Impact of Green Credit Financing and Carbon Emission Limits on the Supply Chain Based on POF

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Abstract: In recent years, environmental protection has been paid more and more attention. Green credit policy (GCP) is one of the significant preferential policies for government to encourage enterprises to vigorously develop green projects. We are interested in the impact of the central bank’s GCP on the profits and optimal strategies of manufacturers and suppliers related to POF (purchase order financing). Specifically, we build a game-theoretical model consisting of a manufacturer, a bank and a green supplier and a non-green supplier. Furthermore, the optimal strategies of the manufacturer and suppliers when the bank or the government sets a carbon emission cap on suppliers are discussed. We come to some important conclusions about a GCP that promotes the development of green projects since it brings higher profits to both the manufacturer and suppliers than the lack of a GCP. Furthermore, the higher the production cost, the better the effect of a GCP. Under the carbon emission restrictions required by the government, the effect of GCP is weakened and the profits of the manufacturer and the suppliers are reduced to zero due to the gradually increasing delivery risks as production costs increase.

Keywords: supply chain; purchase order financing (POF); green credit financing; carbon emission limits

1. Introduction

The characteristics of small suppliers in developing countries with price advantages make them a key choice for some large manufacturers. However, many suppliers are often small in scale, lack a performance record and credibility, and rely on external financing for start-up capital [1]. The capital-constraint suppliers can obtain financing through many channels, such as trade credit financing (TCF), which reduces the profit loss of the supply chain caused by the inability to organize production normally. Additionally, their financing sources can be manufacturers, financial institutions, etc. Financial institutions that target incentive and risk management policies to avoid moral hazards and adverse selection can monitor the flow of supplier funds to prevent asset transfers, something that non-financial institutions cannot achieve through controllable costs [2]. Facing to the high threshold of banking, financing and other financial institutions, some small- and medium-sized suppliers cannot borrow sufficient cash from banking, financing, and other financial institutions. At this time, manufacturers can be guarantors, which help these small- and medium-sized suppliers to obtain the loan for producing the products. Sometimes, however, manufacturers do not have enough fixed assets to qualify them as guarantors. Therefore, the operating conditions of small-sized suppliers have become a major problem. To solve this problem, we propose purchase order financing (POF), which is a good risk-sharing mechanism. As collateral, the physical assets of small- and medium-sized enterprises (SMEs) have become an innovative financing model for SMEs in their infancy [3]. The difference with other supplier financing schemes is that financial institutions determine whether to provide loans to small-sized suppliers based on purchase orders issued by buyers instead of credit guarantees, and suppliers fulfill the orders...
with a certain probability. The supplier with POF needs to sell an item to the buyer at a higher price even when the item is valuable and the supplier has a certain degree of credit [4]. The rational allocation of financial resources would be promoted under this pattern, allowing SMEs to occupy a position in the market and the entire supply chain to operate efficiently. At the same time, the green supply chain has also become a popular topic among scholars at home and abroad [5–7], and the degree of industrial pollution is particularly prominent in developing countries [8]. Enterprises using cleaner technology are under a cost disadvantage in reality and the type of green supply chain may disappear under market competition [9]. The organic combination of green supply chain, supply chain finance, and green finance forms the green supply chain finance. Green supply chain finance is to pay more attention to environmental protection on the basis of general supply chain finance, so as to realize the mutual development of enterprises and ecological environment. The exploration of green supply chain finance is still in its infancy. The goal of green supply chain finance is to maximize financing efficiency while minimizing pollution. Hence, the green credit policy (GCP), a special incentive mechanism, is designed for environmental protection and sustainable development [10]. A GCP, which aims to stimulate enterprises to make green investments, is a type of green financial service that is applied to sustainable development projects. If the supplier is an environmentally friendly enterprise, the state gives certain subsidies to encourage financial institutions to increase the loan amount or reduce the loan interest rate. Manufacturers then adopt relevant strategies to try to reduce the pollution caused by the production of small-sized suppliers to obtain government incentives [11]. In this article, we study how banks charge loan interest rates from the green supplier in the three-party POF schemes of the manufacturer, the suppliers, and the bank based on a GCP and observe the sensitivity of the discount rate and the required reverse ratio cut (RRR cut) in government subsidies to interest rates. Moreover, we find the financing equilibrium domain with and without carbon emission limits.

2. Literature Review

Different from bank financing that banks directly issue loans to capital-constrained enterprises, supplier financing involves the participation of core companies. Supplier financing is a form through which core enterprises (listed companies or large enterprises) provide financing to upstream and downstream enterprises with performance credit as guarantee; that is, core enterprises sell their accounts receivable to banks to help upstream and downstream enterprises obtain financing. Supplier financing gives buyers the right to extend the repayment period to improve supply chain performance [12]. Supplier financing is more suitable for retailers than bank financing under the assumption that both retailers and suppliers need short-term financing and banks do not pursue profits. In the case that both retailers and suppliers are at bankruptcy risk, supplier financing can improve suppliers’ profit and supply chain efficiency compared with bank financing. Moreover, supplier financing helps to realize risk sharing among supply chain members [13–15]. Even if supplier financing cannot fully coordinate the supply chain—other financing schemes such as in-house factoring fully coordinate the supply chain—in situations where bank loans are attractive to suppliers, it is still considered a better financing mode. Similar conclusions can be drawn when the manufacturer’s production costs are not too high or when the information about the known supplier is better than that of the bank [16,17]. Compared with bank credit, the trade credit model in the supply chain can more effectively alleviate agency conflicts and enable retailers to achieve optimal inventory strategies at a lower cost without excessive investment under bank credit [18]. The profits of supply chain members, whether through supplier financing or bank financing, are higher than those in the non-financing model [19]. The supplier can also choose equity financing or debt financing when it has financial constraints. Wang et al. [20] found that while the supplier will accept debt financing, it will accept equity financing only under certain conditions. There is partial credit guarantee in some countries. Usually, the partial credit guarantee is
provided by a third-party, such as government, financial institutions, or private companies. The third-party guarantors have their own credit resources and charge guaranty premiums from SMEs. They will share the part of the banks’ risk. Moreover, they will weaken the capital restrictions of banks for SMEs and help SMEs obtain loans from banks. Lu et al. [21] revealed that the preference of SMEs is related to market risk and guarantee rate. The buyer-backed purchase order financing (BPOF) mode, in which buyers provide credit guarantees to financial institutions, creates an opportunity for SMEs to complete financing. When reputable manufacturers act as buyer intermediaries to finance SMEs, high order quantities and high revenues would be generated [22,23]. The risk-taking behavior of buyers will generate incentives for this type of financing, which can be reflected in the large number of profitable orders issued by the buyer and the high yield of the market [24]. Assuming that the supplier is the leader, in the purchase financing scheme among the supplier, retailer and bank, the supplier will manipulate the selling price to benefit itself and improve the efficiency of the supply chain [25]. Unlike assumption in the buyer-backed form of financing, in this paper, risk is shared by the supplier and the bank who determines the loan interest rate charged based on the purchase order issued by the buyer and the delivery probability of the supplier [26].

Due to people’s increasing awareness of environmental protection, green enterprises are motivated to promote green products and green services [27]. In 2016, the China Green Consumer Report released by the Ali Research Institute showed that green consumer groups are growing rapidly. Green consumers also pay attention to the product quality of core enterprises controlling the production process of products in the whole supply chain, which makes green supply chain management (GSCM) increasingly important [28]. Green supply chain management (GSCM) will expand the core competitiveness of suppliers and improve the operation performance of large manufacturers [29]. Upstream enterprises refer to the beginning of the whole industrial chain, including the mining and supply of important resources and raw materials, as well as parts manufacturing and production industries. Downstream enterprises refer to the industries at the end of the industrial chain that process raw materials and parts, manufacture finished products, and engage in production and service. Upstream enterprises are relative to downstream enterprises, which mainly produce the necessary raw materials and primary products for downstream enterprises. To obtain higher performance of the whole green supply chain, downstream enterprises must value the green decisions of the upstream partners [30]. The green level of the supply chain will expand due to the increase in the proportion of credit provided by the upstream enterprises to downstream enterprises, and the profits of the upstream enterprises will increase accordingly. The profits of the downstream enterprises, however, will instead be eroded [7]. In a situation where domestic manufacturing promotes green transformation and frequent international trade frictions, Liu et al. [31] found that the imposition of import tariffs reduces the greenness of products and the profits of supply chain members. Through data analysis of the role of natural resource rents and green investment in reducing carbon emissions in China’s 30 provinces from 1995 to 2017, it is found that green investment is negatively correlated with carbon dioxide, while natural resource rents are positively correlated with carbon emissions [32]. Green credit financing is a type of financial service provided by banks to encourage borrowers to commit green investment and achieve sustainable development. The bank offers the manufacturer green credit financing only if his carbon emissions do not exceed a certain carbon cap, which is imposed by the government. The policy of carbon emission limits cannot be abolished because they are designed to protect the environment. Only if the investment is sustainable can the government support enterprises to finance from banks. Therefore, the government encourages enterprises to make green upgrading in order to achieve sustainable operation. Carbon emission refers to the emission of greenhouse gases, which causes the greenhouse effect and makes the global temperature rise. Therefore, it is necessary for the government to implement carbon emission restriction policies. In the supply chain, manufacturers can set an appropriate green investment scope to achieve a win-win situation with suppliers.
when a relatively strict carbon emission policy is established, and social welfare with carbon emission constraints is lower than it would be without carbon emission constraints under these circumstances [33]. As an incentive policy of GSCM, the GCP has some shortcomings that need to be addressed [34]. Even if implementation is not easy, it can effectively reduce the degree of environmental pollution [10]. Under the bank financing and supplier financing models, the implementation of the GCP makes significant efforts to increase the profits of the entire supply chain [19]. By researching the green credit ratio, Yin et al. [35] reached the conclusion that the GCP is less correlated with bank risks, which contributes to the implementation of the GCP. In this paper, government subsidies are added to the POF scheme to observe the impact of the GCP on bank interest rates, after which the payoffs of manufacturers and suppliers are analyzed. This paper has made the following contributions. First, the decisions of the suppliers and the manufacturer facing capital constraints under the GCP are considered, which, to the best of our knowledge, have thus far received little attention from scholars. Second, the effects of the GCP on the profit of supply chain members are analyzed. Finally, the financing equilibrium domain of the suppliers and the manufacturer under a GCP is analyzed. The rest of this article is organized as follows. In the second section, we introduce the model and obtain the equilibrium solution under a GCP. The third section provides a detailed numerical analysis of profits and government subsidies. In the fourth section, we draw the corresponding conclusions.

3. The Model

Noting the interactions of manufacturers, suppliers, and a bank in a supply chain related to POF, we build a game-theoretical model consisting of a manufacturer, suppliers, and a bank. This model is divided into three stages. In the first stage, the manufacturer gives the supplier a purchase order. In the second stage, to successfully complete the order, the supplier applies for POF loans from a bank due to the shortage of available funds. The supplier then produces according to the terms of the order contract. In the last stage, the supplier sells the products and repays the loan.

We divide two suppliers into the green supplier and the non-green supplier and assume that the market order demand is known. To simplify the model, this paper sets the demand as 1 without losing generality. Notations are summarized in Table 1.

3.1. The Basic Model

It is logical to assume that the supplier has no current assets, only some necessary fixed assets $a$, such as factory equipment and transportation facilities. We denote the production cost of the supplier by $c$ and set $a \leq c$. In reality, suppliers face the risk of not being able to deliver on schedule or even failing to deliver because of the product being of poor quality. Forty percent of suppliers delay delivery, and 5% cause huge losses to banks and buyers who issue purchase orders [36]. The supplier can only fulfill the order with a certain delivery probability $e$. Therefore, the manufacturer bears the risk of not being able to receive the goods. At the same time, to improve the probability, suppliers are willing to pay part of the monitoring cost $k e^2$, where $k > 0$. There is a quadratic nonlinear relation between the supplier’s efforts for monitoring and delivery probability, which indicates that the supplier’s monitoring difficulty will gradually increase. We use $i$ to represent the green supplier and $j$ to represent the non-green supplier. The green supplier represents the enterprises that incorporate the concept of sustainability into their production and management to maintain the organic unity of social benefits and environmental protection benefits. Then, the non-green supplier is an ordinary enterprise correspondingly, which usually ignores sustainability and regards corporate performance as their sole concern. As a Stackelberg leader, the manufacturer purchases from the green supplier or the non-green supplier and sets the order contract price $p_i/p_j$. If the green supplier or the non-green supplier thinks the price is acceptable, to ensure a smooth production process, he will actively apply for POF loan $c_i/c_j$ from the bank. The bank determines the lending rate $r_i/r_j$
based on a variety of factors, in particular, the green supplier \( i \) can enjoy GCP subsidies, including the financial position of the supplier (the only fixed assets) \( a_i / a_j \), the order price paid by the manufacturer \( p_i / p_j \), the discount rate \( F \) and the targeted RRR cut \( O \) under the GCP. Therefore, when the green supplier or the non-green supplier makes a successful delivery with a certain delivery probability \( e_i / e_j \), he receives payment \( p_i / p_j \) from the manufacturer and repays the principal and interest \( (1 + r_j)c_i / (1 + r_j)c_j \) to the bank; if the goods are not delivered on time, the probability that the green/non-green supplier fails to deliver the goods to the manufacturer is represented by \( 1 - e_i / 1 - e_j \), the manufacturer does not have to pay the supplier and needs to buy the products urgently through other channels at price \( v_i / v_j \). The green supplier or the non-green supplier can only receive 0 and pay the fixed assets \( a_i / a_j \) of the bank. In order to reduce the risk of the supplier becoming a defaulter, the bank can determine whether the supplier is qualified for the loan according to the size of the company and the degree of credit. If the supplier borrows money from the bank successfully, under the incentive of green credit policy implemented by the bank, the supplier will improve its delivery probability. The supplier itself also spends monitoring costs to ensure the smooth progress of orders. At this time, as long as the preferential power of the bank is high enough, the delivery probability and revenue of the supplier will be improved. Therefore, the bank can prevent the supplier from breaching contracts by carefully checking their suppliers’ operating conditions and implementing green credit policy. However, the bank is not profit-seeking, they do not spend money to monitor suppliers. The sequence of events under POF is shown in Figure 1.

Table 1. List of notations.

| Notation | Description |
|----------|-------------|
| \( a \)  | Supplier’s fixed assets |
| \( c \)  | Supplier’s production cost |
| \( e \)  | Supplier’s delivery probability |
| \( e_c \) | Supplier’s delivery probability under the carbon emission limits |
| \( k \)  | Supplier’s monitoring cost |
| \( p \)  | The contract price provided by manufacturer |
| \( v \)  | The price at which a manufacturer buys a product from another source |
| \( r \)  | The lending rate determined by the bank |
| \( r_c \) | The lending rate determined by the bank under the carbon emission limits |
| \( s \)  | Deposit-reserve ratio |
| \( D \)  | The amount of bank deposits |
| \( F \)  | The discount rate |
| \( O \)  | The targeted required reverse ratio cut (RRR cut) granted to the bank by the central bank |
| \( H \)  | The amount of green re-loans obtained by the bank |
| \( G \)  | The targeted RRR cut coefficient |
| \( T \)  | The carbon emission cap required by the bank or the government |
| \( t \)  | Suppliers’ initial cap emissions per unit production |
| \( \theta \) | The carbon emission reduction per unit cost |
Figure 1. Sequence of events under purchase order financing (POF).

If the manufacturer does not cooperate with suppliers, then the manufacturer can only buy alternative products from other sources at the price $v$, in which case the manufacturer costs $v$. Under the cooperative state of both parties, suppliers have a probability of successful delivery $e$, and the manufacturer will pay the price $p$; or the deal falls apart and the manufacturer still needs to buy from somewhere else. In this case, the manufacturer costs $ep + (1 - e)v$. Suppliers’ involvement in the supply chain can save the manufacturer $v - [ep + (1 - e)v]$. Compared to purchasing from two suppliers and emergency purchasing, the cost savings of the manufacturer are

$$\pi_M = v_1 - [e_1p_1 + (1 - e_1)v_1] + v_2 - [e_2p_2 + (1 - e_2)v_2] = e_1(v_1 - p_1) + e_2(v_2 - p_2). \quad (1)$$

The suppliers can fulfill the order issued by the manufacturer with a probability of $e$ and obtain the profit $p - c(1 + r)$; otherwise, it needs to pay $a$ to the bank with the possibility of $1 - e$. In the production process of the order, the suppliers generate the monitoring cost $k\sigma^2$, so the total profit of the two suppliers is

$$\pi_S = [p_i - c_i(1 + r_i)] \cdot e_i - a_i \cdot (1 - e_i) - k_i\sigma^2 + [p_j - c_j(1 + r_j)] \cdot e_j - a_j \cdot (1 - e_j) - k_j\sigma^2. \quad (2)$$

The bank provides loans to two suppliers, a green supplier $i$ and a non-green supplier $j$. After the suppliers complete the order, they pay principal and interest $c(1 + r)$ to the bank; otherwise, the supplier pays the fixed asset $a$ to the bank.

The central bank or the government provide some GCPs, such as policies for restricted industries regulated by the state, policies for environmental and social risk management and policies for fulfilling environmental and social responsibilities, for the bank to improve the development of green projects. Here, reducing the deposit–reserve ratio and providing discount interest and green reloans to the bank are considered. These policies encourage the bank to make more loans at lower interest rates to the green supplier. Meanwhile, the bank needs to maintain a new balance in the case with GCPs relative to one in the case without non-GCPs, as follows:

$$c_i(1 + r_i) \cdot e_i + a_i \cdot (1 - e_i) + c_j(1 + r_j) \cdot e_j + a_j \cdot (1 - e_j) + F \cdot c_i + (s - O) \cdot D = D + H, \quad (3)$$

where $c_i(1 + r_i) \cdot e_i + a_i \cdot (1 - e_i)$ and $c_j(1 + r_j) \cdot e_j + a_j \cdot (1 - e_j)$ are the bank’s profit expectations for the two suppliers, $F$ is the discount rate, $O$ is the targeted RRR cut granted to banks by the central bank, $s$ is the deposit-reserve ratio, $D$ is the amount of bank deposits, and $H$ is the amount of green re-loans obtained by the central bank. We can see that the assets of the bank appear on the left-hand side of the Formula (3). The bank
may receive the principal and interest paid by the supplier at probability $e$ or it may only get collateral $a$ from the supplier at probability $1 - e$ otherwise. The bank also receives interest discounts $F \cdot c_i$ under the GCP as well as reserve payments to the central bank after deducting targeted RRR cuts. On the right-hand side of the Formula (3) is the bank’s liabilities, including deposits and green re-loan by the central bank. The right-hand side of the Formula (3) shows the bank’s liabilities, including deposits and green re-loan by the central bank. The balance of assets and liabilities is a requirement of a bank that does not adopt a profit-seeking behavior.

The targeted RRR cut depends on the proportion of green credit $c_i$ in the total credit $c_i + c_j$. The higher the green credit amount is, the more favorable the central bank’s policy will be for banks to reduce the RRR, and the more effective it will be to reduce the pollution level. Therefore, it can be expressed as

$$O = \frac{c_i}{c_i + c_j}$$

where $G$ represents coefficient.

The relevant indexes of the non-green supplier $j$ as constants are set to highlight the green suppliers and simplify the model. It is not difficult to obtain the optimal delivery probability that makes the supplier’s total profit reach the maximal value.

$$e_i^* = \frac{p_i - (1 + r_i)c_i + a_i}{2k_i}$$

Let $A = (1 - s)D + H - [c_i(1 + r_i)e_j + a_j(1 - e_j)]$; then, the formula of the bank balance can be expressed as

$$r_i = \frac{A - a_i \cdot (1 - e_i) - F \cdot c_i + \frac{c_i}{c_i + \phi} \cdot DG}{c_i \cdot e_i} - 1,$$

where $b = c_j$.

Combining the delivery probability equation with the interest rate equation, the optimal solutions are obtained as follows:

$$e_i^* = \frac{p_i + \sqrt{p_i^2 - 8k_i(M - a_i)}}{4k_i},$$

$$r_i^* = \frac{p_i - \sqrt{p_i^2 - 8k_i(M - a_i)}}{4k_i},$$

where $M = A - F \cdot c_i + \frac{DGc_i}{c_i + \phi}$.

Let $W = [p_j - c_j(1 + r_j)] \cdot e_j - a_j \cdot (1 - e_j) - k_e^2$ and $E = e_j(v_j - p_j)$; then, the optimal profits of the suppliers and the manufacturer are

$$\pi_S = [p_j - c_j(1 + r_j)] e_j^* - a_j(1 - e_j^*) - k(e_j^*)^2 + W,$$

$$\pi_M = e_i^*(v_i - p_i) + E.$$

**Proposition 1.** Considering a GCP, the central bank providing the discount rate $F$, the targeted RRR cut $O$ and the amount of green re-loans $H$ for the bank, based on the Stackelberg model consisting of the green supplier, the non-green supplier, the manufacturer, and the bank, we can find their optimal solutions as follows:

$$e_i^* = \frac{p_i + \sqrt{p_i^2 - 8k_i(M - a_i)}}{4k_i}, r_i^* = \frac{p_i - \sqrt{p_i^2 - 8k_i(M - a_i)}}{4k_i},$$
where $p_i$ represents the contract price offered by the manufacturer to the green supplier, $a_i$ denotes the fixed assets mortgaged by the green supplier to banks, $c_i$ represents the supplier’s production cost, $M$ is the same as in (7) and $k_i$ is the weight of $e_i^2$.

Our research focuses on the behavior of green suppliers under the green credit policy and does not emphasize these two constraints of $W \geq 0$ and $E \geq 0$ in this article, the relevant indexes of the non-green supplier $j$ as constants are set to highlight the green suppliers and simplify the model. These two constraints are, of course, true. They would be used as references for parameter setting.

We note that the profits need to meet the two constraints of

$$[p_i - c_i(1 + r_i)] \cdot c_i - a_i \cdot (1 - c_i) - k_i e_i^2 \geq 0 \quad \text{and} \quad v_i - p_i \geq 0,$$

Hence, the important proposition about equilibrium domains is received as follows.

**Proposition 2.** In a supply chain consisting of a green supplier, a non-green supplier, a manufacturer, and a bank, the following equilibrium domains exist:

1. When $a_i \geq \max \left\{ \frac{v_i^2}{2k_i}, \frac{v_i^2 - v_j \sqrt{v_i^2 - 4k_i s}}{2k_i} - M \right\}$, the delivery probability of the green supplier $e_i = \sqrt{\frac{v_i}{v_j}}$, the bank provides loans at interest rate $r_i = \sqrt{\frac{v_i}{v_j}} \frac{(M - a_i)}{c_i} + \frac{a_i}{c_i} - 1$, the contract price $p_i = \sqrt{\frac{v_i}{v_j}} \cdot (M + a_i)$, the manufacturer’s profit $\pi_M = v_i \sqrt{\frac{v_i}{v_j}} - M - a_i + E$, and the total payoffs of two suppliers are given as $\pi_S = W$.

2. When $M - \frac{v_i^2}{2k_i} \leq a_i \leq \frac{v_i^2}{2k_i}$, the delivery probability of the green supplier $e_i = \frac{v_i}{2k_i}$, the bank provides loans at interest rate $r_i = \frac{4k_i(M - a_i)}{v_i c_i} + \frac{a_i}{c_i} - 1$, and the contract price $p_i = \sqrt{\frac{v_i}{v_j}} \cdot (M + a_i)$. Also, $\pi_M = \frac{v_i^2}{2k_i} - M + a_i + E$ and $\pi_S = \frac{v_i^2}{2k_i} - a_i + W$.

3. When $a_i < \max \left\{ M - \frac{v_i^2}{2k_i}, \frac{v_i^2 - v_j \sqrt{v_i^2 - 4k_i s}}{2k_i} - M \right\}$, the manufacturer does not purchase from the green supplier.

The proof is available in Appendix A.

### 3.2. The Model with Carbon Emission Limits

In this section, based on the above model, we consider that suppliers are subject to carbon emission limits. Considering the current state of the ecological environment, the government implements the total carbon emission control plan. The green supplier can only get preferential GCP support when the carbon emission is reduced to the standard required by the government. Banks can obtain information on carbon emissions from the past disclosure reports of the green supplier. The relevant variables under carbon emission limits remain the same as those under no carbon limits, but the difference lies in the delivery probability $e_i$ and the interest rate $r_i$ set by the bank. $T$ represents the carbon emission cap required by the bank or the government, and $t$ represents the suppliers’ initial cap emissions per unit production. Only when the carbon emissions generated by suppliers are less than the upper limit $T$ will the bank provide POF loans under the GCP. Moreover, the carbon emission reduction per unit cost is denoted by $\theta$. Similarly, $i$ represents the green supplier and $j$ represents the non-green supplier.

The government’s carbon constraint on the green supplier is \( (t_i - \theta e_i) e_i + t_i(1 - e_i) \leq T_i \). The optimal problems for the manufacturer and the green supplier are, respectively, as follows:

$$\begin{align*}
\max_{\pi_M} \pi_M &= \max_{e_i} \left\{ v_i - [e_i(p_i - (1 - e_i) v_j)] + v_j - [e_i(p_j + (1 - e_j) v_j)] \right\} \\
&= \max_{e_i} \left\{ e_i(v_i - p_i) + e_j(v_j - p_j) \right\} \\
\text{s.t.} \ & (t_i - \theta e_i) e_i + t_i(1 - e_i) \leq T_i, \quad (12)
\end{align*}$$
and

$$\max_{e_{j,i}} \pi_M = \max_{e_{j,i}} \left\{ p_j - c_i(1 + r_{i,i})e_{j,i} - a_i(1 - e_{j,i}) - k_{e_{j,i}} - \left( p_j - c_i(1 + r_{i,i}) \right)e_{j,i} - a_i(1 - e_{j,i}) - k_{e_{j,i}}^2 \right\}$$

$$s.t. (l_i - \theta_i c_i)e_{j,i} + t_j (1 - e_{j,i}) \leq T_i.$$  \hspace{1cm} (13)

By the Lagrange multiplier method, we obtain the delivery probability

$$e_{j,i}^* = \begin{cases} \frac{\mu + \sqrt{\mu^2 - 8k_i(M-a_i)}}{8k_i} & T_i \geq T_i^G \\ \frac{\mu_i - T_i}{8k_i} & T_i < T_i^G \end{cases}$$  \hspace{1cm} (14)

where $T_i^G = t_i - (\mu_2 \sqrt{\mu^2 - 8k_i(M-a_i)} \theta_i c_i$. The proof is available in Appendix A.

Similarly, the carbon constraint equation of the bank’s balance of payment is as follows:

$$c_i(1 + r_{i,i})e_{j,i} + a_i(1 - e_{j,i}) + Fc_i + (s - O)D + c_j(1 + r_j)e_j + a_j(1 - e_j) = D + H.$$  \hspace{1cm} (15)

Substituting the formula of delivery probability into the interest rate identity yields

$$r_{j,i}^* = \begin{cases} \frac{\mu_1 - \sqrt{\mu_1^2 - 8k_i(M-a_i)}}{8k_i} + \frac{\mu_i}{\theta_i c_i} - 1, & T_i \geq T_i^G \\ \frac{\theta_i(A-a_i(1-f_{G})) - Fc_i + t_j}{T_i^G - T_i^G} - 1, & T_i < T_i^G \end{cases}$$  \hspace{1cm} (16)

We reveal that when $T_i \geq T_i^G$, the optimal profits are equal to those without carbon emission limits; when $T_i < T_i^G$, the manufacturer and suppliers’ optimal profits are

$$\pi_M^* = e_{j,i}^* (v_j - p_j) + W,$$

$$\pi_S^* = [p_i - c_i(1 + r_{i,i})]e_{j,i}^* - a_i(1 - e_{j,i}^*) - k_i(e_{j,i}^*)^2 + E.$$  \hspace{1cm} (18)

When the green supplier is not involved in the supply chain, the government’s carbon constraint on the green supplier is $(t_j - \theta_i c_i)e_{j,i} + t_j (1 - e_{j,i}) \leq T_j$. The optimal problems for the manufacturer and the non-green supplier are respectively as follows:

$$\max_{e_{j,i}} \pi_{M,i} = \max_{e_{j,i}} \left\{ v_j - \left[ e_{j,i}p_j + (1 - e_{j,i})v_j \right] \right\}$$

$$s.t. (l_i - \theta_i c_i)e_{j,i} + t_j (1 - e_{j,i}) \leq T_j.$$  \hspace{1cm} (19)

and

$$\max_{e_{j,i}} \left\{ p_j - c_i(1 + r_{i,i})e_{j,i} - a_i(1 - e_{j,i}) - k_{e_{j,i}}^2 \right\}$$

$$s.t. (l_i - \theta_i c_i)e_{j,i} + t_j (1 - e_{j,i}) \leq T_j.$$  \hspace{1cm} (20)

Based on [26], the carbon constraint equation of the bank’s balance of payment is as follows:

$$c_j(1 + r_j)e_j + a_j(1 - e_j) = c_j.$$  \hspace{1cm} (21)

Similarly, the delivery probability is

$$e_{j,i}^* = \begin{cases} \frac{\mu + \sqrt{\mu^2 - 8k_i(c_i - a_i)}}{8k_i} & T_j \geq T_j^G \\ \frac{\mu_i - T_j}{8k_i} & T_j < T_j^G \end{cases}$$  \hspace{1cm} (22)
where $T_j^G = t_j - \left( \frac{p_j + \sqrt{p_j^2 - 8k_j(c_j - a_j)}}{4k_j} \right) \theta_j c_j$ and

$$r_{j,\ell}^* = \begin{cases} \frac{p_j - \sqrt{p_j^2 - 8k_j(c_j - a_j)}}{2c_j} + \frac{a_j}{c_j} - 1, & T_j \geq T_j^G, \\ \frac{\theta_j(c_j-a_j(1-T_j^{-1}T_j))}{t_j^{-1}-t_j} - 1, & T_j < T_j^G. \end{cases}$$

(23)

We find that when $T_j \geq T_j^G$, the optimal profits are equal to those without carbon emission limits (see [26]); when $T_j < T_j^G$, the manufacturer and the non-green supplier’s optimal profits are

$$\pi_M^* = e_{j,\ell}^*(v_j - p_j),$$

(24)

$$\pi_S^* = [p_j - c_j(1 + r_{j,\ell}^*)]e_{j,\ell}^* - a_j(1 - e_{j,\ell}^*) - k_j(e_{j,\ell}^*)^2.$$  

(25)

**Proposition 3.** When a GCP and carbon emission limits are considered, first, the optimal strategy of the manufacturer and the suppliers for their optimal profits satisfying (9) and (10) is as follows:

$$e_{j,\ell}^* = \begin{cases} \frac{p_j + \sqrt{p_j^2 - 8k_j(M-a_j)}}{4k_j} & T_i \geq T_i^G, \\ \frac{\theta_j(A-a_j(1-T_j^{-1}T_j)) - F_{c_j} + \frac{T_j}{T_j^{1/2}} DG}{T_i^{-1}T_j} - 1 & T_i < T_i^G. \end{cases}$$

(26)

where $T_i^G = t_i - \left( \frac{p_j + \sqrt{p_j^2 - 8k_j(M-a_j)}}{4k_j} \right) \theta_j c_i$.

Moreover, when the bank’s balance of payment satisfies (15), the bank’s optimal loan interest rate is achieved as follows:

$$r_{i,\ell}^* = \begin{cases} \frac{p_j - \sqrt{p_j^2 - 8k_j(M-a_j)}}{2c_j} + \frac{a_j}{c_j} - 1, & T_i \geq T_i^G, \\ \frac{\theta_j(A-a_j(1-T_j^{-1}T_j)) - F_{c_j} + \frac{T_j}{T_j^{1/2}} DG}{T_i^{-1}T_j} - 1, & T_i < T_i^G. \end{cases}$$

(27)

Furthermore, the optimal strategy of the manufacturer and the non-green supplier satisfying (17) and (18) is shown below:

$$e_{j,\ell}^* = \begin{cases} \frac{p_j + \sqrt{p_j^2 - 8k_j(c_j-a_j)}}{4k_j} & T_j \geq T_j^G, \\ \frac{\theta_j(c_j-a_j(1-T_j^{-1}T_j))}{t_j^{-1}-t_j} - 1 & T_j < T_j^G. \end{cases}$$

(28)

where $T_j^G = t_j - \left( \frac{p_j + \sqrt{p_j^2 - 8k_j(c_j-a_j)}}{4k_j} \right) \theta_j c_j$ and

$$r_{j,\ell}^* = \begin{cases} \frac{p_j - \sqrt{p_j^2 - 8k_j(c_j-a_j)}}{2c_j} + \frac{a_j}{c_j} - 1, & T_j \geq T_j^G, \\ \frac{\theta_j(c_j-a_j(1-T_j^{-1}T_j))}{t_j^{-1}-t_j} - 1, & T_j < T_j^G. \end{cases}$$

(29)

**Remark:** Heavy industry and long-distance transport are sectors where carbon emissions will be particularly difficult to reduce—largely because the key technologies needed to reduce carbon emissions in these sectors are still in the early stages of development (large-scale physical experimentation and demonstration), which highlights the need to accelerate clean technology innovation in key areas. I think our model can be applied to heavy industry to make it more focused on dealing with emissions from existing fixed assets. The country will invest in decarbonisation in heavy industry and heavy transport, and this is the perfect time to reshape industry and move to a more competitive low-carbon industrial model, while also reducing air pollution.
4. Numerical Analysis

In this section, we focus on the impact of the production cost on the manufacturer and suppliers’ profits and the equilibrium domains of the strategies related to the production cost and the targeted RRR cut. We discuss the optimal profits and the strategy domains with and without carbon emission limits.

4.1. The Numerical Analysis without Carbon Emission Limits

Let \( k_i = 1.99, k_j = 1.95, a_i = 0.008, a_j = 0.008, p_i = 4.95, p_j = 4.306, v_i = 6.45, v_j = 6, D = 1.2, s = 0.165 \) and \( r_j = 0.08 \).

We investigate how the production costs have different effects on the profit of manufacturer and supplier under different conditions of \( F, H, G \). Here, we set \( F = 0.015 \) and \( F = 0.02, H = 0.01 \) and \( H = 0.05 \), and \( G = 0.2 \) and \( G = 0.3 \).

Figure 2 shows that when the production cost \( c \) is small, the profit obtained by the manufacturer providing procurement contracts to both the green supplier and the non-green supplier is higher than that obtained only from the non-green supplier. The government’s targeted cuts to the required reserve ratio policy will encourage banks to increase the loan amount and reduce the loan cost for the green supplier. Green reloans from the government to the central bank will also indirectly lower the loan interest rate for the green supplier. Therefore, the manufacturer entrusts both types of suppliers to generate higher revenue. However, it is concluded that the manufacturer’s profit always decreases with increasing costs. The increase in production costs makes manufacturers tend to invest only in non-green supplier. When the production costs reach a certain scale, the two types of suppliers are unwilling to make efforts to improve the delivery probability, so they both become fixed-value, and their profits tend to be balanced. However, the equilibrium return brought by the two types of suppliers to the manufacturer is higher than that brought by only the non-green supplier. The dotted lines in Figure 2a,b reveal that the GCP underpins the profitability of the manufacturer, but it only applies to the case where the supplier’s production cost \( c \) is low. The high cost implies that the delivery probability decreases and delivery of goods is at a higher risk, so the cost of small green enterprises gives a boost to the manufacturer’s earnings.

![Figure 2. The profit of the manufacturer (a) Different values of \( G \) and \( H \); (b) Different values of \( F \) and \( H \).](image-url)

By observing Figure 3, we see that when production cost \( c \) is small \( (c < 1.25) \), it is always beneficial for the manufacturer to invest in both types of suppliers since the loan cost for the green supplier will be lower than that for the non-green supplier under government incentives. However, due to the high investment proportion of the non-green suppliers, the total profit of suppliers would only be slightly higher than that of the non-green supplier. When \( c \) is between 1.25 and 1.35, we observe that the profit of the green supplier is negative and that the manufacturer will only invest in the non-green supplier to obtain the optimal payoff at the purple dotted line. When \( c \) is greater than 1.35, the advantages
of the government’s three incentive measures gradually emerge in the market with the expansion of the proportion of the loan amount of the green supplier. The subsidy is enough to offset the delivery risk due to the increase in the loan amount, and the suppliers’ profits will increase sharply. Through the solid line in blue, we can conclude that the profits of the non-green supplier have been decreasing. The delivery probability of the non-green supplier at $c = 1.55$ has been reduced to a constant value, the reason why the profits of the non-green supplier have been steadily decreasing since the loan amount gradually increased. When $c < 1.25$, $F$, $G$ and $H$ help increase the profit of the suppliers even more (Figure 3a,b).

![Figure 3](image.png)

Figure 3. The profit of the suppliers (a) Different values of $G$ and $H$; (b) Different values of $F$ and $H$.

Next, we discuss the equilibrium domain for the production cost, $c$, and the coefficient of the targeted RRR cut, $G$, under different discount rates.

Considering the case with the lending amount $1.114 < c < 1.314$, from Figure 4, we can describe the corresponding equilibrium outcomes as follows:

1. There exists a critical point $(1.153, 0.125)$ in the left image of Figure 4 where the total profit of the manufacturer and suppliers will not change due to the participation of the green supplier.
2. (Non-green dominates) In region IV of Figure 4, only the non-green supplier can bring profits to the manufacturer; the green supplier brings negative profits.
3. (Pareto zone) There exists a Pareto zone for the GCP (region II in Figure 4), such that both the green supplier and the manufacturer generate positive profits, which will increase with $G$.

![Figure 4](image.png)

Figure 4. Equilibrium domain of the manufacturer and suppliers under different discount rates (a) $F = 0.015$; (b) $F = 0.02$. 
The solid lines in Figure 4 are the indifference yield curves of the two types of suppliers. The dotted line connects all the no-difference points that the manufacturer purchases from the green supplier and the non-green supplier. Similarly, the upper area of the two curves indicates that the participation of the green supplier drives the profit of the manufacturer, while the bottom area shows that the manufacturer only provides the order to the non-green supplier because the GCP is not enough to offset the high cost and high risk of the green supplier. Comparing Figure 4a,b, the increase of the discount rate means the expansion of the Pareto zone and a reduction in the size of the other three regions; thus, the profit equilibrium point \( G \) of suppliers and the manufacturer decrease correspondingly. The profit of supply chain members has been improved under the government discount and RRR cut subsidies, a win-win situation for both the manufacturer and suppliers.

First, when the ranges of \( c \) and \( G \) are in region I, the government subsidy coefficient \( G \) is relatively small, and the green supplier does not have enough incentive to borrow from the bank. Because of the low fixed asset, it does not have the ability to produce a high delivery probability. At this time, the green supplier is not willing to accept the manufacturer’s order, but the manufacturer is interested in the low loan cost for the green supplier, which can result in higher profits for the manufacturer.

Second, the case where \( c \) and \( G \) are larger (region III in Figure 4) is considered. Government subsidies motivate green suppliers to accept orders and apply for POF loans from the bank to obtain the contract price \( p \) given by the manufacturer. However, the manufacturer will not purchase from the green supplier for fear of default caused by high production costs. In the above two regions, neither the manufacturer nor the green supplier can reach equilibrium.

Finally, we observe that for any loan cost \( c \) in regions II and IV, the equilibrium domain dominated by the green supplier is larger than that dominated by the non-green supplier, and the profits of the manufacturer and the supplier in region II are higher than those in region IV. The Pareto zone provides a profit margin for the green supplier and the manufacturer because \( G \) is larger at this time, and the delivery probability of the green supplier will increase. When the RRR cut coefficient \( G \) of the bank increases, that is, the bank’s subsidy intensity increases, the subsidy of the green supplier increases and the loan cost of the green supplier decreases, then the performance will increase accordingly. In contrast, the participation of the green supplier in region IV only reduces the efficiency of the whole supply chain, which is uneconomic for both the manufacturer and the green supplier.

4.2. The Numerical Analysis with Carbon Emission Limits

In this section, the profits of the manufacturer and suppliers with and without carbon emission limits are compared. Moreover, we also research the equilibrium domain of the strategies with carbon emission limits under different discount rates.

Without the loss of generality, it assumed that carbon emission caps for the green supplier and the non-green supplier required by the government are \( T_i = 5 \) and \( T_j = 5.2 \), respectively; the green supplier’s and the non-green supplier’s initial carbon emissions are \( t_i = 5.6 \) and \( t_i = 5.8 \), respectively; and the green supplier’s and the non-green supplier’s carbon emission reduction per unit cost are \( \theta_i = 1.5 \) and \( \theta_j = 1.8 \), respectively.

Figure 5 depicts the profit of manufacturers with and without carbon emission limits. In the absence of carbon limitation, the manufacturer’s income is the highest when both the green and the non-green suppliers participate. The manufacturer’s profit will be greatly reduced once the government puts the carbon emission limitation policy into effect, as shown by the dotted line in Figure 5. When the borrowing cost is low, the manufacturer tends to source from two types of suppliers, and even existing carbon emission limits and GCPs will help the green supplier overcome difficulties and deliver products to the manufacturer with a higher probability of generating revenue. However, when the loan cost is high, the manufacturer prefers to issue procurement contracts to non-green suppliers that do not have carbon constraints. Carbon emissions are regulated by the government,
which raises the production costs of the green supplier and reduces the effect of subsidies; as a result, the benefits of the green supplier and the manufacturers are limited. At this time, the advantage of the non-green supplier that is not subject to carbon emission restrictions gradually emerges in the market, such that it is more beneficial for the manufacturer to choose only the non-green supplier. The manufacturer will not order products only from the non-green supplier under carbon emission limits because there is no obvious way to make a high profit in this supply chain. By comparing Figures 2 and 5, we can see that suppliers with high costs under the restriction of carbon emissions will bring a low delivery probability, which causes the manufacturer’s profit to continue to decline but not tend to be stable. However, the absence of carbon emission limits does not affect manufacturers’ preference for purchasing from low-cost suppliers.

![Figure 5. The comparison of the manufacturer’s profit with and without carbon emission limits.](image_url)

The trends of the profits of the manufacturer and the suppliers in different situations are consistent, as shown in Figures 5 and 6. The government’s willingness to subsidize low-cost green suppliers encourages them to apply for POF loans, which leads them to actively participate in the market. Figure 5 also shows that the manufacturer affords green suppliers purchasing opportunities to earn high profits under the condition of carbon emission limits. Once the production cost is high (when $c > 1.125$), the manufacturer withdraws from the market where it has begun to generate negative returns, while the non-green supplier without a carbon emission limit seizes the market. The non-green supplier has little awareness of environmental protections and produces more harmful substances that sharply reduce the profit of the non-green supplier under the existence of carbon emission restrictions; in other words, they will not be able to obtain market share (Figure 6). Therefore, we illustrate that carbon emission restrictions adversely impact profits for both manufacturers and suppliers. A production scale at high credit costs corresponds to high pollution, so subsidies under the GCP are conditional—the government’s green subsidies can play a positive role only when the production cost is small. The sharp distinction between Figures 3 and 6 is that the GCP does not provide a continuous revenue stream for the green supplier with carbon emission constraints, indicating that the supplier also tries to reduce costs rather than expand rapidly.
Similarly, we investigate the equilibrium domain of the strategies with carbon emission limits under different discount rates.

Considering the case with the lending amount $1.015 < c < 1.329$, from Figure 7, we can describe the corresponding equilibrium profits (with carbon emission limits) as follows:

1. There exists a critical point at which the total profit of the manufacturer and suppliers will not change due to the participation of the green supplier with carbon emission limits.

2. (Non-green dominates) In region IV of Figure 7, only the non-green supplier without carbon emission limits can create revenue for the manufacturer; the green and non-green suppliers under the carbon emission restriction have no competition in the market.

3. (Pareto zone) There exists a Pareto zone for the GCP (region II in Figure 7), such that both the green and non-green suppliers with carbon emission limits generate positive profits, which will increase with $G$.

![Figure 7](https://example.com/figure7.png)

**Figure 7.** Equilibrium domain with carbon emission limits of the manufacturer and suppliers under different discount rates (a) $F = 0.015$; (b) $F = 0.02$.

Figure 7 describes the decision area of the manufacturer and the suppliers with or without carbon emission limits. There are two kinds of decisions in the graph: the upper areas of both solid and dotted lines represent the participation of the non-green supplier...
and the green supplier that are subject to carbon emission limits in the supply chain; the bottom area of the graph shows that profits determine that both parties choose only the non-green supplier without carbon emission restrictions. Similarly, the intersection indicates that the two decisions are indistinguishable for both the manufacturer and the suppliers. By comparing Figure 7a,b, we reveal that the increase in discount rate $F$ signifies the expansion of the Pareto zone, and the profit equilibrium point $G$ of the manufacturer and the suppliers decreases correspondingly, indicating that they will not strictly require the RRR coefficient under the high discount rate.

First, region I in Figure 7 shows that the non-green supplier is unable to bear the extra costs caused by the carbon emission limit policy and that the green supplier is unwilling to produce with carbon emission restrictions due to the lack of sufficient government subsidies under the low loan costs and government subsidy coefficient $G$. In contrast, the manufacturer is interested in the low loan cost of the suppliers, and its profit will not affect the expectation of the green supplier under the carbon emission limits.

Next, when $c$ and $G$ are larger, we consider region III in Figure 7. Government subsidies offset the adverse effects of carbon emission limits on both types of suppliers, giving them an incentive to borrow more of their production costs and raising their expectations. The safest option for the manufacturer is to source from the non-green supplier with no carbon emission limits because there is no additional benefit from taking the risk.

Finally, the profits of manufacturers and suppliers in region II are significantly higher than those in region IV, with ranges of $c$ and $G$. The Pareto zone means that the delivery probability of the green and non-green suppliers under carbon emission limits will increase. When the discount rate $F$ is small, the suppliers’ requirement for coefficient $G$ is higher; otherwise, it is the manufacturer’s requirement that is more demanding, which indicates that the manufacturer’s earnings are more affected by the targeted RRR policy. However, the carbon emission limits in region IV will affect the profits of all parties, and both the manufacturer and the suppliers will reject the regulation of the carbon emission limits; thus, only the participation of the non-green supplier without carbon emission limits is accepted. In addition, the differences between Figures 4 and 7 are the size of the Pareto zone and the intersection point $G$. It is clear that the region will shrink, and the suppliers and the manufacturer need a more relaxed GCP when the government implements carbon emission restrictions.

5. Conclusions

As a financing scheme for small and medium-sized suppliers, POF benefits manufacturers and suppliers through the delivery probability. The established supply chain models involving the participation of the green supplier are our innovation. Therefore, we study various influencing factors of profits under the introduction of the GCP and reinforce the evidence that regardless of the model, the manufacturer prefers to purchase from low-cost green enterprises with less risk through numerical analysis. The positive impact of GCP on supplier performance is also more concentrated in low-cost enterprises. GCP with carbon emission restrictions increases the risk that suppliers will not deliver on time and, therefore, their benefits are limited. The policy will not reverse the trend of manufacturers accepting only low-cost suppliers. Then, a Pareto zone is obtained by studying the equilibrium domain of the manufacturer and suppliers under a GCP. As long as the government’s targeted RRR reduction is high enough, the green supplier and the manufacturer are willing to participate in POF loans. The green supplier strives to improve the delivery probability and seeks more benefits for all parties in the supply chain, in which the total benefit is significantly higher than that in the traditional supply chain (not involving the green supplier), especially under an increase in the discount rate. This study provides technical support for the green development of supply chain finance, observes the role of GCP under the POF mode in different industries, and the convenience of financing creates conditions for the adoption of low-carbon technology, the upgrading of high energy consuming equipment and the production of low-carbon green raw materials in the upstream
enterprises of the supply chain. The goal of supply chain finance development promoted by GCP is more balanced, which promotes the integration of economic benefits, social benefits and environmental benefits, and strengthens the regulation of carbon emission by banks or the government on enterprises. The state will improve the ecological environment while pursuing the maximization of economic benefits of the supply chain, so as to improve the efficiency of the whole society in the utilization of resources. The incentive mechanism forms the mutual restriction of supply chain members and stimulates the environmental awareness of enterprises. Although partial performance of the supply chain is sacrificed, a good environment brings strong positive externalities.

6. Further Research

This paper only covers the influence of the GCP on the POF financing mode under information symmetry. On this basis, we will focus on the financing process when the information of banks and manufacturers is asymmetric under different financing models (such as in-house factoring) in the future. Classifying the operating conditions of suppliers to facilitate the identification of banks will become our next focus. In addition, we do not consider the POF under the supervision of banks. In the future work, we will assume that the bank adopts profit-seeking behavior, and then bring the bank’s regulatory cost into the model, which is more in line with the reality and greatly reduces the default risk of the loan enterprise.

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Appendix A

The proof of Proposition 2.

First, we apply (5) to suppliers’ constraint \( |p_i - c_i (1 + r_i)| \cdot e_i - a_i \cdot (1 - e_i) - k_i e_i^2 \geq 0 \), we obtain that \( p_i - (1 + r_i) c_i + a_i \geq 2 \sqrt{k_i a_i} \). That is, \( \frac{p_i - (1 + r_i) c_i + a_i}{2k_i} \geq \frac{2 \sqrt{k_i a_i}}{2k_i} \). Noting \( e_i = \frac{p_i - (1 + r_i) c_i + a_i}{2k_i} \), we can easily get \( e_i \geq \sqrt{\frac{a_i}{c_i}} \).

Second, \( e_i = p_i + \sqrt{p_i^2 - 8k_i (M - a_i)} \) shows that the relationship between \( e_i \) and \( p_i \) is \( p_i = 2k_i e_i + \frac{M - a_i}{e_i} \). The manufacturer’s constraint \( v_i - p_i \geq 0 \), which can be expressed in \( e_i \) using this equation of \( p_i \), holds if and only if

\[
e_i \in \left[ \frac{v_i}{4k_i} - \frac{\sqrt{v_i^2 - 8k_i (M - a_i)}}{4k_i}, \frac{v_i}{4k_i} + \frac{\sqrt{v_i^2 - 8k_i (M - a_i)}}{4k_i} \right].
\]

The manufacturer’s profit is \( \pi_M = e_i (v_i - p_i) = e_i v_i - 2k_i e_i^2 - (c_i - a_i) \).

The optimal problem is as follows:

\[
\max_{e_i} \pi_M = \max_{e_i} \{ e_i v_i - 2k_i e_i^2 - (c_i - a_i) \}.
\]
we suppose the manufacturer only sources from an internal supplier, and the profit is corresponding optimal value
\[ \pi_i^* = \sqrt{i^2 - 8k_i(M-a_i)}, \]

The Lagrange function is
\[ L = \frac{\nabla^2 - 8k_i(M-a_i)}{4k_i} \]

By considering the optimal solution is \( \pi^* = \frac{\sqrt{4}}{4k_i} \). In addition, (7) represents \( v^2 - 8k_i(M-a_i) \geq 0 \), and we have \( a_i = M - \frac{v^2}{8k_i} \).

The optimal value of \( e_i \) without any constraints in the manufacturer’s problem is
\[ e_i = \frac{\sqrt{v_i}}{4k_i}. \]

1. If \( \frac{v_i}{4k_i} \geq \sqrt{\frac{v_i}{k_i}} \), then \( e_i = \frac{v_i}{4k_i} \) satisfies \( e_i \in [\frac{v_i}{4k_i} - \frac{\sqrt{v_i^2 - 8k_i(M-a_i)}}{4k_i}, \frac{v_i}{4k_i} + \frac{\sqrt{v_i^2 - 8k_i(M-a_i)}}{4k_i}] \).

When \( M - \frac{v^2}{8k_i} \leq a_i \leq \frac{v^2}{8k_i}, \pi_S \geq 0, \pi_M \geq 0 \) are obtained, so the optimal solution is \( e_i^* = \frac{v_i}{4k_i} \).

2. If \( \frac{v_i}{4k_i} < \sqrt{\frac{v_i}{k_i}} \), i.e., \( a_i > \frac{v^2}{8k_i} \), then we need to examine whether \( \sqrt{\frac{v_i}{k_i}} \) is in the upper and lower bounds of \( e_i \). Case 1. If \( \sqrt{\frac{v_i}{k_i}} \leq \frac{v_i}{4k_i} + \frac{\sqrt{v_i^2 - 8k_i(M-a_i)}}{4k_i} (\text{or, equivalently, when } a_i \geq \frac{v^2 - v_i \sqrt{v_i^2 - 4k_i}}{2k_i} - M) \), then the boundary solution \( e_i = \sqrt{\frac{v_i}{k_i}} \) is the optimal solution. We can get \( \pi_S = k_i e_i^2 - a_i + W = W, \pi_M = v_i \sqrt{\frac{v_i}{k_i}} - M - a_i + E \geq 0 \) accordingly. Case 2.

If \( \sqrt{\frac{v_i}{k_i}} > \frac{v_i}{4k_i} + \frac{\sqrt{v_i^2 - 8k_i(M-a_i)}}{4k_i} \), equivalently, when \( a_i < \frac{v^2 - v_i \sqrt{v_i^2 - 4k_i}}{2k_i} - M \), combining \( a_i < M - \frac{v^2}{8k_i} \), we conclude that there is no feasible solution for the manufacturer’s profit when \( a_i < \max(M - \frac{v^2}{8k_i}, \frac{v^2 - v_i \sqrt{v_i^2 - 4k_i}}{2k_i} - M) \).

Therefore, we can substitute the value of \( e_i^* \) into the corresponding equation and obtain the values of the other variables.

The proof of Equation (14).

The optimal problem for the green supplier is respectively as follows:

Maximise \( \pi_{S} \) subject to \( t_i(1 - \theta_i c_i) e_{i,c} + t_i(1 - e_{i,c}) \leq T_i \).

The Lagrange function is \( L(e_{i,c}) = \pi_S + \lambda \cdot [(t_i - \theta_i c_i) e_{i,c} + t_i(1 - e_{i,c}) - T_i], \) where \( \lambda \geq 0 \) is the Lagrange multiplier. The condition \( (t_i - \theta_i c_i) e_{i,c} + t_i(1 - e_{i,c}) \leq T_i \) is non-holonomic because its dependence. Therefore, we can only guarantee that \( \lambda [(t_i - \theta_i c_i) e_{i,c} + t_i(1 - e_{i,c}) - T_i] = 0, (t_i - \theta_i c_i) e_{i,c} + t_i(1 - e_{i,c}) - T_i = 0 \) cannot be directly obtained. Therefore, we can obtain the Karush–Kuhn–Tucker condition

\[
\begin{align*}
& \frac{\partial L}{\partial e_{i,c}} = p_i - c_i(1 + r_{i,c}) + a_i - 2k_i e_{i,c} - \lambda \theta_i c_i = 0 \\
& \lambda [(t_i - \theta_i c_i) e_{i,c} + t_i(1 - e_{i,c}) - T_i] = 0 \\
& \lambda \geq 0
\end{align*}
\]

1. When \( \lambda = 0, (t_i - \theta_i c_i) e_{i,c} + t_i(1 - e_{i,c}) \leq T_i, e_{i,c}^* = \frac{p_i + \sqrt{v_i^2 - 8k_i(M-a_i)}}{4k_i}. \)
\[ (2) \quad \text{When } \lambda > 0, (t_i - \theta_i c_i) e_{i,\lambda} + t_i (1 - e_{i,\lambda}) = T_i e_{i,\lambda}^* = \frac{h_i - T_i}{\theta_i c_i}. \]

Therefore,

\[ e_{i,\lambda}^* = \begin{cases} p_i + \sqrt{\frac{p_i^2 - 8 k_i (M - a_i)}{4k_i}} & T_i \geq T_i^G \smallskip \\
\frac{1 - T_i}{\theta_i c_i} & T_i < T_i^G \end{cases} \]

where \( T_i^G = t_i - \frac{(p_i + \sqrt{p_i^2 - 8 k_i (M - a_i)}) \theta_i c_i}{\theta_i c_i} \).

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