problem in CLSC with double risk-averse retailers and one manufacturer. The results indicated that if either retailer's risk aversion factor became larger, both their sales prices were lower. However, when the recycling rate wholesale price was higher, the two retailers sacrificed their profits to rise the manufacturer's revenue. Sun et al. [22] concentrated on the issues about the complex production decision-making integrated remanufacturing operations with financial hedging in CLSC when maximizing the remanufacturer's utility in the mean-variance model, having access to get the conclusion that the remanufacturers' expected revenue increased first and then decreased, and the quantities of the remanufactured products went down when the risk aversion parameter went up through the Monte Carlo simulations.

Zhang et al. [23] aimed at the optimal pricing decisions in the two types of recycling mode, namely the retailer recycled model and the third-party recycled model, taking the uncertain quality of the waste products into consideration. The conclusion showed that when the uncertainty quality of the waste product was higher, the lower the recycling price of remanufactured products, the higher the sales price of the remanufactured products. It makes the incentive of the manufacturer to recycle waste products lower. Yang et al. [24] committed to resolving the pricing decisions in producing fund-limited CLSC, which consists of a capital-limited and risk-averse manufacturer and one dominant retailer, in the advance payment and equity financing scenarios. The outcome showed that the manufacturer will obtain higher utility if the level of risk aversion is rational, whereas the retailer will acquire less revenue if the level is high enough in the two financing approaches.

Nevertheless, a majority of the previous research was based on the optimal operational decision that premeditates the risk aversion derived from the uncertain merchandise requirements or uncertain returnable rate on CLSC operations, yet omitting the influence of the distributor's risk aversion originated from the uncertainty of producing expenditure on the remanufacturing procedure during the pricing decisions.

In a concise summary, all of the above-mentioned studies either aim to optimize the operation decision on the downstream participating member with limited funds in the CLSC or premeditate the risk aversion behavior preference that originates from the uncertainty of merchandise requirement in the market. However, since the downstream distributor in CLSC recycled the used cores and remanufactured the recycled products, the fluctuations in the producing expenditure of the remanufacturing procedure will make the distributor more inclined to become risk-averse. It affects the operational decisions of all the participants in the CLSC operation management. Hence, it is of great and realistic significance for us to solve this urgent issue on pricing decisions and financing approach selection in a CSLC composed of one capital-deficient manufacturer and a risk-averse distributor.

In a concise summary, the distinctive research aspects of our work differ from the previous studies and are exhibited in Table 1.

3. Problem Clarification and Variables Illustration

In the single-period distributor-remanufacturing CLSC model, which had one capital-deficient manufacturer and a single risk-averse distributor, the manufacturer is the leader, while the distributor is the follower in the Stackelberg game. The manufacturer with limited funds produces new products, sells them to the downstream distributor, and authorizes the distributor to produce remanufactured products, and the distributor sells these two types of products to the market. Focusing on the research of the pricing decision model of the four cases, namely, when the manufacturer has sufficient funds (Model MN), when the funds are limited but not financing (Model MY), when the manufacturer applies debt financing (Model MD), and when the manufacturer applies equity financing (Model ME). When the manufacturer gets the necessary capital from external financing, the specific operating progress of the two financing methods is depicted in Figures 1(a) and 1(b), respectively. In the debt financing method, the manufacturer should not only bear the debt financing risk during the entire managing process but also return the financing capital and corresponding interest at the end of the selling period. However, the manufacturer will benefit more from debt financing than producing with self-own capital if and only if the shadow price λ is greater than the financing rate r_b. If the manufacturer selects the equity financing method, the manufacturer is ought to defray the investor a certain percentage of the sales profit to share the manufacturer's revenue.

Finally, all the variables' illustrations presented on this paper are enumerated in Table 1.

There are some specific assumptions related to this article, which are listed as follows:

(1) Based on the previous research of Liu et al. [25] and Zhang et al. [26], the market size is standardized to 1 for the convenience of calculation and analysis.

(2) Assuming that the producing cost of the unit remanufactured products is $\tilde{c}_r$, since the quality of the recycled cores is uneven, we suppose that the cost is a random variable $\tilde{c}_r$, which follows a normal distribution with the mean value c_r and variance σ^2. Moreover, to make remanufacturing profitable, it satisfied $c_r + f < p_r$.

(3) Following the classical research of Ferrer and Swaminathan [27] and Oersdemir et al. [28], the demand functions of the new and remanufactured products are as follows:

Table 1: Correlative literature comparison.

Correlative literature	Inherent capital	Budget-limited player Upstream downstream	Risk appetite origin Producing expenditure merchandise Requirement	Ecological influence
Zhang and Chen [16]	Yes	Yes	Yes	NO
Zhang et al. [17]	Yes	Yes		Yes
Zheng et al. [18]	Yes	Yes		NO
Li et al. [19]	NO	Yes	Yes	NO
Yang et al. [24]	Yes	Yes	Yes	NO
Our work	Yes	Yes	Yes	Yes

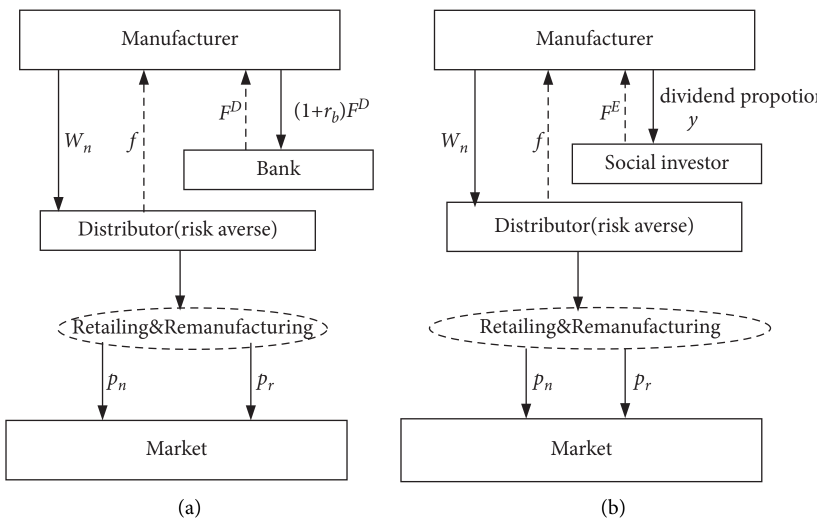


Figure 1: The operating progress chart of financing in distributor-remanufacturing mode. (a) Debt financing operations procedure. (b) Equity financing operations procedure.

$$q_n = \frac{p_n - p_r}{1-\delta} \cdot q_r = \frac{\delta p_n - p_r}{\delta(1-\delta)}. \tag{1}$$

The notation δ represents the customer's value discount for the remanufactured product. The consumer's acceptance for the remanufactured product is a partition $\delta \in (0,1)$ comparing with the new one, which indicates that the larger the δ, the stronger the willingness of the customer to purchase the remanufactured products.

(4) Only focus on the single-period remanufacturing model like Wang et al. [29], that is to say, all of the recycled products can participate in remanufacturing activity, and all the remanufactured products can be sold.

(5) Supposing that the manufacturer is in a mighty position in CLSC, the manufacturer plays the role as the leader, while the distributor is the follower. The manufacturer is risk-neutral, and the distributor is risk-averse on the basis of the research from Chiu et al. [30] and Choi et al. [31], adopting the mean-variance method to weigh the distributor's utility in the following manner:

$$U_D = E(\pi_D) - k_d\sqrt{\operatorname{var}(\pi_D)}. \tag{2}$$

(6) Because of the previous investigations from Zou et al. [32], the consumer surplus refers to the difference between the highest price that a consumer is willing to pay for a certain commodity and the actual market price of these commodities. The formulations of CS and their increment ΔCS are denoted as follows:

$$CS = \int_{\frac{p_n-p_r}{1-\delta}}^{\delta} (v - p_n)dv + \int_{\frac{p_r}{\delta}}^{\frac{p_n-p_r}{1-\delta}} (\delta v - p_r)dv = \frac{\delta q_r^2 + q_n^2 + 2\delta q_n q_r}{2}, \Delta CS = CS^{ME*} - CS^{MD*}. \tag{3}$$

(7) Because of the universal acknowledgement on the previous research on Esenduran et al. [33] and Wang and Chen [34], the total carbons includes the carbon emissions of the two types of products. Furthermore, the producing process in the remanufactured product is eco-friendlier than the new one, i.e., $e_n^m > e_r^m$; as for the using stage is equal, i.e., $e_n^u = e_r^u$. The total carbon emissions E^{j*} and its increment ΔE are calculated as follows:

$$E^{j^*} = q_n^{j^*}\left(e_n^m + e_n^u\right) + q_r^{j^*}\left(e_r^m + e_r^u\right), j = MD, ME, \Delta E = E^{ME*} - E^{MD*}. \tag{4}$$

4. Model Setup and Analysis

In this sector, we focus on studying the optimal pricing strategies under the distributor-remanufacturing mode in the four cases, analyzing and comparing the optimal sales volume, and studying the expected profit and utility under four situations successively. As a result, the manufacturer makes optimal decisions by revenue maximization, while the distributor takes the utility maximization into consideration when it decides in all cases.

4.1. Case 1: Manufacturer Is with Ample Capital (Model MN). In this case, the manufacturer acts as a supplier of new products, and the distributor acts as a remanufacturer. The manufacturer sells the new product to the distributor and gives patent to the distributor to remanufacture. Finally, the distributor sells the two kinds of products to the customer.

The manufacturer's revenue function and the distributor's revenue function are as follows:

$$\max_{w_n, f} \pi_M = (w_n - c_n)q_n + f q_r \tag{5}$$

and

$$\max_{p_n, p_r} \pi_D = (p_n - w_n)q_n + (p_r - c_r - f)q_r, \tag{6}$$

separately.

Moreover, the mean and variance of π_D is listed as follows:

$$\begin{aligned} E(\pi_D) &= (p_n - w_n)q_n + (p_r - c_r - f)q_r,\\ \operatorname{var}(\pi_D) &= E\left[(\pi_D - E(\pi_D))^2\right] = q_r^2\sigma^2. \end{aligned} \tag{7}$$

Furthermore, based on the $M - V$ utility calculating function from the existing literature [28, 29], the distributor's utility function is denoted as follows:

$$\max_{p_n, p_r} U_D = (p_n - w_n)q_n + (p_r - c_r - f)q_r - k_d q_r \sigma. \tag{8}$$

To list the equilibrium solutions for simplicity, we denote $F_1 = \delta - c_r - k_d\sigma$, $F_2 = 1 + c_r + k_d\sigma - c_n - \delta$, and $F_3 = \delta c_n - c_r - k_d\sigma$ for concise expression. Moreover, all of the proof process about the propositions, corollaries, and remarks are enumerated in the Appendix.

Proposition 1. *In model MN, the equilibrium solutions of the wholesale price, patent fee, and retailing price are concluded in the following manner:*

$$\begin{aligned} w_n^{MN*} &= \frac{c_n + 1}{2},\\ f^{MN*} &= \frac{(\delta - c_r - k_d\sigma)}{2} = \frac{F_1}{2},\\ p_n^{MN*} &= \frac{3 + c_n}{4},\\ p_r^{MN*} &= \frac{c_r + 3\delta + k_d\sigma}{4}. \end{aligned} \tag{9}$$

On the basis of the one-to-one correspondence between the price and demand, the relevant sales volume, expected revenue, and utility are listed in Corollary 1.

Corollary 1. *In model MN, the corresponding equilibrium sale quantities of the two types of products, total quantities, expected profits, and utility are successively listed as follows:*

$$\begin{aligned} q_n^{MN*} &= \frac{(1 + c_r + k_d\sigma - c_n - \delta)}{4(1-\delta)} = \frac{F_2}{4(1-\delta)},\\ q_r^{MN*} &= \frac{(\delta c_n - c_r - k_d\sigma)}{4\delta(1-\delta)} = \frac{F_3}{4\delta(1-\delta)},\\ q_t^{MN*} &= \frac{(\delta - c_r - k_d\sigma)}{4\delta},\\ \pi_M^{MN*} &= \frac{\delta(1-c_n)F_2 + (\delta - c_r - k_d\sigma)F_3}{8\delta(1-\delta)},\\ E\left(\pi_D^{MN*}\right) &= \frac{\delta(1-c_n)F_2 + (\delta - c_r + 3k_d\sigma)F_3}{16\delta(1-\delta)},\\ U_D^{MN*} &= \frac{(\delta(1-c_n)F_2 + (\delta - c_r - k_d\sigma)F_3)}{16\delta(1-\delta)}. \end{aligned} \tag{10}$$

4.2. Case 2: Manufacturer Is under Capital Limit (Model MY). This case devotes to studying the circumstance that the manufacturer is limited by its producing capital level without any financing activities. The decision procedure is in common with model MN. In this case, the manufacturer's revenue function and the distributor's utility function are as follows:

$$\begin{aligned} &\max_{w_n, f} \pi_D = (w_n - c_n)q_n + f q_r,\\ &\text{s.t.} \quad c_n q_n \le N. \end{aligned} \tag{11}$$

and

$$\max_{p_n, p_r} U_D = (p_n - w_n)q_n + (p_r - c_r - f)q_r - k_d q_r \sigma, \quad (12)$$

separately.

Proposition 2. *In this case, the equilibrium solutions of the wholesale price, patent fee, and retailing price can be listed as follows:*

$$\begin{aligned} w_n^{MY^*} &= w_n^{MN^*} + \frac{\lambda c_n}{2}, \\ f^{MY^*} &= f^{MN^*}, \\ p_n^{MY^*} &= p_n^{MN^*} + \frac{\lambda c_n}{4}, \\ p_r^{MY^*} &= p_r^{MN^*}. \end{aligned} \quad (13)$$

On the basis of the one-to-one correspondence between the price and demand, the relevant sales volume, expected revenue, and utility are enumerated in Corollary 2.

Corollary 2. *In model MY, the corresponding equilibrium sales volume of the two types of products, total quantities, expected profits, and utility are expressed successively as follows:*

$$\begin{aligned} q_n^{MY^*} &= q_n^{MN^*} - \frac{\lambda c_n}{4(1-\delta)}, \\ q_r^{MY^*} &= q_r^{MN^*} + \frac{\lambda c_n}{4(1-\delta)}, \\ q_t^{MY^*} &= q_t^{MN^*}, \\ \pi_M^{MY^*} &= \pi_M^{MN^*} - \frac{(\lambda c_n)^2}{8(1-\delta)}, \\ E\left(\pi_D^{MY^*}\right) &= E\left(\pi_D^{MN^*}\right) + \frac{\lambda c_n(\lambda c_n - 2F_2)}{16(1-\delta)}, \\ U_D^{MY^*} &= U_D^{MN^*} + \frac{\lambda c_n(\lambda c_n - 2F_2)}{16(1-\delta)}. \end{aligned} \quad (14)$$

4.3. Case 3: Manufacturer Executes Debt Financing Approach (Model MD). When the manufacturer's inherent capital is extremely deficient, the manufacturer can obtain more revenues using the debt financing approach by borrowing money from the bank than manufacturing with inherent capital. In this model, the manufacturer's financing amount of money is equivalent to $F^D = c_n q_n - N$. In other words, the manufacturer's financing capital is exploited to produce new products. At last, the manufacturer returns the principal capital and its interest to the bank at the end of finishing the sale activity.

Following the previous literature of the Li et al. [8] and Shen et al. [35], the manufacturer's revenue function and the distributor's utility function in the bank loan are as follows:

$$\begin{aligned} \max_{w_n, f} \pi_M &= (w_n - c_n)q_n + f q_r + N + F^D - (1 + r_b)F^D - N \\ &= (w_n - c_n)q_n + f q_r - r_b F^D. \end{aligned} \quad (15)$$

and

$$\max_{p_n, p_r} U_D = (p_n - w_n)q_n + (p_r - c_r - f)q_r - k_d q_r \sigma, \quad (16)$$

separately.

Proposition 3. *In model MD, the equilibrium solutions of the wholesale price, patent fee and retailing price can be expressed as follows:*

$$\begin{aligned} w_n^{MD^*} &= w_n^{MN^*} + \frac{c_n r_b}{2}, \\ f^{MD^*} &= f^{MN^*}, \\ p_n^{MD^*} &= p_n^{MN^*} + \frac{c_n r_b}{4}, \\ p_r^{MD^*} &= p_r^{MN^*}. \end{aligned} \quad (17)$$

According to the one-to-one correspondence between the price and demand, the relevant sales volume, expected revenue, and utility are showed in Corollary 3.

Corollary 3. *In model MD, the corresponding equilibrium sales quantities of the two types of products, total quantities, expected profits, and utility are successively denoted as follows:*

$$\begin{aligned} q_n^{MD^*} &= q_n^{MN^*} - \frac{c_n r_b}{4(1-\delta)}, \\ q_r^{MD} &= q_r^{MN^*} + \frac{c_n r_b}{4(1-\delta)}, \\ q_t^{MD^*} &= q_t^{MN^*}, \\ \pi_M^{MD^*} &= \pi_M^{MN^*} + \frac{r_b\left(c_n^2 r_b - 2c_n F_2\right)}{8(1-\delta)} + B r_b, \\ E\left(\pi_D^{MD^*}\right) &= E\left(\pi_D^{MN^*}\right) + \frac{c_n r_b(c_n r_b - 2F_2)}{16(1-\delta)}, \\ U_D^{MD^*} &= U_D^{MN^*} + \frac{c_n r_b(c_n r_b - 2F_2)}{16(1-\delta)}. \end{aligned} \quad (18)$$

4.4. Case 4: Manufacturer Executes Equity Financing Approach (Model ME). Through the equity financing approach, it is generally believed that that the quota of the equity financing capital is $F^E = c_n q_n^{MN^*} - N$ to remove the manufacturing capital constraint inequality. However, the manufacturer defrays a certain ratio y of the sales revenues to the social investor at the end of the sales activity. The specific model is listed as follows:

On the basis of the literature of Yang et al. [36], the manufacturer's income function and the distributor's utility are as follows:

$$\max_{w_n, f} \pi_M = (1-y)\left((w_n - c_n)q_n + f q_r + N + F^E\right) - N. \quad (19)$$

and

$$\max_{p_n, p_r} U_D = (p_n - w_n)q_n + (p_r - c_r - f)q_r - k_d q_r \sigma. \quad (20)$$

successively.

Furthermore, the social investor can get the rest of the manufacturer's sales revenue after the sales period. Hence, its revenue function is expressed in the following manner:

Social investor's revenue: $\pi_S^{ME^*} = y((w_n - c_n)q_n + f q_r + N + F^E) - F^E$

Proposition 4. *The equilibrium solutions of the wholesale price, patent fee, and retailing price in model ME can be enumerated in the following manner:*

$$w_n^{ME^*} = w_n^{MN^*}, f^{ME^*} = f^{MN^*}, p_n^{ME^*} = p_n^{MN^*}, p_r^{ME^*} = p_r^{MN^*}. \quad (21)$$

Proposition 4 implies that in model ME, the equilibrium solutions of the decision variables are the same as those in model MN. For the reason that the social investor provides the manufacturer with ample manufacturing capital without any interest, the manufacturer is able to achieve the optimal solutions, such as the operations state of manufacturing without capital limit. It drops a hint that compared with the benchmark model, equity financing enables the decision variables to remain unchanged.

According to the above optimal solution set, the relative equilibrium solutions on the sales volumes, the manufactures' and investors' revenue, and the expected revenue and utility of the distributor can be concluded as Corollary 4.

Corollary 4. *In model ME, the corresponding equilibrium sales volume of the two types of products, total quantities, expected profits, and utility are given successively as follows:*

$$\begin{aligned} q_n^{ME^*} &= q_n^{MN^*}, q_r^{ME^*} = q_r^{MN^*}, \pi_M^{ME^*} \\ &= (1-y)\left(\pi_M^{ON*} + F^E + N\right) - N, \pi_s^{ME^*} \\ &= y\left(\pi_M^{ON*} + F^E + N\right) - F^E, E\left(\pi_D^{ME^*}\right) \\ &= E\left(\pi_D^{MN^*}\right), U_D^{ME^*} = U_D^{MN^*}. \end{aligned} \quad (22)$$

Corollary 4 illustrates that when the manufacturer engages in equity financing, the sales volume of the two types of products is equal successively, and the utility value and expected revenue of the distributor are the same as those of model MN. Moreover, the manufacturer shares a proportion of the sales revenue to the social investor and keeps the rest of the income to himself until the end of the sales period in model ME.

Corollary 5. *When $N^D \leq N < N^S$, the manufacturer is unable to get benefits by the debt financing approach. If $N < N^D$, the manufacturer will be profited by the debt financing approach, of which $N^D = c_n F_2 - c_n^2 r_b / 4(1-\delta)$, and $N^S = c_n F_2 / 4(1-\delta)$.*

Corollary 5 gives two thresholds of the manufacture's inherent manufacturing capital, of which N^S represents the critical value of the manufacturer's sufficient producing capital in the Stackelberg game, and N^D stands for the threshold of the manufacturer to tend to seek funds using debt financing. It indicates that only when the manufacturing capital is extremely deficient, i.e., $N < N^D$, the manufacturer is profited by debt financing.

Corollary 6. *When $N < N^D$, the utility of the distributor and the manufacturer's revenue under model MD and model MN satisfy $U_D^{MD^*} > U_D^{MN^*}$, $\pi_M^{MD^*} < \pi_M^{MN^*}$.*

Since the manufacturer's self-own capital is strongly deficient, it applies the debt financing approach to maintain normal operations in CLSC. The sale volumes of new products are lower, and the sale volumes of the remanufactured products are higher than those of the ample capital case, respectively, which makes the distributor's utility value in model MD lower than that of the manufacturer produce with ample capital case, i.e., $U_D^{MD^*} < U_D^{MN^*}$. Moreover, the manufacturer needs to defray the interest to the bank. Therefore, the manufacturer's revenue in the model MD is lower than the manufacturer MN, i.e., $\pi_M^{MD^*} < \pi_M^{MN^*}$.

Corollary 7. *When $N < N^S$, the effect of the self-owned capital N on the equilibrium solutions of wholesale price, patent fee, retailing price, sales volume, CLSC player's profits, and utility in model MY are denoted in the following manner:*

(1) $\partial w_n^{MY^*}/\partial N < 0$, $\partial f^{MY^*}/\partial N = 0$, $\partial p_n^{MY^*}/\partial N > 0$, $\partial w_n^{MY^*}/\partial N > 0$, $\partial q_r^{MY^*}/\partial N < 0$, $\partial q_t^{MY^*}/\partial N = 0$

(2) $\partial U_D^{MY^*}/\partial N < 0$, $\partial^2 \pi_M^{MY^*}/\partial N^2 < 0$

Corollary 7 shows that when the self-owned capital is insufficient, the wholesale price and retailing price of the new products will decrease as N increases, while the sales volume of the new products will increase when N goes up. Afterward, the sales volumes of the remanufactured products will decrease when N increases, while the total sales volumes have nothing to do with N. Moreover, when the manufacturer has a dearth of funds, the manufacturer needs to sell new products at a lower wholesale price to obtain more sales, and at the same time, the distributors also need to sell new products at a lower retail price to maintain the revenue when they observe the manufacturer's decisions. However, the incline in the sales of new products has led to a decline in the sales of remanufactured products, which has led to a crowding out effect in the CLSC system. Moreover, the decrease in the sales of remanufactured products has led to a reduction in the income of patent fee. It results in the decline of the manufacturer's revenue ultimately. In addition, the manufacturer's revenue is a *concave function of N, and the profit increases at first and then decreases. It fully shows that the scarcity of self-owned capital will lead to fierce competition in the system.*

That is to say, when the manufacturer lacks manufacturing fund and when the self-owned capital N increases, the manufacturer will reduce the wholesale price of new products as much as possible to increase the sales volume of new products. At this time, the risk-averse distributor will reduce the sales volume of remanufactured products to avoid revenue losses. In this way, new products will have a crowding out effect on remanufactured products, which brings about a fierce competition in the system. Thus, it is of practical significance for the capital-deficient manufacturer to adopt the optimal financing approach.

Corollary 8. *When $N < N^S$, the influences of k_d on the sales volume, patent fee, price, CLSC player's profit, and utility of the four cases are enumerated in the following manner:*

(1) $\partial f^{j*}/\partial k_d < 0$, $\partial p_r^{j*}/\partial k_d > 0$, $\partial q_n^{j*}/\partial k_d > 0$, $\partial q_r^{j*}/\partial k_d < 0$, $\partial q_t^{j*}/\partial k_d < 0$, $\partial F^D/\partial k_d > 0$, $\partial F^E/\partial k_d > 0$, $\partial \pi_M^{j*}/\partial k_d < 0$, $\partial U_{RM}^{j*}/\partial k_d < 0$, and $j = MN^*, MD^*, ME^*$

(2) $\partial w_n^{MY^*}/\partial k_d > 0$, $\partial f^{MY^*}/\partial k_d < 0$, $\partial p_n^{MY^*}/\partial k_d > 0$, $\partial p_r^{MY^*}/\partial k_d > 0$, $\partial q_r^{MY^*}/\partial k_d < 0$, $\partial q_t^{MY^*}/\partial k_d < 0$, and $\partial U_D^{MY^*}/\partial k_d < 0$

Corollary 8 implies that enlightenment consists of two aspects. On the one hand, when the self-owned funds are deficient, it implies that the first derivative order of the sales volume, retailing price, revenues, and utility on k_d is equal in models MD, ME, and MN. Both show that the distributor reduces the utility values when k_d increases. To minimize the utility loss caused by the risk loss originating from fluctuations in the remanufacturing cost, the distributor will reduce the sales volumes of remanufactured products, causing the incline in the sales volumes of new products, which has also led to an increase in the amount of manufacturer's financing capital. Meanwhile, the distributor will also increase the retailing price of remanufactured products to maintain their utility value. As for the manufacturer, because of the decrease in the sales of remanufactured products, to minimize the risk of loss, the manufacturer will reduce the authorization fee. Although the sales of new products increase, the incline in the profits brought by selling the new product is far less than the decline in the patent fee income. Hence, the manufacturer's revenue decreases as k_d increases. In this way, there exists an increase in the amount of financing capital for the capital-deficient manufacturer, and the dealers will also increase the price of remanufactured products at this time to maintain their utility value.

On the other hand, when funds are constrained and the manufacturer does not adopt financing, the distributor will reduce the utility value when k_d increases. To minimize the utility loss caused by risk aversion, the distributor will reduce the sales volumes of remanufactured products, causing the incline in the selling price of remanufactured products, and the distributor will also increase the sales price of remanufactured products to maintain their utility value. For the purpose of minimizing the impact of revenue loss that arises from the risk-averse, the manufacturer will also reduce the authorization fee and rely on increasing the wholesale price of new products to maintain his own revenue. Since the self-owned capital is the major factor affecting the new product sales in this situation, new product sales have nothing with the risk aversion parameter. However, the total sales volume of the two types of products also fell because of the drop in the sales volume of remanufactured products.

Corollary 9. *When $N < N^S$, if the manufacturer and the social investor tend to carry out the equity financing approach. When the manufacturer's income and social investor's revenue satisfy this combination of inequalities, $\begin{cases} \pi_M^{ME^*} > \pi_M^{MY^*} \\ \pi_s^{ME^*} > 0 \end{cases}$, of which the left and right bounds of the executable equity dividend proportion are obtained in the following manner:*

$$y^L = \frac{2\delta\left(c_n F_2 - 4N(1-\delta)\right)}{(1+c_n)\delta F_2 + (\delta - c_r - k_d\sigma)F_3}, y^R = \frac{\delta\left(\lambda^2 c_n^2 + 2c_n F_2 - 8N(1-\delta)\right)}{(1+c_n)\delta F_2 + (\delta - c_r - k_d\sigma)F_3}. \tag{23}$$

Corollary 9 gives guidance about the boundaries of the interval numbers on the dividend proportion the manufacturer and the social investor commonly approve of, which are the left and right bounds of the executable equity dividend proportion, denoted as y^L and y^R. When the the equity financing approach is thoughtful for the two participants in the CLSC, it will meet these two necessary conditions: one thing is that his revenue in the case ME benefits more than that of the case MY that is to say $\pi_M^{ME^*} > \pi_M^{MY^*}$, and another thing is that the social financier's income is bigger than zero, i.e., $\pi_S^{ME^*} > 0$. This corollary supplies a theoretical basis for the manufacturer to carry out the equity financing approach when the dividend proportion locates in a rational interval.

Corollary 10. *When $N < N^S$, the effect of the distributor's risk altitude factor k_d and manufacturer's self-owned capital N on the executable equity dividend proportion y is denoted successively as follows:*

(1) $\partial y^L/\partial k_d > 0$, $\partial y^R/\partial k_d > 0$, $\partial \Delta y/\partial k_d > 0$

(2) $\partial y^L/\partial N < 0$, $\partial y^R/\partial N < 0$, $\partial \Delta y/\partial N < 0$

Corollary 10 implies that under model ME, the left and right bounds of the executable equity dividend proportion increase when k_d goes up. Meanwhile, the width of the interval increases with k_d. It indicates that the incline speed on the right bound of the interval is faster than that of the left bound. Moreover, the left and right bounds of the *executable equity dividend proportion decrease with the increase of the self-owned capital, while the width of the interval decreases while N increases. It implies that if the manufacturer's inherent capital owned is more, the amount of financing capital that needs to be obtained from the investor will be decreased. Hence, the proportion of sales profit shared with the investor will be reduced, which causes a decline in the left and right bounds of the executable equity dividend proportion. Thus, it is vital for an investor to show close attention to the degree of the distributor's risk aversion and the inherent capital the manufacturer owned.*

5. Contrast and Analysis of the Two Financing Approaches

Firstly, this sector has done a specific contrast and analysis on the equilibrium solutions in the two financing approaches. Then, it studies the comparison of the relative size of CS and total carbon emissions under models MD and ME. Secondly, it compares and analyzes the revenue of the manufacturer in the two financing models, obtaining the boundary conditions for choosing the optimal financing approach by comparing. Finally, when the self-owned fund is relatively deficient, having step into a further discussion and study, achieving the corollary about the selection of the financing approach preference for both CLSC members.

5.1. Contrast and Analysis on the Equilibrium Solutions in the Two Financing Approaches

Remark 1. The comparisons of equilibrium solutions on the wholesale price, patent fee, and retailing price of the two types of products between the two financing approaches satisfy $w_n^{ME^*} < w_n^{MD^*}$, $p_r^{ME^*} = p_r^{MD^*}$, $p_n^{ME^*} < p_n^{MD^*}$, and $f^{ME^*} = f^{MD^*}$.

In debt financing, the wholesale and retailing prices of new products are higher, while the retailing price of the remanufactured product is the same as equity financing. When the retailing price of the new product is lower than debt financing, the manufacturer keeps the patent fee unchanged to decrease the profit loss originating from patent fee revenue.

Remark 2. The comparisons of the equilibrium solutions on sales volumes of the two types of the two products, expected revenue, and utility satisfy $q_n^{ME^*} > q_n^{MD^*}$, $q_r^{ME^*} < q_r^{MD^*}$, $q_t^{ME^*} = q_t^{MD^*}$, $E(\pi_D^{ME^*}) > E(\pi_D^{MD^*})$, $U_D^{ME^*} > U_D^{MD^*}$, and $\partial \Delta U_D/\partial k_d > 0$.

In the equity financing approach, the output of remanufactured products is lower, and the output of new products is higher. It results in less loss of selling remanufactured products and prompting the manufacturer to make more benefits from selling new products than debt financing. As a result, the expected revenue and utility of the distributor and retailer are both higher in the equity financing approach, indicating that equity financing is always more beneficial to the distributor. However, the increment of the distributor's utility increases when k_d goes up, dropping a hint that the distance of the utility between the two financing approaches becomes bigger when k_d increases.

5.2. Contrast of the Consumer Surplus. According to the calculating formulations from the Chiu et al. [30], CS in the two financing approaches is denoted in Proposition 5 as follows:

Proposition 5. *CS in models MD and ME is denoted in the following manner:*

$$
\begin{aligned}
CS^{MD^*} &= \frac{\left((1 - c_n - 2c_n r_b)\delta F_2 + (\delta - c_r - k_d\sigma)F_3 + \delta c_n^2 r_b^2\right)}{32\delta(1-\delta)},\\
CS^{ME^*} &= \frac{\left(\delta(1-c_n)F_2 + (\delta - c_r - k_d\sigma)F_3\right)}{32\delta(1-\delta)}.
\end{aligned} \tag{24}
$$

From calculating and comparison, Remark 3 is listed below.

Remark 3. $CS^{ME^*} > CS^{MD^*}$, $\partial CS^{MD^*}/\partial k_d < \partial CS^{ME^*}/\partial k_d < 0$, $\partial \Delta CS/\partial k_d > 0$, and $CS^{ME^*} > CS^{MD^*}$

Based on Remark 1, we can see that the consumer can benefit more from buying the remanufactured product because of the lower price than that of debt financing. This remark exhibits the enlightenment that CS in model ME is greater than that in model MD. It is on account of the sales volumes of the remanufactured products in the equity financing, which is much bigger than debt financing. As the first order of the remanufactured product on k_d is negative, it results in the decline of the customer's purchasing benefits in the two financing approaches. However, the increment of CS increases when k_d goes up, which indicates that the customer favors the equity financing when the downstream distributor is more risk-averse in CLSC.

5.3. Contrast of the Environmental Impact. On the basis of the assumptions referred above, the carbon emissions consist of the producing process and using stage of new and remanufactured products, which is mentioned by Choi et al. [31]. By calculating the environmental impact during these two financing approaches, Proposition 6 can be listed as follows:

Proposition 6. *the total carbon emissions in model MD and model ME are calculated as follows:*

$$
\begin{aligned}
E^{ME^*} &= \frac{F_2}{4(1-\delta)}\left(e_n^m + e_n^u\right) + \frac{F_3}{4\delta(1-\delta)}\left(e_r^m + e_r^u\right),\\
E^{MD^*} &= \frac{F_2 - c_n r_b}{4(1-\delta)}\left(e_n^m + e_n^u\right) + \frac{F_3 + c_n r_b}{4\delta(1-\delta)}\left(e_r^m + e_r^u\right).
\end{aligned} \tag{25}
$$

Remark 4. $E^{ME^*} > E^{MD^*}$, $\partial CS^{MD^*}/\partial k_d < \partial CS^{ME^*}/\partial k_d < 0$. When $\delta > \delta^0$, $\partial CS^{MD^*}/\partial k_d < \partial CS^{ME^*}/\partial k_d > 0$, and vice versa.

Remark 4 shows that debt financing releases less carbons, which is eco-friendlier. The first order of the environmental impact on k_d is equal, which indicates that the monotonicity of k_d is the same. If the customer's evaluation of the remanufactured product is more than the threshold value δ^0, the environmental impact will increase when k_d increases, and vice versa.

5.4. The Analysis of the Optimal Financing Approach Selection. As a matter of fact, the manufacturer's optimal financing approach relies on the expected revenue brought by the different financing approaches when it is with limited capital. Since the debt financing rate is exogenous, the revenues of both members in CLSC can be calculated in the debt financing model, whereas the incomes of the investor and manufacturer will be influenced by the dividend proportion in the equity financing mode. Thus, the manufacturer's financing approach selection counts on the specific scale of the dividend proportion. The manufacturer's financing approach selection is illustrated by Corollary 11.

Corollary 11.

(1) When $N^D \le N < N^S$, the manufacturer tends to select the equity financing approach if the dividend proportion satisfies $y < y^{EY}$. Otherwise, if $y \ge y^{EY}$, the manufacturer engages in producing activity with its initial capital.

(2) When $N < N^D$, the manufacturer prefers to select the equity financing approach rather than debt financing, if the dividend proportion satisfies $y < y^{ED}$. Otherwise, if $y \ge y^{ED}$, the manufacturer tends to select the debt financing approach. y^{ED} and y^{EY} are denoted as follows:

$$y^{EY} = \frac{\delta\left(\lambda c_n^2 + 2c_nF_2 - 8N(1-\delta)\right)}{(1+c_n)\delta F_2 + (\delta c_n - c_r - k_d\sigma)F_3}, y^{ED} = \frac{2\delta c_n F_2(1+r_b) - \delta c_n^2 r_b^2 - 8\delta(1-\delta)(1+r_b)N}{(1+c_n)\delta F_2 + (\delta - c_r - k_d\sigma)F_3}. \quad (26)$$

Corollary 11 illustrates that upon comparing the manufacturer's expected revenue on the equilibrium state under different financing methods, it is natural for us to obtain the two dividend proportion thresholds y^{EY} and y^{ED} when the manufacturer is confronted with different degrees of manufacturing fund deficiency. It provides a theoretical guidance for the manufacturer to choose the optimal financing approach.

5.5. The Contrast and Analysis on Expected Revenue of the Whole CLSC. The expected profit of CLSC is the sum of the expected revenue of the manufacturer and the distributor in CLSC, which are denoted in the Proposition 7 as follows:

Proposition 7. *The expected revenue in models MD and ME is calculated as follows:*

$$\begin{aligned} E\left(\pi_{SC}^{MD^*}\right) &= E\left(\pi_M^{MD^*}\right) + E\left(\pi_D^{MD^*}\right) = \pi_M^{ON\,*} + Nr_b + \pi_D^{MN^*} + \frac{3c_nr_b(c_nr_b - 2F_2)}{16(1-\delta)}, \\ E\left(\pi_{SC}^{ME^*}\right) &= E\left(\pi_M^{ME^*}\right) + E\left(\pi_D^{ME^*}\right) = (1-y)\left(\pi_M^{MN^*} + F^E + N\right) - N + \pi_D^{MN^*}. \end{aligned} \quad (27)$$

Remark 5. $\partial E(\pi_{SC}^{MD^*})/\partial N > 0$, $\partial E(\pi_{SC}^{MD^*})/\partial k_d < 0$, and $\partial E(\pi_{SC}^{ME^*})/\partial N < 0$. If $\pi_M^{MD^*} + \pi_D^{MD^*} < \pi_M^{MY^*} + \pi_D^{MN^*}$, there generates a threshold $y_{SC}^{ED} \in (y^{ED}, y^R)$, when $y < y_{SC}^{ED}$, $E(\pi_{SC}^{ME^*}) > E(\pi_{SC}^{MD^*})$, and vice versa.

This remark shows that the expected revenues in model MD increase when N grows up, while the total profits of CLSC in model ME decrease as N increases. If $\pi_M^{OD\,*} + \pi_D^{OD\,*} > \pi_M^{OY\,*} + \pi_D^{ON\,*}$, when the dividend proportion satisfies $y < y_{SC}^{ED}$, the total expected revenue of the supply chain during equity financing is better than the total revenue in debt financing, which shows the enlightenment that it is of great significance for a social investor to focus on the specific dividend proportion in the realistic operations management.

6. Numerical Comparisons and Simulation Analysis

In fact, the actual data is derived from the research work of Long et al. [11] and Zou et al. [32]. It is set as $c_n = 0.8$, $c_r = 0.5$, $\delta = 0.65$, $\sigma = 0.10$, $e_n^m = 6$, $e_r^m = 5$, and $e_n^u = e_r^u = 2$. The financing rate $r_b = 0.045$ follows the investigation data from the commercial bank in China, which is in accordance with the practical operation situation.

As is shown below, the influence of k_d on sales volume and CS in the two financing approaches and the impact of N and k_d on the left and right bounds of the executable equity dividend proportion in model ME are exhibited in Figures 2 and 3, respectively. Moreover, when the producing capital is

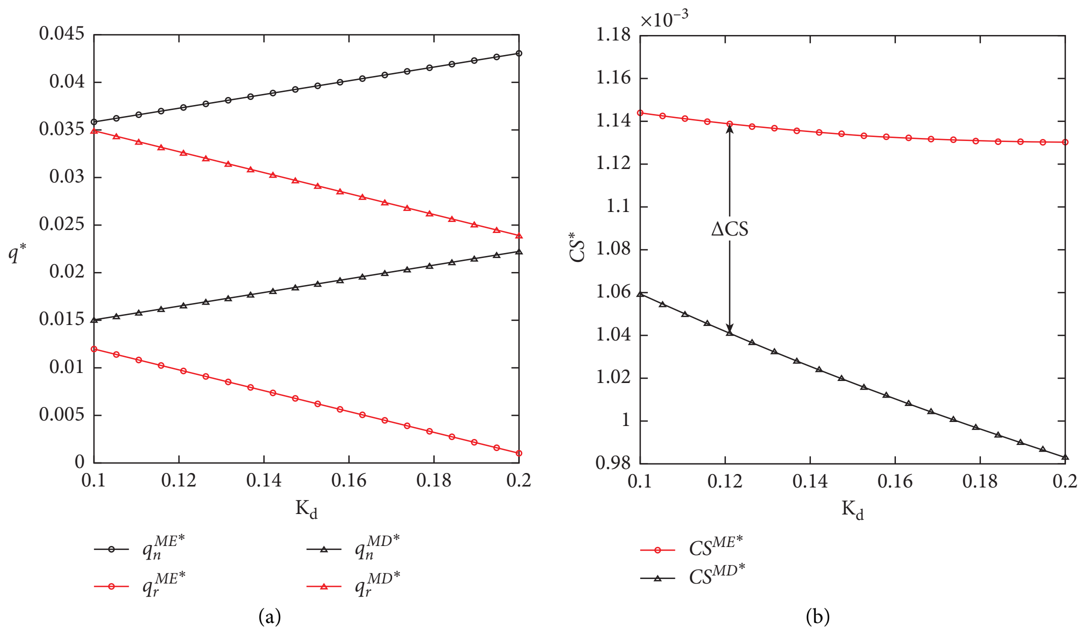


Figure 2: k_d affect sales volumes and CS in models MD and ME.

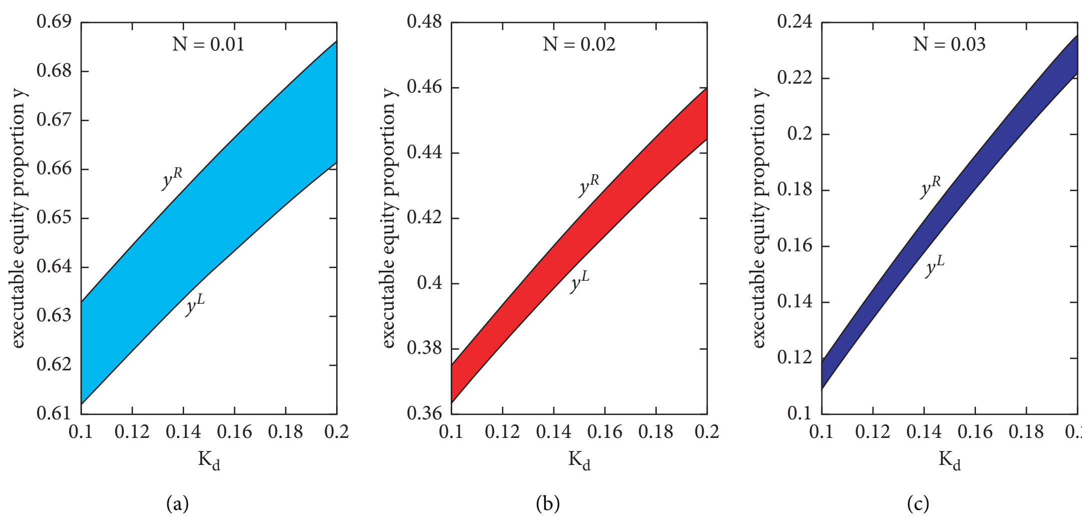


Figure 3: k_d and N jointly affect the executable dividend proportion in model ME.

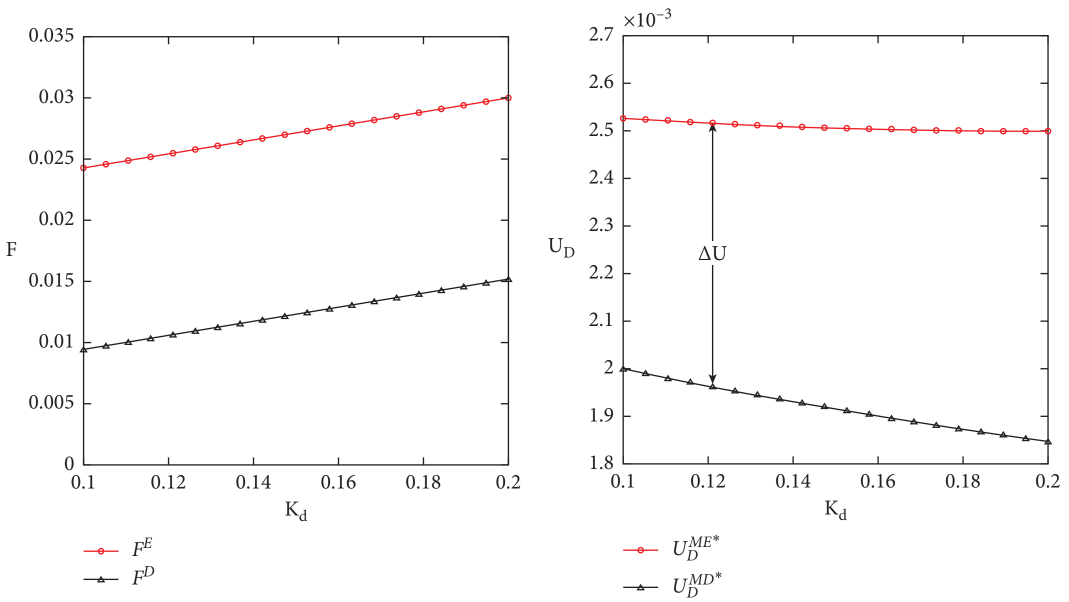
limited, the impact of self-owned capital on sales volume and member's revenue are simulated in Figure 4. Furthermore, the degree of self-owned capital deficiency has a significant influence on the optimal financing approach selection in model MY, and it is listed in Table 2.

6.1. Influences of Risk-Averse Parameter. The impact of the risk aversion parameter on the sales volume of the two types of products and the CS of the two financing approaches are presented in figures 2(a) and 2(b), respectively.

As showed in figure 2(a), with the increase ofk_d, the sales volume of the new products increases, while the sales volume of the remanufactured products decreases in the two financing models. Figure 2(b) indicates that CS decreases as k_d increases in both financing methods, however, the decline speed is faster in the debt financing model than that in the equity financing mode. The increment of CS becomes larger when k_d goes up, which also verifies the justifiability of Corollary 8 and Remark 3.

The joint impact of the risk aversion coefficient k_d and self-owned fund N on the left and right bounds of the dividend proportion and the interval size of the executable dividend proportion are presented in figures 3(a) ~ 3(c) below.

As depicted in Figure 3, Figures 3(a)–3(c) indicate that as the self-owned fund N ranges from 0.01 to 0.03, the lower and upper bounds of the acceptable dividend proportion



(a) (b)

Figure 4: N affects the sales volume and CLSC member's revenue in model MY.

Table 2: The clarifications of all the variables.

Variables	Illustration
w_n	The wholesale price of the new product
f	Patent fee
p_n/p_r	Retailing price of the new/remanufactured product
k_d	Distributor's risk aversion factor
N	Manufacturer's self-owned capital
N^S	Manufacturer's sufficient producing fund in the CLSC model
N^D	Manufacturer's threshold of self-owned capital on executing debt financing approach
F^D/F^E	The amount of manufacturer financing capital in model **MD/ME**
$e_n^m(e_n^u)/e_r^m(e_r^u)$	Carbon emissions of the two products in the producing process and using stage
λ	Lagrange multiplier (shadow price of N)
c_n/c_r	The producing cost of each new/remanufacturing product
δ	The customer value discount for the remanufactured product
q_n/q_r	Sales volume of new/remanufacturing products
r_b	Bank financing rate
y	The executable equity dividend proportion in model **ME**, $0 < y < 1$
(y^L, y^R)	The left and right bound of the dividend proportion in model **ME**
y^{EY}/y^{ED}	The minimum threshold of the manufacturer's dividend proportion
y_{SC}^{ED}	Minimum proportion in preferring equity financing than debt financing in CLSC
$\Delta E/\Delta U_D$	Increment of ecological effect/distributor's utility between models ME and MD
$\pi_M^{MN^*}/\pi_M^{MY^*}\pi_M^{MD^*}/\pi_M^{ME^*}$	Manufacturer's revenue in the four cases successively

declined gradually, and the interval size of y becomes smaller. For each certain subfigure, y^L and y^R increase when k_d grows up, which further verified the rationality of Corollary 10. Therefore, it is vital for venture investors to pay close attention to the amount of manufacturer's inherent capital and the degree of the downstream distributor's risk averse in CLSC.

The effect of k_d on financing capital and distributor's utility are depicted as follows:

Figure 5(a) shows that under the two financing methods, the amount of financing capital increases when the risk averse factor increases, which is consistent with the clarification reflected in Corollary 8, since the sales volume of new products in equity financing is lower than that of debt financing; which results in the higher financing fund under the equity financing method. Figure 5(b) shows that the distributor's utility under debt financing has declined faster, while the decreasing speed is relatively gentle in equity financing. The increment of the

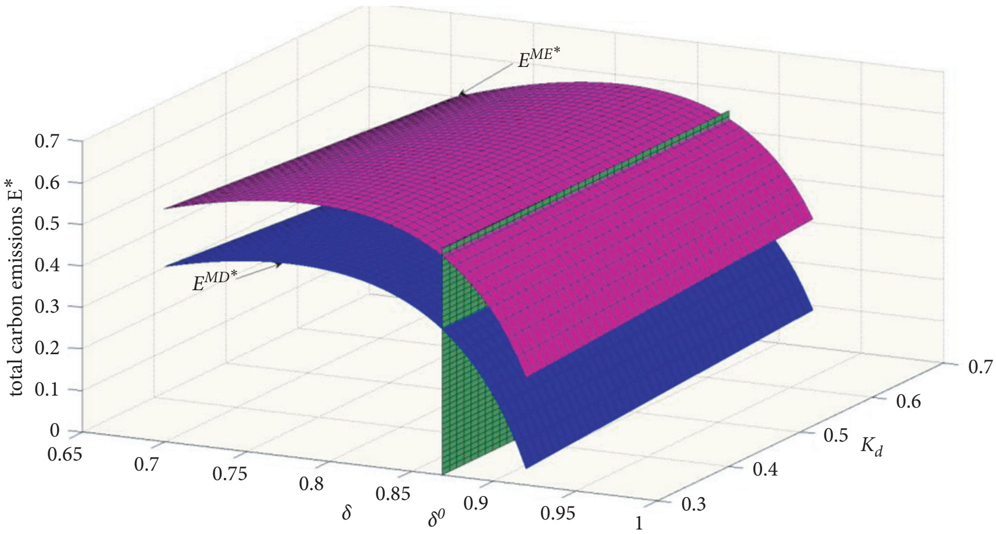


Figure 5: The impact of k_d on financing capital and distributor's utility.

distributor's utility increases as k_d grows, which further verifies the rationality of Corollary 8 and Remark 2.

The influence of the risk aversion coefficient and the acceptance of remanufactured products on the total carbon emissions under MD and ME scenarios is shown in Figure 6 below.

As shown in the three-dimensional schematic diagram in Figure 6, the red and blue surfaces in the figure represent the total carbon emissions of equity financing and debt financing, respectively, showing the joint effect of the risk-averse parameter and the acceptance of remanufactured products on the total carbon emissions under the two financing models. The environmental impact of equity financing is always greater than that of debt financing. From Figure 6, it can be seen that when the acceptance of the remanufactured products is higher than threshold δ^0, the total carbon emissions increase with the increase along with k_d, and the red and blue images rise upward and show an upward trend. When the acceptance of remanufactured is less than δ^0, the total carbon emissions under the two financing methods decrease while k_d grows up. The two graphs are recessed toward the origin point of the bottom corner and show a declining trend, which also verifies the rationality of Remark 4.

6.2. Specific Analysis on the Influence of Self-Owned Capital N. Based on Corollary 7, when the manufacturer's self-owned fund is restrained, that is to say $N < N^A$, if the manufacturer does not adopt financing, the competitive situation between the manufacturer and the distributor will be affected. The specific effect of the self-owned fund on the sales volume and revenue is presented in Figures 6(a) and 6(b)$_2$ successively.

It can be seen from figure 4(a) that the sales volume increase as the self-owned capital goes up, while the sales volume of remanufactured products decreases while N increases, however, the total sales volume of the two types of products remains unchanged, resulting in a crowding out effect on remanufactured products in the supply chain system, which is in line with Corollary 7.

Furthermore, as is depicted in figure 4(b), the profits of the manufacturer are concave about the self-owned capital N, which reaches its maximum profit when the fund reaches N^S. When the self-owned capital is more than N^S, the manufacturer's revenue decreases afterward, while the expected revenue of the distributor still go up, which drops a hint that a fierce competition occurs between the two members in CLSC. Thus, it is necessary to adopt a reasonable financing approach to ease the financial pressure of the manufacturer to achieve a favorable operation sate in CLSC.

6.3. The Analysis on Manufacturer's Optimal Financing Approach Selection. Through the specific interpretation of Corollary 5, it is easy to obtain the two threshold values $N^D = 0.0172$ and $N^S = 0.0371$. Moreover, the manufacturer's optimal financing approach selection relies on the self-owned fund N and the dividend proportion y on Corollary 11. The specific results about the selection are demonstrated in Table 3. The notation "EF," "WF," and "DF" are the abbreviations about equity financing, without financing, and debt financing, respectively.

It can be seen from the upper part of Table 3 that when the manufacturer's initial capital is not too scarce, i.e., $N^D \leq N < N^S$, the manufacturer will face two choices of equity financing and no financing. At this time, when the dividend proportion y is less than a threshold y^{EY}, equity financing will be more beneficial to the manufacturer. Moreover, as showed in the lower part of Table 3, when the manufacturer is extremely short of initial funds, i.e., $N < N^D$, at that time, the manufacturer will face the comparison of debt financing and equity financing. When the dividend proportion y satisfies $y < y^{ED}$, it can be seen that the manufacturer will adopt the equity financing approach.

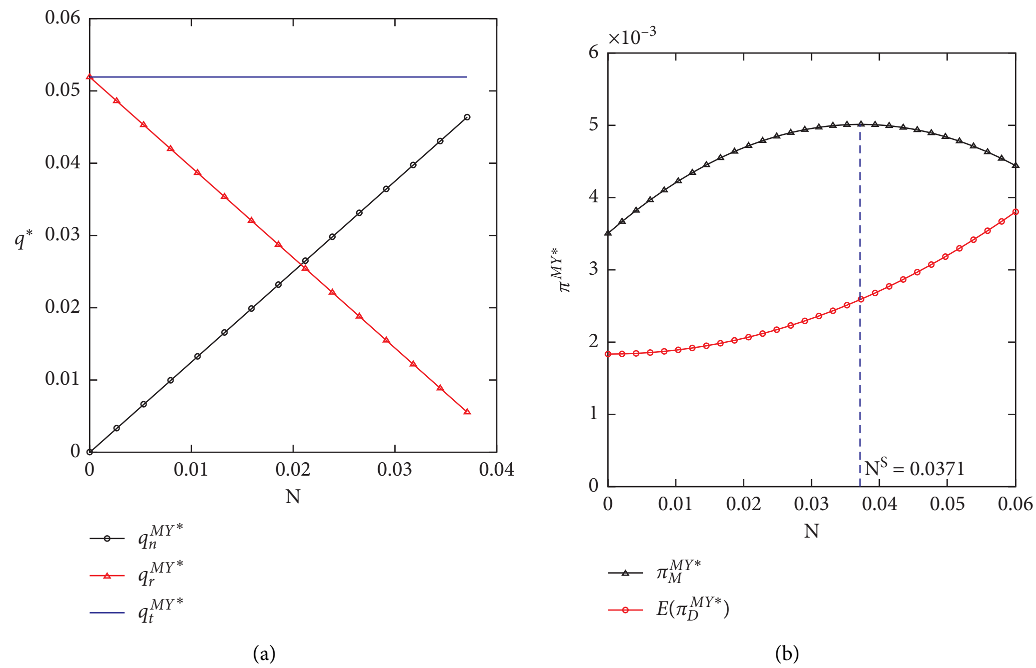


FIGURE 6: The impact of risk aversion factors and acceptance on the environment effect.

TABLE 3: Optimal financing approach selection in the distributor-remanufacturing mode.

N		y	π_M^{MY*}	π_M^{MD*}	π_M^{ME*}	Optimal approach
$N^D \le N < N^S$	$N_1 = 0.0300$	0.05	0.0050	—	0.0102	
		0.15	0.0050	—	0.0058	EF
		$y_1(N_1)$	0.0050	—	0.0050	
		0.25	0.0050	—	0.0016	WF
	$N_2 = 0.0200$	0.25	0.0047	—	0.0116	
		0.35	0.0047	—	0.0074	EF
		$y_1(N_2)$	0.0047	—	0.0047	
		0.45	0.0047	—	0.0032	WF
$N < N^D$	$N_3 = 0.0150$	0.35	0.0043	0.0048	0.0124	
		0.45	0.0043	0.0048	0.0082	EF
		$y_2(N_3)$	0.0043	0.0048	0.0048	
		0.55	0.0043	0.0048	0.0040	DF
	$N_4 = 0.0050$	0.65	0.0039	0.0041	0.0098	
		0.75	0.0039	0.0041	0.0055	EF
		$y_2(N_4)$	0.0039	0.0041	0.0041	
		0.85	0.0039	0.0041	0.0013	DF

Otherwise, if proportion y is more than threshold y^{ED}, debt financing will bring more profits to the manufacturer, which further illustrates the rationality of Corollary 11.

6.4. The Analysis of Financing Approach Preference in the CLSC Operations. In this part, we have investigated the research of exploring and explored which financing approach is preferred by every CLSC member (the manufacturer, the distributor, and the entire supply chain), that is to say, the expected profits on which financing approach is higher through comparisons.

Figure 7 shows when the self-owned capital of the manufacturer is extremely deficient, i.e., $B < B^D$, if $\pi_M^{MD^*} + \pi_D^{MD^*} > \pi_M^{MY^*} + \pi_D^{MN^*}$, each member of the supply chain prefers two financing methods under different self-owned capital and different dividend proportions. Figure 7 has three regions, namely the red region R1 (ME_M, ME_D, ME_{SC}), the green region R2 (MD_M, ME_D, ME_{SC}), and the light blue region R3 (MD_M, ME_D, MD_{SC}), to describe the choice of financing approach preference. OE_M indicates that the manufacturer prefers equity financing to debt financing, and the implication of R1 is that in a region like R1 (ME_M, ME_D, ME_{SC}), when the dividend proportion ranges from y^L to y^{ED}, the manufacturer, distributor, and the whole CLSC can benefit more by equity financing than by debt financing. Under the current circumstances, equity financing alone can enable the manufacturers, distributors, and CLSC to

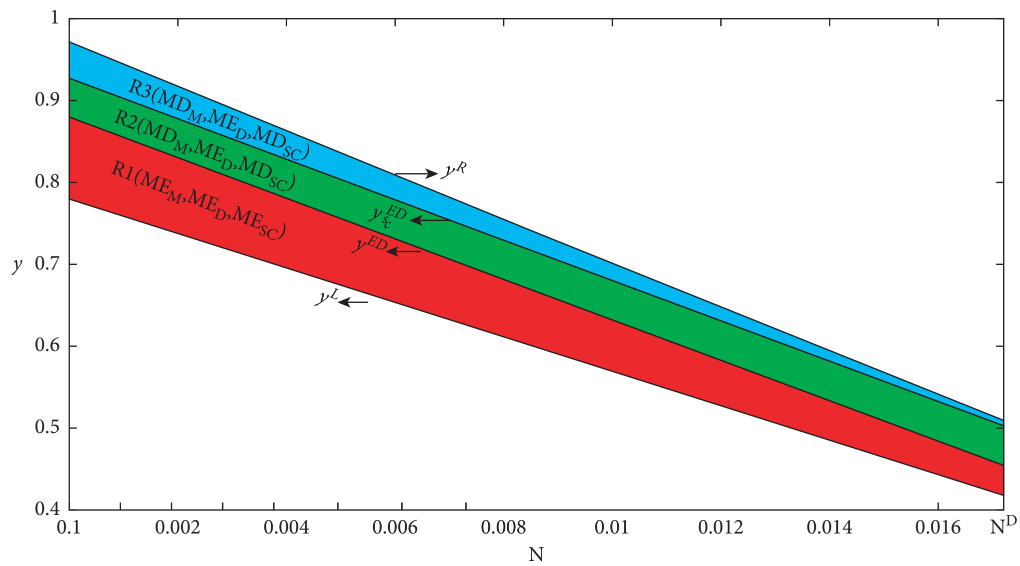


FIGURE 7: The impact of y and N on the financing preferences on the CLSC members.

attain a multibenefit status in the R1 area. This regional illustration also reflects the exactness of Remark 5. As depicted in this figure, the three different types of colored regions represent that the manufacturer can share different executable ratios of his own profits to the capital supporter after the sales period when he has distinctive levels of inherent funds. Furthermore, when the ratio ranges from y^{ED} to y^{R}, it will not change the manufacturer's financing approach selection preference for the debt financing approach. Moreover, the right bound of the proportion thresholds of all regions decrease while the N grows up, that is to say, when the manufacturer has more self-owned capital, the less financing fund he needs, then the manufacturer shows the willingness of seeking less capital from the investor by equity financing with lower dividend proportion, which is in conformity with the real life.

7. Conclusions and Later Study

This article focuses on the pricing decision and the best financing strategy selection for a remanufacturing CLSC, which consists of a single risk-averse distributor and one capital-constrained manufacturer. It mainly studies these four cases, namely when the manufacturer is with sufficient funds, when the manufacturer is restricted by limited capital, when the manufacturer raises funds from debt financing, and when the manufacturer raises funds from equity financing. The equilibrium solutions on the Stackelberg game in the four situations are obtained by backward introduction, comparing and analyzing the influence of self-owned manufacturing fund, and risk aversion parameters on decision variables. Firstly, a benchmark model without capital constraint is constructed, focusing on the impact of risk aversion factors on the wholesale price and sales price. Secondly, the optimal pricing decisions for manufacturer under capital constraints is solved by the envelope theorem combined with the KKT conditions in convex planning theory, deriving the threshold value of the initial capital for the manufacturer to adopt debt financing rather than manufacturing with its self-owned capital. Finally, a comparative analysis of retailing prices, sales volume, consumer surplus, environmental impact, and the expected profit of the supply chain under the two financing strategies is given. It provides a scientific basis for the manufacturer with limited producing capital when considering downstream distributors' risk aversion in the optimal pricing decisions on the CLSC system. The specific conclusions are obtained as follows:

(1) If the manufacturer's producing capital is limited, the scarcity of capital will be an important factor in blocking the valid operation of the whole supply chain system. As the manufacturer's initial capital gradually increases, it will bring about growth in the quantities of new products and a crowding out effect on the remanufactured products. Moreover, only when there is an extreme shortage of manufacturing fund ($N < N^{D}$), the manufacturer prefers to execute debt financing to producing with self-own capital.

(2) The size of the inherent capital and the investor's acceptable equity dividend ratio will impact the manufacturer's optimal choice of financing methods. When the manufacturer's capital is not too deficient ($N < N^{D}$), if the equity dividend ratio is low to a certain level y^{ED} (i.e., $y < y^{EY}$), equity financing is more beneficial to the manufacturer. Otherwise, the manufacturer will tend to use its own funds for manufacturing. When the manufacturer's initial capital is extremely deficient ($N < N^{D}$) and if the dividend ratio is lower than the threshold y^{ED} (i.e. $y < y^{ED}$), the manufacturer prefers to adopt equity financing to debt financing.

(3) The consumer can benefit more from equity financing, while debt financing is eco-friendlier because of its less carbon emissions than equity financing. The increase in risk aversion factors will result in a narrower width of the executable dividend ratios both parties in the CLSC acknowledge. Therefore, the manufacturer ought to show close awareness of the distributor's risk aversion degree to make a reasonable decision in the capital-limited CLSC operations.

(4) For the entire supply chain, regardless of the manufacturer's extent on the lack of inherent capital, the distributor's expected profit in debt financing is lower than that of equity financing, only when the inherent fund is overly short (i.e. $N < N^D$), when the executable proportion is lower than a certain threshold (i.e. $y < y^{ED}$), the adoption of equity financing strategy will create a win-win area for the both players in the CLSC. Thus, when the manufacturer has a strong sense of social responsibility and cares about the performance of the whole supply chain, he will prefer equity financing to debt financing.

In actual production activities, the deficiency of producing fund had tremendous impacts on the excavator industry and the home appliance industry. Doosan Group had to look for financing funds from the Wells Fargo Bank by debt financing. Also, it has been advertising the excellent features of the excavating machinery DH55 to raise the capital of chemical materials company SKC by equity financing. In addition, the recycling channel of SEVALO, who is the distributor of Doosan, was blocked, which affected the normal operations. The other example is that the supply chain in the home appliance GREE industry has been affected. GREE industry had to search capital support from the bank through debt financing and attracted investment through equity financing by promoting the excellent characteristics of its own air purification products. The manufacturing fund as a kind of resource in enterprises is always constrained, which results in the nonideal operation decisions. Hence, it is truly significant to track down rational financing approach to achieve the ideal pricing operations in CLSC management as much as possible. By integrating the conclusions of the research work and major contributions in this article and combining industry practices in the tangible world, the key enlightenments are listed as follows:

(1) In the practical production and operation management of enterprises, the limitation of the manufacturer's inherent producing capital will trigger fierce competition in the remanufacturing CLSC system, and a rational financing approach is a useful method to alleviate this issue. Thus, the manufacturer can execute the optimal selections of the financing approach according to the manufacturer's self-owned fund level and the executable equity dividend proportion to boost the operations of the CLSC system effectively.

(2) From the perspective of sustainable operation in CLSC management, it is crucial for the investor to show wide awareness about the level of the downstream member's risk appetite and the manufacturer's inherent fund. Besides, only the executable ratio lies in a specified range. It will be more profitable to execrate equity financing for the fund-deficient manufacturer. In this way, the investor is supposed to take the upstream member's amount of financing fund and the degree of the distributor's risk appetite into the scope of the key account.

(3) In the current life, since the government requires manufacturers to have more awareness of social duty in certain regulations and law legislations, as for the manufacturer, it is more appropriately to consider the earnings optimality, but also take the social welfare into account. Moreover, the carbon emissions, consumer surplus, and distributor's expected revenue are an integral part of social welfare. Therefore, on the one hand, the manufacturer should pay attention to the total carbon emissions and the level of self-owned capital deficiency. On the other hand, they should focus on the bank financing rate to select the best financing approach.

However, this article still has several shortcomings. This article concentrates on the analysis of the equilibrium solutions in a one-period game alone between a single manufacturer and one risk-averse distributor. The directions for future research expansions are as follows: ① the pricing decision and operations decision-makings of multiple manufacturers and distributors can be expanded in multiple cycles, ② the market demand of the products will also take into account the other uncertain circumstances, such as the grey, rough, and interval variables, and ③ the risk adversion is subject to an unkown distribution sense. These will be the author's later investigative issues.

Appendix

A

Proof of Proposition 1 and Corollary 1

We are accustomed to obtaining the equilibrium solutions on model MN, model MY, model MD, and model ME by the backward introduction. The specific proof progress is presented in the following manner:

Based on the distributor's utility function from model MN listed in (A.1)

$$\max_{p_n, p_r} U_D = (p_n - w_n)q_n + (p_r - c_r - f)q_r - k_d q_r \sigma. \quad (A.1)$$

The universal demand function is listed in (A.2)-(A.3) as follows:

$$q_n = 1 - \frac{p_n - p_r}{1 - \delta}. \quad \text{(A.2)}$$

$$q_r = \frac{\delta p_n - p_r}{1 - \delta}. \quad \text{(A.3)}$$

Firstly, it is of great significance for us to prove the concavity of U_D on the decision variables p_n and p_r. As usual, substitute the formulations (A.2) and (A.3) in (A.1). The second-order partial derivative about p_n and p_r on U_D are obtained in the following manner:

$$\frac{\partial^2 U_D}{\partial p_n^2} = \frac{2}{\delta - 1}, \frac{\partial^2 U_D}{\partial p_r^2} = \frac{2}{\delta(\delta - 1)}, \frac{\partial^2 U_r}{\partial p_n \partial p_r} = \frac{\partial^2 U_r}{\partial p_r \partial p_n} = \frac{2}{1 - \delta} \quad \text{(A.4)}$$

Hence, the corresponding Hessian matrix T_1, which is relevant to p_n and p_r, is enumerated in the following manner:

$$T_1 = \begin{bmatrix} \frac{2}{\delta - 1} & \frac{2}{1 - \delta} \\ \frac{2}{1 - \delta} & \frac{2}{\delta(\delta - 1)} \end{bmatrix}. \quad \text{(A.5)}$$

$2/\delta - 1$ is negative, and the second-order principal and subform of T_1 is computed as $4/\delta(1 - \delta)$, which is positive. Therefore, T_1 is a negative definite matrix, which means that there exists a unique optimal solution in the case of the first-order of p_n and p_r, which is equal to zero. The results of the first-order are presented in the formulations (A.6) and (A.7) below.

$$\frac{\partial U_D}{\partial p_n} = \frac{c_r + \delta + 2p_n - 2p_r - w_n + f - 1 + k_d \sigma}{\delta - 1}. \quad \text{(A.6)}$$

$$\frac{\partial U_D}{\partial p_r} = \frac{2p_r - c_r - f + \delta w_n - 2\delta p_n - k_d \sigma}{\delta(\delta - 1)}. \quad \text{(A.7)}$$

It is common for us to make formulations (A.6) and (A.7) to zero and solve this formulation group simultaneously. The equilibrium solutions on p_n and p_r listed in formulations (A.8) and (A.9) are as follows.

$$p_n^{MN^*} = \frac{w_n + 1}{2}. \quad \text{(A.8)}$$

$$p_r^{MN^*} = \frac{c_r + \delta + f + k_d \sigma}{2}. \quad \text{(A.9)}$$

Also, the manufacturer's revenue is as follows:

$$\pi_M = (w_n - c_n) q_n + f q_r. \quad \text{(A.10)}$$

As usual, substitute the formulations (A.6) and (A.7) in (A.2) and (A.3), and upon taking these into formulations (A.8), it is obvious for us to get the second-order partial derivative of w_n and f of π_m, which are revealed in the following manner:

$\partial^2 \pi_m / \partial w_n^2 = 1/(\delta - 1)$, $\partial^2 \pi_m / \partial f^2 = 1/\delta(\delta - 1)$, and $\partial^2 \pi_M / \partial w_n \partial f = \partial^2 \pi_M / \partial f \partial w_n = 1/(1 - \delta)$

Hence, the corresponding Hessian matrix T_2, which is relevant to w_n and f, is enumerated as follows:

$$T_2 = \begin{bmatrix} \frac{1}{(\delta - 1)} & \frac{1}{(1 - \delta)} \\ \frac{1}{(1 - \delta)} & \frac{1}{\delta(\delta - 1)} \end{bmatrix}. \quad \text{(A.11)}$$

$1/\delta - 1$ is negative, and the second-order principal and subform of T_2 is computed as $1/\delta(1 - \delta)$, which is positive. Thus, T_2 is a negative definite matrix, which means that there exists a unique optimal solution in the case of the first-order of w_n and f, which is equal to zero. The results of the first-order presented in formulations (A.9) and (A.10) are as mentioned below.

$$w_n^{MN^*} = \frac{c_n + 1}{2}. \quad \text{(A.12)}$$

$$f^{MN^*} = \frac{(\delta - c_r - k_d \sigma)}{2}, \quad \text{(A.13)}$$

whereas, it is necessary to substitute formulations (A.9) and (A.10) in formulations (A.6) and (A.7) and receive the equilibrium solutions of $p_n^{MN^*}$ and $p_r^{MN^*}$ listed in (A.12) and (A.13).

$$p_n^{MN^*} = \frac{3 + c_n}{4}. \quad \text{(A.14)}$$

$$p_r^{MN^*} = \frac{c_r + 3\delta + k_d \sigma}{4}. \quad \text{(A.15)}$$

Then, substitute formulations (A.11) and (A.12) in formulations listed in (A.1) and (A.2), and obtain the equilibrium solutions of $q_n^{MN^*}$ and $q_r^{MN^*}$ in formulations (A.12) and (A.13) in the following manner:

$$q_n^{MN^*} = \frac{1 + c_r + k_d \sigma - c_n - \delta}{4(1 - \delta)} = \frac{F_2}{4(1 - \delta)}. \quad \text{(A.16)}$$

$$q_r^{MN^*} = \frac{\delta c_n - c_r - k_d \sigma}{4\delta(1 - \delta)} = \frac{F_3}{4\delta(1 - \delta)}. \quad \text{(A.17)}$$

Eventually, substitute E (A.4) and (A.14) in (A.1), (A.2), and (A.8). The corresponding equilibrium solution on the manufacturer's revenue, the distributor's revenue, and the distributor's utility in model MN is represented as follows:

(1) $\pi_M^{MN^*} = \delta(1 - c_n) F_2 + (\delta - c_r - k_d \sigma) F_3 / 8\delta(1 - \delta)$
(2) $\pi_D^{MN^*} = \delta(1 - c_n) F_2 + (\delta - c_r - k_d \sigma) F_3 / 16\delta(1 - \delta)$
(3) $U_D^{MN^*} = \delta(1 - c_n) F_2 + (\delta - c_r - k_d \sigma) F_3 / 16\delta(1 - \delta)$

Thus, Proposition 1 and Corollary 1 are proved.

Proof. of Proposition 2 and Corollary 2.

The concavity about U_D in p_n and p_r is proved in the aforementioned proof procedure. Then, the formulations of (A.9), (A.10), (A.13), and (A.14) are also available for the proof of the concavity of this linear program, which is composed of (A.15) and (A.16), and we can prove it with the first-order KKT condition.

The linear program consists of π_M, and the inequality restriction is denoted as follows:

$$\max_{w_n, f} \pi_M = (w_n - c_n)q_n + f q_r. \tag{A.18}$$

$$s.t. c_n q_n < N. \tag{A.19}$$

As usual, substitute the formulations (A.9), (A.10), (A.13), and (A.14) in (A.16). For the reason of the constraint condition, (A.16) is transformed into formulation (A.17) in the following manner:

$$\frac{c_n(2(1-\delta) - (w_n + 1 - c_r - \delta - f - k_d\sigma))}{2(1-\delta)} - N = 0. \tag{A.20}$$

As a result, it is clear that the object function (A.16) and the equivalent conversion constraint (A.18) are both concave about w_n and f.

As usual, substitute the formulations (A.9), (A.10), (A.13), and (A.14) in (A.15) and (A.16), and establish the Lagrange function G. We obtain the formulations of (A.18) and (A.22) with the KKT conditions in the following manner:

$$G = (w_n - c_n)q_n + f q_r + \lambda(B - c_n q_n). \tag{A.21}$$

$$s.t. \begin{cases} \dfrac{\partial G}{\partial w_n} = \dfrac{\delta - c_r - c_n + 2w_n - 2f - 1 - \lambda c_n - k_d\sigma}{2(\delta - 1)} = 0 \\ \dfrac{\partial G}{\partial f} = \dfrac{c_r + 2f - 2\delta w_n + \delta c_n + \lambda\delta c_n + k_d\sigma}{2\delta(\delta - 1)} = 0 \\ \lambda(N - c_n q_n) = 0 \\ \lambda \geq 0 \end{cases}. \tag{A.22}$$

B

Hence, we can obtain the optimal solutions using the KKT conditions under the convex programming theory. When $\lambda > 0$, the optimal solutions are solved using the backward introduction as mentioned subsequently, listed in formulations (B.1) and (B.2).

$$w_n^{MY*} = \frac{c_n(1+\lambda) + 1}{2} = w_n^{MN*} + \frac{\lambda c_n}{2}. \tag{B.1}$$

$$f^{MY*} = \frac{(\delta - c_r)}{2} = f^{MN*}. \tag{B.2}$$

Let the formulations (B.1) and (B.2) be substituted in the formulations (A.12) and $(A.13)_2$ respectively, and we can obtain the equilibrium solutions of p_n and p_r in model MY in the following manner:

$$p_n^{MY*} = \frac{3 + c_n + \lambda c_n}{4} = p_n^{MN*} + \frac{\lambda c_n}{4}. \tag{B.3}$$

$$p_r^{MY*} = \frac{3\delta + c_r + k_d\sigma}{4} = p_r^{MN*}. \tag{B.4}$$

According to formulations (B.1)–(B.4), Proposition 2 is proved, since the one-to-one correspondence correlations between price and sales volume, the optimal solutions on the two varieties of products about the sales volume are listed in the (B.5) and (B.6):

$$q_n^{MY*} = q_n^{MN*} - \frac{\lambda c_n}{4(1-\delta)}. \tag{B.5}$$

$$q_r^{MY*} = q_r^{MN*} + \frac{\lambda c_n}{4(1-\delta)}. \tag{B.6}$$

Moreover, the specific progress is the same as **Corollary 1.** We omit it for simplicity. Also, the equilibrium solutions of the CLSC members' profits and distributors' utility are listed in the following manner: $\pi_M^{MY*} = \pi_M^{MN*} - (\lambda c_n)^2/8(1-\delta)$, $\pi_D^{MY*} = \pi_D^{MN*} + \lambda c_n(\lambda c_n - 2F_2)/16(1-\delta)$, and $U_D^{MY*} = U_D^{MN*} + \lambda c_n(\lambda c_n - 2F_2)/16(1-\delta)$.

Thereby, we proved **Corollary 2**.

Proof. of Propositions 3 and 4 and Corollaries 3. and 4.

Since the specific proof procedure of model MD and model ME is the same as that of model MN by backward introduction as mentioned above, we omit the proving progress of Propositions 3–4) and their corresponding Corollaries 3 and 4 for simplicity.

Proof. of Corollary 5.

In model MY, on the basis of the specific proof progress listed above, it is obvious for us to achieve this conclusion that if $\lambda > 0$, this formulation (B.7) is satisfied in the following manner:

$$N = c_n q_n^{MY*} = \frac{c_n(F_2 - \lambda c_n)}{4(1-\delta)}. \tag{B.7}$$

Upon solving the formulations (B.7), it is clear for us to obtain (B.8) in the following manner:

$$\lambda = \frac{c_n F_2 - 4N(1-\delta)}{c_n^2}. \tag{B.8}$$

The revenue of the capital-limited manufacturer is represented as $\pi_M^{MY*} = \max_{w_n, f} G(w_n, f, N)$. In the light of the first-order optimality proposition in Kuhn–Tucker conditions with envelope theorem, formulation (B.9) is obtained in the following manner:

$$\frac{\partial \pi_M^{MY*}}{\partial N} = \frac{\partial \pi_M^{MY*}}{\partial w_n}\frac{\partial w_n}{\partial N} + \frac{\partial \pi_M^{MY*}}{\partial f}\frac{\partial f}{\partial N} + \frac{\partial \pi_M^{MY*}}{\partial N} = 0.\frac{\partial w_n}{\partial N} + 0.\frac{\partial f}{\partial N} + \frac{\partial \pi_M^{MY*}}{\partial N} = \lambda. \tag{B.9}$$

Since the parameter λ is the shadowing price, which indicates that if the unit profit of the manufacturer (λ) in model MY is greater than the unit financing cost of the manufacturer $((r_b))$, as a result, the manufacturer will benefit more through the DF approach.

That is to say, the manufacturer has the tendency to choose debt financing if and only if it satisfied this inequality,

$$\lambda - r_b > 0. \tag{B.10}$$

By solving (B.10), we can get the threshold value $N^D = c_n F_2 - c_n^2 r_b / 4(1-\delta)$, which means that if the inherent capital $N < N^D$, the manufacturer will prefer to choose the debt financing approach to producing with its own inherent capital.

Due to $\partial^2 \pi_M^{MN^*} / \partial N^2 = 4(\delta - 1)/c_n^2 < 0$, which indicates that the manufacturer's revenue is concave about the self-owned capital N; furthermore, the manufacturer will obtain its maximum sales revenue when it satisfies this necessary formulation in the following:

$$\frac{\partial \pi_M^{MN^*}}{\partial N} = 0. \tag{B.11}$$

Upon solving (B.11), we can obtain the threshold value $N^* = N^S = c_n F_2 / 4(1-\delta)$, which indicates that if the self-owned capital of the manufacturer attains N^S, it will obtain the maximum revenue. However, $N^S = c_n q_n^{MN^*}$, and this value is exactly the well-funded threshold in the model MN, which implies that if the self-owned capital of manufacture is over N^S; the manufacturer's producing status is not influenced by the fund.

If $N^D \leq N < N^S$, the manufacturer will engage in manufacturing and operating through the self-owned capital. Otherwise, if $N < N^D$, the manufacturer will undertake the producing activity through the debt financing approach. Corollary 5 is proved. □

Proof. of Corollaries 6 and 7.

As $N < N^D = c_n F_2 / 4(1-\delta)$, it is clear for us to obtain the inequalities $\pi_M^{MD^*} - \pi_M^{MN^*} = c_n r_b (c_n r_b - 2F_2)/16(1-\delta) < 0$, $\pi_M^{MD^*} - \pi_M^{MN^*} = c_n r_b (c_n r_b - 2F_2)/16(1-\delta) < 0$, and $U_D^{MD^*} - U_D^{MN^*} = c_n r_b (c_n r_b - 2F_2)/16(1-\delta) < 0$.

On the basis of the equilibrium solutions listed in Proposition 2 and Corollary 2, substitute λ in them, the first partial derivatives of all the equilibrium solution sets on N are presented in the following manner:

$\partial w_n^{MY^*}/\partial N = 2(\delta - 1)/c_n < 0$, $\partial q_r^{MY^*}/\partial N = -1/c_n < 0$, $\partial f^{MY^*}/\partial N = \partial p_r^{MY^*}/\partial N = 0$, $\partial p_n^{MY^*}/\partial N = \delta - 1/c_n < 0$, $\partial q_n^{MY^*}/\partial N = 1/c_n > 0$, $\partial q_t^{MY^*}/\partial N = 0$, $\partial^2 \pi_M^{MY^*}/\partial N^2 = 4(\delta - 1)/c_n^2 < 0$, and $\partial U_D^{MY^*}/\partial N = 2(1-\delta)N/c_n^2 > 0$.

Corollaries 6 and 7 are proved. □

Proof. of Corollary 8.

(1) Because of the equilibrium solution listed in models MN, MD, ME above, it is easy to obtain the first-order derivate of k_d in the following manner:

$$\begin{aligned}
&\frac{\partial f^{j*}}{\partial k_d} = -\frac{\sigma}{2} < 0, \frac{\partial p_r^{j*}}{\partial k_d} = \frac{\sigma}{4} > 0, \frac{\partial q_n^{j*}}{\partial k_d} = \frac{\sigma}{4(1-\delta)} > 0, \frac{\partial q_r^{j*}}{\partial k_d} = \frac{\sigma}{4\delta(\delta - 1)} < 0, \frac{\partial F^B}{\partial k_d} = \frac{\partial F^S}{\partial k_d} = \frac{c_n \sigma}{4(1-\delta)} > 0, \frac{\partial q_t^{j*}}{\partial k_d} \\
&= \frac{-\sigma}{4\delta} < 0, \frac{\partial \pi_M^{j*}}{\partial k_d} = \frac{-\sigma F_3}{4\delta(1-\delta)} < 0, \\
&\frac{\partial U_D^{MD^*}}{\partial k_d} = \frac{-\sigma (F_3 + \delta c_n r_b)}{8\delta(1-\delta)} < 0, \frac{\partial U_D^{MN^*}}{\partial k_d} = \frac{\partial U_D^{ME^*}}{\partial k_d} = \frac{-\sigma F_3}{8\delta(1-\delta)} < 0, j = MN, MD, ME.
\end{aligned} \tag{B.12}$$

As is depicted above, the first-order of the partial derivate on all the equilibrium solution sets for k_d in models MN, MD, and ME are equal.

(2) Aiming at model MY, substitute multiplier λ in all the equilibrium solutions sets. The results about the first-order derivate on factor k_d are presented in the following manner:

$$\begin{aligned}
&\frac{\partial w_n^{MY^*}}{\partial k_d} = \frac{\sigma}{2} > 0, \frac{\partial f^{MY^*}}{\partial k_d} = -\frac{\sigma}{2} < 0, \frac{\partial p_n^{MY^*}}{\partial k_d} = \frac{\sigma}{4} > 0, \frac{\partial p_r^{MY^*}}{\partial k_d} = \frac{\sigma}{4} > 0, \frac{\partial q_r^{MY^*}}{\partial k_d} = -\frac{\sigma}{4\delta} < 0, \\
&\frac{\partial q_t^{MY^*}}{\partial k_d} = -\frac{\sigma}{4\delta} < 0, \frac{\partial U_D^{MY^*}}{\partial k_d} = \frac{-\sigma F_1}{8\delta} < 0.
\end{aligned} \tag{B.13}$$

Proof. of Corollary 9 and 10.

As $\partial(\pi_M^{ME^*}-\pi_M^{MN^*})/\partial y=-(\pi_M^{MN^*}+F^E+N)<0$ and $\partial\pi_S^{ME^*}/\partial y=\pi_M^{MN^*}+F^E+N>0$, it is of great necessity to satisfy this combination of inequalities $\begin{cases}\pi_M^{ME^*}>\pi_M^{MY^*}\\ \pi_s^{ME^*}>0\end{cases}$. The left and the right boundaries of the executable dividend ratio on this inequality group are denoted in the following manner:

$$y^L=\frac{2\delta(c_nF_2-4N(1-\delta))}{(1+c_n)\delta F_2+(\delta-c_r-k_d\sigma)F_3},\ y^R=\frac{\delta\left(\lambda^2c_n^2+2c_nF_2-8N(1-\delta)\right)}{(1+c_n)\delta F_2+(\delta-c_r-k_d\sigma)F_3}. \tag{B.14}$$

Corollary 9 is proved.

As $y^L=2\delta(c_nF_2-4N(1-\delta))/(1+c_n)\delta F_2+(\delta-c_r-k_d\sigma)F_3$ and $y^R=\delta(\lambda^2c_n^2+2c_nF_2-8N(1-\delta))/(1+c_n)\delta F_2+(\delta-c_r-k_d\sigma)F_3$, it is clear to get these results in the following manner:

$$\Delta y=\frac{\delta\lambda^2c_n^2}{(1+c_n)\delta F_2+(\delta-c_r-k_d\sigma)F_3},\frac{\partial y^L}{\partial N}=\frac{-8\delta(1-\delta)}{(1+c_n)\delta F_2+(\delta-c_r-k_d\sigma)F_3}<0,\frac{\partial y^R}{\partial N}=\frac{8\delta(1-\delta)(-\lambda-1)}{(1+c_n)\delta F_2+(\delta-c_r-k_d\sigma)F_3}<0. \tag{B.15}$$

The first-order partial derivate of k_d about Δy is calculated as $\partial\Delta y/\partial N=-8\delta(1-\delta)\lambda/(1+c_n)\delta F_2+(\delta-c_r-k_d\sigma)F_3<0$.

To calculate the result for simplicity, set $(1+c_n)\delta G_2+(\delta-c_r-k_d\sigma)G_3=Y$, $F_2=1+c_r+k_d\sigma-c_n-\delta$, and $F_3=\delta c_n-c_r-k_d\sigma$. Taking them into y^L and Δy, the first-order about k_d is listed as follows: $\partial y^L/\partial k_d=(2\delta c_nF_2/Y-8N\delta\ (1-\delta)/Y)=(2\delta c_nF_2/Y-8N\delta\ (1-\delta)/Y)=2\delta c_n(\sigma(Y-(2c_r+2k_d\sigma)F_2))/Y^2+8N\delta(1-\delta)/Y^2Y\prime$, while $2\delta c_n\sigma\ ((F_1+F_3)F_2+F_1F_3)/Y^2>0$. Hence, $\partial y^L/\partial k_d>0$.

It is clear to obtain $\partial\Delta y/\partial k_d=\delta((\lambda^2c_n^2)/Y)\ '=\delta(2\lambda c_n^2(\sigma/c_n)Y-Y\prime(\lambda^2c_n^2)/Y^2)=\delta2\lambda c_nY\sigma-Y\prime(\lambda^2c_n^2)/Y^2=\delta2\lambda\sigma(c_nY-(\lambda c_n^2)(c_r+k_d\sigma))/\ Y^2=\delta2\lambda\sigma(c_nY-(c_nF_2-4N(1-\delta))(c_r+k_d\sigma))/\ Y^2>\delta2\lambda\sigma(c_nY-(c_nF_2)(c_r+k_d\sigma))/Y^2$.

Since $\delta2\lambda\sigma(c_n(Y-F_2(c_r+k_d\sigma)))/Y^2=\delta2\lambda\sigma(c_n((\delta+G_3)F_2+(\delta-c_r-k_d\sigma)F_3))/Y^2>0$, $\partial\Delta y/\partial k_d>0$ is justified. Since $\partial y^R/\partial k_d=\partial y^L/\partial k_d+\partial\Delta y/\partial k_d>0$, Corollary 10 is proved.

Proof. of Remarks 1 and 2.

On the basis of Propositions 3 and 4, it is easy to obtain $w_n^{ME^*}-w_n^{MD^*}=-c_nr_b/2<0$, $p_n^{ME^*}-p_n^{MD^*}=-c_nr_b/4<0$, $p_r^{ME^*}-p_r^{MD^*}=0$, and $f^{ME^*}-f^{MD^*}=0$. It is clear that Remark 1 is to be proved.

Since $q_n^{ME^*}-q_n^{MD^*}=c_nr_b/4(1-\delta)>0$, $q_r^{ME^*}-q_r^{MD^*}=c_nr_b/4(\delta-1)<0$, $\Delta U_D=U_D^{ME^*}-U_D^{MD^*}=c_nr_b(2F_2-c_nr_b)/16(1-\delta)>0$, and $\partial\Delta\ U_D/\partial k_D=2c_nr_b\sigma/16(1-\delta)0$, it is clear that Remark 2 is to be proved. ☐

Proof. of Remarks 3 and 4.

As $CS^{ME^*}=(\delta(1-c_n)F_2+(\delta-c_r-k_d\sigma)F_3)/32\delta(1-\delta)$, $CS^{MD^*}=((1-c_n-2c_nr_b)\delta F_2+(\delta\ -c_r-k_d\sigma)F_3+\delta c_n^2r_b^2)/32\delta(1-\delta)$.

$$\frac{\partial CS^{ME^*}}{\partial k_d}=\frac{-\sigma F_3}{16\delta(1-\delta)}<0,\frac{\partial CS^{MD^*}}{\partial k_d}=\frac{-\sigma(F_3+\delta c_nr_b)}{16\delta(1-\delta)}<0,\Delta CS=CS^{ME^*}-CS^{MD^*}$$
$$=\frac{c_nr_b(2F_2-c_nr_b)}{32(1-\delta)},\frac{\partial(\Delta CS)}{\partial k_d}=\frac{c_nr_b\sigma}{16(1-\delta)}>0,\frac{\partial(\Delta CS)}{\partial r_b}=\frac{2c_n(F_2-c_nr_b)}{32(1-\delta)}>0. \tag{B.16}$$

Remark 3 is just to be proved.

According to $\Delta E=E^{ME^*}-E^{MD^*}=c_nr_b(e_n^m-e_r^m)\ /4(1-\delta)\ >0$, the inequality $E^{ME^*}>E^{MD^*}$ is justified. However, $\partial E^{ME^*}/\partial k_d=\partial E^{MD^*}/\partial k_d=\sigma(\delta e_n^m\ -e_r^m+(\delta-1)\ e_n^u)/4\delta(1-\delta)$. It is easy to obtain this condition, i.e., if $\delta>\delta^0=e_r^m+e_n^u/e_n^m+e_n^u$, $\partial E^{MD^*}/\partial k_d=\partial E^{ME^*}/\partial k_d>0$, while $\delta<\delta^0$, and $\partial E^{MD^*}/\partial k_d=\partial E^{ME^*}\ /\partial k_d<0$. Remark 4 is just to be proved. ☐

Proof. of Corollary 11.

(1) If $N^D\le N<N^S$, the manufacturer has the tendency to choose the equity financing approach if and only if it satisfies this condition, which is listed as follows:

$$\Delta\pi_M^{MEY}=\pi_M^{ME^*}-\pi_M^{MY^*}>0. \tag{B.17}$$

Since $\partial\Delta\ \pi_M^{MEY}/\partial y=-((1+c_n)\delta F_2\ +(\delta-c_r-k_d\sigma)F_3/8\delta(1-\delta))\ <0$, it means that if $y<y^{EY}=\delta(\lambda c_n^2+2c_nF_2-8N(1-\delta))/\ (1+c_n)\delta\ F_2+(\delta c_n-c_r-k_d\sigma)F_3$, the manufacturer has the tendency to choose

the equity approach. Otherwise, the manufacturer will engage in producing activity with inherent capital.

(2) If $N < N^D$, the manufacturer has the tendency to choose the equity financing approach if and only if it satisfies this condition, which is listed as follows:

$$\Delta\pi_M^{MED} = \pi_M^{ME^*} - \pi_M^{MD^*} > 0. \tag{B.18}$$

Since $\partial\Delta\ \pi_M^{MED}/\partial y = -((1+c_n)\delta\ F_2 + (\delta - c_r - k_d\sigma)F_3 /8\delta(1-\delta)) < 0$, which means if $y < y^{ED} = 2\delta c_n F_2(1+r_b) - \delta c_n^2 r_b^2 - 8\delta(1\ \ -\delta)(1+r_b)N/(1+c_n)\delta F_2 + (\delta - c_r - k_d\sigma)F_3$, the manufacturer tends to choose the equity approach. Otherwise, the manufacturer will prefer engaging in the producing activity with the debt financing approach. Corollary 11 is proved. □

C

Proof. of Remark 5.

Proof: the expected revenue of the entire CLSC in models **MD** and **ME is** listed as follows:

$$E\left(\pi_{SC}^{MD^*}\right) = E\left(\pi_M^{MD^*}\right) + E\left(\pi_D^{MD^*}\right) = \pi_M^{MN^*} + Nr_b + \pi_D^{MN^*} + \frac{3c_n r_b(c_n r_b - 2F_2)}{16(1-\delta)}. \tag{C.1}$$

$$E\left(\pi_{SC}^{ME^*}\right) = E\left(\pi_M^{ME^*}\right) + E\left(\pi_D^{ME^*}\right) = (1-y)\left(\pi_M^{MN^*} + F^E + N\right) - N + \pi_D^{MN^*}. \tag{C.2}$$

It is obvious to get these inequalities in the following manner:

$\partial E(\pi_{SC}^{MD^*})/\partial N = r_b + 3c_n^2 r_b/8(1-\delta) > 0$, and $\partial E(\pi_{SC}^{ME^*})/\partial N = -y - 1 < 0$.

On the basis of $\partial(E(\pi_{SC}^{ME^*}) - E(\pi_{SC}^{MD^*}))/\partial y = -(\pi_M^{MN^*} + F^E + N) < 0$ and $\pi_D^{ME^*} = \pi_D^{MN^*}$, if $E(\pi_{SC}^{ME^*}) > E(\pi_{SC}^{MD^*})$, it is obvious to get the thresholds of the dividend ratio $y < y_{SC}^{ED} = 1 - \pi_M^{MY^*} + N/\pi_M^{MN^*} + F^E + N$ by comparing the formulations (C.1) and (C.2).

On the basis of Corollary 10, the executable equity dividend proportion satisfies $y^L < y < y^R$. Furthermore, the left and right boundaries of the dividend proportion is listed in the following manner:

$$y^L = \frac{F^E}{\pi_M^{MN^*} + F^E + N} = 1 - \frac{\pi_M^{MN^*} + N}{\pi_M^{MN^*} + F^E + N}, y^R = 1 - \frac{\pi_M^{MY^*} + N}{\pi_M^{MN^*} + F^E + N}. \tag{C.3}$$

If $\pi_M^{ME^*} > \pi_M^{MD^*}$, i.e., $(1-y)(\pi_M^{MN^*} + F^E + N) - N > \pi_M^{MD^*}$, it is easy to get the inequality $y < y^{ED} = 1 - \pi_M^{MD^*} + N/\pi_M^{MN^*} + F^E + N$.

Because of Corollary 7, the conclusion is $\pi_D^{MD^*} > \pi_D^{MN^*}$, which can be transformed into $E(\pi_{SC}^{MD^*}) - \pi_D^{MN^*} + N > \pi_M^{MY^*} + N$, holding this inequality $y^{ED} < y_{SC}^{ED}$.

If $\pi_M^{MD^*} + \pi_D^{MD^*} > \pi_M^{MY^*} + \pi_D^{MN^*}$, which can be turned into $E(\pi_{SC}^{MD^*}) - \pi_D^{MN^*} + N < \pi_M^{MY^*} + N$, letting $y_{sc}^{ED} = 1 - E(\pi_{SC}^{MD^*}) - \pi_D^{MN^*} + N/\pi_M^{MN^*} + F^E + N < y^R = 1 - \pi_M^{MY^*} + N/\pi_M^{MN^*} + F^E + N$ to be justified. It generates a threshold $y_{SC}^{ED} \in (y^{ED}, y^R)$, if $y < y_{SC}^{ED}$, such that $E(\pi_{SC}^{ME^*}) > E(\pi_{SC}^{MD^*})$, and vice versa, Remark 5 is just to be proved. □

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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