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Optimal Financing Strategy in a Green Supply Chain with Capital Constraint and Yield Uncertainty

Abstract. *Green innovation has become the focus of sustainable development and green supply chain transformation. However, the limited capital available and uncertain yield prevent the green supply chain from investing in green technologies. This paper focuses on capital constraint and yield uncertainty, and constructs a green supply chain to investigate the optimal financing strategies of the manufacturer and supplier under the bank credit and trade credit modes. The results show that the green innovation level under the trade credit mode is consistently higher than that under the bank credit mode. However, the optimal financing strategies of the manufacturer and supplier, who are profit-driven, depend on the manufacturer's initial capital and the relationship between the interest rate of bank credit and trade credit. Although the manufacturer's initial capital plays a crucial role in determining the financing strategies of the green supply chain and eases the manufacturer's funding pressure, there exists an upper bound. Interestingly, keeping a low initial capital can increase profits for all firms in the green supply chain, thus leading to a win-win situation under the trade credit mode.*

Keywords: *green supply chain, capital constraint, yield uncertainty, bank credit, trade credit, game theory.*

JEL Classification: C70, D80, G20.

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1. Introduction

The increasing concern about sustainable development, especially the environmental damage caused by industrial activities, has exerted severe pressure on firms (Ranjbar et al., 2023). Green innovation has emerged as a vital measure for overcoming resource and environmental constraints, thereby promoting sustainable industrial development. (Huang et al., 2024). To improve resource efficiency and enhance competitiveness, a large number of firms in the green supply chain (GSC) attempt to upgrade green technologies to achieve green transformation. For example, PepsiCo (*pepsico.com*) designs and produces the first low-carbon version of the Pepsi bottle, which achieves a full supply chain of low-carbon products from production to recycling. BYD (*bydglobal.com*) develops the blade battery for new energy vehicles, which effectively reduces carbon emissions in the automobile supply chain (Feng et al., 2024). Therefore, how to effectively promote green innovation has been an urgent issue in addressing the environmental problems of industrial activities.

Although green innovation is vital to achieve sustainable development and promote GSC transformation (Fan et al., 2024). However, the limited capital available for the GSC to upgrade green innovation technologies is an obstacle to achieving green transformation (Wu et al., 2023). When the manufacturer faces capital constraint, financing from the bank is a common way to solve the capital problem (Zhang et al., 2016). Under the bank credit mode, the manufacturer first applies for loans from the bank to purchase parts of green product before ordering from suppliers. Then the manufacturer produces and processes green products with green innovation technologies and sells green products to consumers. Finally, the manufacturer repays the previous loans at a certain interest rate of the bank credit. In practice, the Foxconn obtained a loan of CNY 300 million from the Agricultural Bank of China in 2017, which supports the construction of green building projects of green transformation. Furthermore, financing from other members of the GSC is increasingly effective in addressing the production problems of capital-constrained manufacturers. For example, the BYD developed a supply chain finance platform "Dilink", to provide financing services to capital constrained enterprises within the supply chain. Additionally, when the manufacturer faces capital constraint under the trade credit mode, other members of GSC (e.g., supplier or retailer) are usually willing to provide capital with an interest rate of trade credit to the manufacturer to support green products' production because firms realise that increasing cooperation within the supply chain can greatly improve their competitiveness (Li et al., 2022).

Such green innovation may also significantly hamper the ability of GSC to navigate because of yield uncertainty (Chen et al., 2022). The introduction of green innovation technologies has impact on the manufacturer's production (e.g., the changes in production plans, fluctuations in workforce capacity, and high risk of mechanical damage), which leads the actual outputs that deviate from the initial expected outputs (Qu et al., 2024), i.e., the actual quantity the manufacturer produces may be lower than the expected quantity planned before. In particular, under the

circumstance of yield uncertainty, the manufacturer, who focuses on maximising profits, makes decisions in the GSC involving green innovation, which further increases the concerns and difficulty of upgrading green transformation.

In this paper, we consider a circumstance of capital constraint and yield uncertainty and develop a GSC to explore the optimal financing strategies. Correspondingly, we tend to investigate the following questions: (1) Under two different credit modes, how do the manufacturer and supplier determine the optimal financing strategies for their profit maximisation? (2) How do the unit production cost, green innovation cost, manufacturer's initial capital as well as production's fluctuating level affect the optimal decisions of the manufacturer and supplier? (3) What conditions enable the manufacturer and supplier in the GSC to be naturally aligned, and then resulting in a win-win situation? To address the aforementioned questions, it is a Stackelberg game model that this paper constructs under the bank credit and trade credit modes, respectively. Based on two different credit modes, the optimal financing strategies of the manufacturer and the supplier in GSC are analysed. Furthermore, this paper also investigates the sensitivity analyses of key parameters, including the unit production cost, green innovation cost, manufacturer's initial capital and production's fluctuating level. From the perspective of the manufacturer and supplier, the optimal financing decisions and profits are also obtained, which can help firms in the GSC determine their optimal financing strategies while enhancing their own competitiveness and promoting sustainability.

This work reveals the innovation points to the relevant research in three aspects. First, the existing literature on supply chain finance is mostly discussed under the circumstance of deterministic supply. However, green innovation is bound to complicate the production process so that firms prudently take into account the yield uncertainty. Thus, this paper considers uncertain yield. Under two different credit modes, the optimal financing strategies of firms in GSC can be obtained so that firms facing capital constraint and yield uncertainty are able to support the production of green products.

Second, the sensitivity analyses of key parameters are investigated to acquire the optimal decisions and financing strategies of the manufacturer and supplier in the GSC. Note that the GSC's financing decisions are independent of the manufacturer's initial capital under two credit modes, whereas it is essential for confirming the financing strategies of firms in GSC.

Third, this paper further designs a financing framework for the GSC. The initial capital owned by the manufacturer can ease the funding pressure, but it is not conducive to increasing profits. Keeping a low level of initial capital under the trade credit mode not only benefits the manufacturer, but also results in a win-win situation, which provides theoretical support for capital-constrained firms and contributes to the GSC transformation.

The rest of this paper is arranged as follows. Section 2 reviews the relevant current literature. Section 3 describes our model formulation. Comparisons between two different credit modes are in Section 4. Section 5 provides the numerical analysis to validate the feasibility of our model. Section 6 elucidates conclusions and managerial insights.

2. Literature review

The relevant research mainly involves three literature streams (1) green supply chain, (2) supply chain finance, and (3) yield uncertainty. First, many scholars examine the green supply chain including pricing decisions, the government subsidy applied to GSC, consumers' green preference and other behaviours in the GSC. Besides, green innovation is also the research focus of GSC. For instance, Xie et al. (2019) analyse the interactions between firm's financial performance and green technology improvement, which shows that upgrading the green technology in process and product areas can optimise the firm's financial performance. Chai et al. (2024) investigate how process innovation strategies affect green products. They show that the cooperative remanufacturing strategy benefits the supplier but hurts the manufacturer, whereas introducing government subsidies can achieve Pareto improvement. Huang et al. (2024) investigate the collaborative strategy of green innovation technologies in the GSC, they discover that the willingness of collaborative innovation increases with the green innovation capability.

Second, our paper also belongs to a topic of recent research on supply chain finance. There exist two financing modes in the supply chain, i.e., external and internal credit finance (Zhang et al., 2024). The majority of the external credit financing research focuses on bank credit finance. For instance, Zhang et al. (2016) examine the financing equilibriums in a supply chain considering risk aversion and capital constraint and then determine the optimal ordering and pricing under the bank credit mode. In contrast, the internal trade credit mode is regarded as a vital means to coordinate the whole supply chain (Zhang et al., 2017). Yan et al. (2020) analyse the strategic dual-channel pricing decisions in a supply chain with online and offline channels. The e-retailer who provides financing services to the capital-constrained supplier can not only ease upstream funding pressure, but also expand the own market share. Furthermore, due to the advantages and characteristics of different credit modes, many scholars have compared different financing strategies. Ma and Li (2023) analyse the influence of credit modes including bank credit and trade credit on remanufacturing decisions of the supply chain under different remanufacturing modes.

The third stream involves yield uncertainty. Yield uncertainty implies that the actual output deviates from the expected output, and this output with the investment in innovation technologies is usually lower than the expected output (Huang & Huang, 2024). Cai et al. (2017) compare the option and subsidy contracts under the VMI supply chain and show that the supply chain's performance can be improved by the introduction of the replenishment tactic under the option contract mode. Li et al. (2017) develop a game model considering uncertain yield and demand, and analyse the impact of yield stochastic volatility, demand uncertainty, and relevant parameters on firms' performances and operational strategies of the supply chain. Especially in the GSC, the green transformation with green innovation technologies makes the yield uncertainty increasingly concerned. Zou et al. (2021) consider the manufacturer facing yield uncertainty in the emission-dependent supply chain and

show that the uncertain yield hurts the firms' profits. Additionally, Chen et al. (2024) find that the adverse effect caused by the yield uncertainty can be effectively alleviated in the GSC when the retailer shoulders corporate social responsibility.

However, the previous research has focused on the optimal financing strategies of GSC under deterministic circumstances, but without considering the impact of uncertain yield on financing strategies. Additionally, there exists little supply chain financing research on two different credit modes, i.e., bank credit and trade credit, especially considering capital constraint and yield uncertainty. However, our work fills these gaps. (1) This paper analyses the financing decision-making problem of green products in the GSC with capital constraint and yield uncertainty, which deeply promotes green innovation of the GSC and expands the theoretical research on GSC. (2) This paper focuses on the key parameters, including the green innovation cost, unit production cost, manufacturer's initial capital and production's fluctuating level, which identifies the key factors influencing optimal financing strategies for members within the GSC. (3) This paper provides theoretical support for promoting the green transformation in the GSC. The optimal financing strategies under the bank credit and trade credit modes are obtained for the manufacturer and supplier, which further enhance competitiveness and promote GSC's sustainable development.

3. Model description

Consider a GSC that consists of a manufacturer (he, denoted by M) and a supplier (she, denoted by S). The stakeholders mentioned above depend on each other to create value together in the GSC (Bart et al., 2021). In this GSC, the supplier provides parts of the green product to the manufacturer, and he produces and processes the products and sells to consumers. However, the manufacturer faces capital constraint and yield uncertainty. On the one hand, the manufacturer takes a production risk and fails to process all the parts into finished products due to the application of green technology (Lin & Xu, 2024). On the other hand, the initial capital that the manufacturer holds is inadequate to sustain his production, thus he has to borrow from the bank (supplier) and repay the loans with the interest rate of bank (trade) credit. All firms in GSC are risk-neutral and make decisions to maximise their profits.

Let c represents the supplier's unit production cost. The available green products are $q\chi$, where q denotes the quantity ordered from the supplier, where the wholesale price is w. The random productivity of the manufacturer χ is a non-negative continuous random variable with a mean 1 and a variance σ (Cong et al., 2020). A large σ denotes that the investment in green technology has a high uncertainty about the production of green products. In line with (Cong et al., 2024), the inverse demand function is $p = a - q\chi + g$, where a represents basic market demand, and g represents green innovation level. The manufacturer's green innovation cost is $kg^2/2$ (Cao et al., 2019). The manufacturer's initial capital is B, which constrains $B < wq$

that he has to adopt a financing strategy to support his production. Under the bank (trade) credit mode, the manufacturer borrows capital $wq - B$ from the bank (supplier) before the production season and finally repay the loans with the interest rate of the bank (trade) credit r_B (r_T), wherein the interest rates of bank credit and trade credit r_B, r_T are exogenous.

The two stakeholders of GSC engage in a Stackelberg game, with the supplier acting as the leader and the manufacturer acting as the follower. Accordingly, the timeline of the model is as follows. The supplier first announces a wholesale price w before the production process, and then the follower, the manufacturer simultaneously determines the order quantity q and green innovation level g. In this stage, the capital-constrained manufacturer has to adopt the financing strategy (i.e., bank credit or trade credit) to support his production of green products. The manufacturer's selling quantity is $q\chi$, and he finally sells the products to consumers at a retail price p. Subsequently, the manufacturer should repay the loans with the interest rate of bank credit or trade credit.

3.1 Bank credit

In the GSC under the bank credit mode, the manufacturer with capital constraint borrows from the bank with the interest rate of bank credit r_B to support his production of green products, which is denoted by subscript "B". It can follow the same principle to solve the wholesale price w_B, the order quantity q_B and the green innovation level g_B in the GSC. The structure of GSC under the bank credit mode is shown in Figure 1.

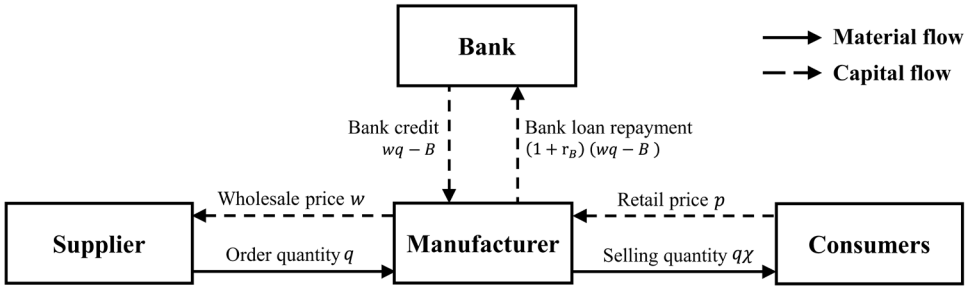

Figure 1. The structure of GSC under the bank credit mode
Source: Authors' own creation.

Based on backward induction, the order quantity q_B and the green innovation level g_B are solved by the manufacturer at the first stage. The excepted profit of the manufacturer is:

$$\pi_M^B = E\left[pq_B\chi - B - \left(w_B q_B - B\right)\left(1 + r_B\right) - kg_B^2/2 \right] \quad (1)$$

Given the supplier's wholesale price, the optimal order quantity q_B^* and green innovation level g_B^* of the manufacturer are $q_B^* = k\left[a-\left(1+r_B\right)w\right]/\left[2\left(1+\sigma\right)k-1\right]$, $g_B^* = \left[a-\left(1+r1\right)w\right]/\left[2\left(1+\sigma\right)k-1\right]$.

Additionally, the supplier is the leader in GSC. The expected of the supplier is as follows:

$$\pi_S^B = E\left[\left(w_B - c\right)q_B\right] \tag{2}$$

Through the above solution process, the supplier first announces the wholesale price. Then the manufacturer determines the order quantity and green innovation level. Thus, the optimal variables of the GSC under the bank credit mode are presented in Proposition 1.

Proposition 1. *When the manufacturer and supplier participate in the GSC under the bank credit mode, the optimal order quantity* q_B^{**} *and green innovation level* g_B^{**} *of the manufacturer, the optimal wholesale price* w_B^{**} *of the supplier and their expected profit are* $q_B^{**} = \dfrac{\left[a-c\left(1+r_B\right)\right]k}{4\left(1+\sigma\right)k-2}$, $g_B^{**} = \dfrac{a-c\left(1+r_B\right)}{4\left(1+\sigma\right)k-2}$, $w_B^{**} = \dfrac{a+\left(1+r_B\right)c}{2\left(1+r_B\right)}$, $\pi_M^B\left(q_B^{**}, g_B^{**}\right) = \dfrac{\left[a-\left(1+r_B\right)c\right]^2 k + 8\left[2\left(1+\sigma\right)k-1\right]Br_B}{16\left(1+\sigma\right)k-8}$, $\pi_S^B\left(w_B^{**}\right) = \dfrac{k\left[a-\left(1+r_B\right)c\right]^2}{4\left[2\left(1+\sigma\right)k-1\right]\left(1+r_B\right)}$.

Moreover, it is the green products that are produced and possessed by manufacturer and supplier with optimal decisions that the GSC must hold $2k\left(1+\sigma\right)-1>0$. Furthermore, the corollary can be obtained as follows.

Corollary 1. *Under the bank credit mode, the impacts of the interest rate of bank credit on the equilibrium decisions: (1)* $\dfrac{\partial q_B^{**}}{\partial r_B}<0$, $\dfrac{\partial g_B^{**}}{\partial r_B}<0$, $\dfrac{\partial w_B^{**}}{\partial r_B}<0$; *(2)* $\dfrac{\partial \pi_S^B\left(w_B^{**}\right)}{\partial r_B}<0$, $\dfrac{\partial \pi_M^B\left(q_B^{**}, g_B^{**}\right)}{\partial r_B}<0$ *if* $B<\dfrac{k\left[a-\left(1+r_B\right)c\right]c}{8\left(1+\sigma\right)k-4}$, *and* $\dfrac{\partial \pi_M^B\left(q_B^{**}, g_B^{**}\right)}{\partial r_B}>0$ *otherwise.*

Corollary 1 denotes that the manufacturer's optimal order quantity, green innovation level and supplier's wholesale price decrease with the interest rate of bank credit, which shows that the interest rate of bank credit is essential for determining optimal decisions of the manufacturer and supplier. Thus, the expected profit of the supplier also monotonously decreases with the interest rate of it. However, it is only when his initial capital remains relatively low that the expected profit of the

manufacturer decreases with the interest rate of it. The intuition is that the manufacturer has so sufficient capital that he can reduce bank loans to maintain their production, and a lower wholesale price caused by the increase of the interest rate of bank credit makes him grab more profit.

Corollary 2. *Under the bank credit mode, the impacts of other key factors on the equilibrium decisions: (1)* $\frac{\partial g_B^{**}}{\partial k}<0$, $\frac{\partial \pi_S^B\left(w_B^{**}\right)}{\partial k}<0$, $\frac{\partial \pi_M^B\left(q_B^{**},g_B^{**}\right)}{\partial k}<0$; *(2)* $\frac{\partial g_B^{**}}{\partial c}<0$, $\frac{\partial \pi_S^B\left(w_B^{**}\right)}{\partial c}<0$, $\frac{\partial \pi_M^B\left(q_B^{**},g_B^{**}\right)}{\partial c}<0$; *(3)* $\frac{\partial g_B^{**}}{\partial B}=0$, $\frac{\partial \pi_S^B\left(w_B^{**}\right)}{\partial B}=0$, $\frac{\partial \pi_M^B\left(q_B^{**},g_B^{**}\right)}{\partial B}>0$; *(4)* $\frac{\partial g_B^{**}}{\partial \sigma}<0$, $\frac{\partial \pi_S^B\left(w_B^{**}\right)}{\partial \sigma}<0$, $\frac{\partial \pi_M^B\left(q_B^{**},g_B^{**}\right)}{\partial \sigma}<0$.

Corollary 2 shows the impact of the green innovation cost coefficient, unit production cost, manufacturer's initial capital and production's fluctuating level on optimal decisions in the GSC. The optimal decisions monotonously decrease with the green innovation cost coefficient, the unit production cost, and production's fluctuating level. For instance, Suzhou Everbright Photonics Co., Ltd., the enterprise's profit has increased positively by 31.26% due to an enhancement in the yield rate from 94.97% to 96.70%, which is consistent with this negative monotonicity of manufacturer and supplier's profits with respect to production's fluctuating level. However, the green innovation level as well as the expected profit of the supplier are independent of the initial capital owned by the manufacturer under the bank credit mode, whereas the expected profit of the manufacturer increases with it.

3.2 Trade credit

In the GSC under the trade credit mode, the capital-constrained manufacturer borrows from the supplier with the interest rate of trade credit r_T to support his production of green products, which is denoted by subscript "T". The backward induction is also used to solve optimal wholesale price w_T , order quantity q_T and green innovation level g_T in the GSC. The structure of GSC under the bank credit mode is shown in Figure 2.

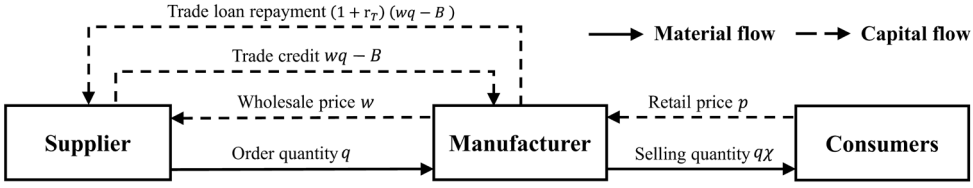

Figure 2. The structure of GSC under the trade credit mode
Source: Authors' own creation.

It can follow the same principle to determine the optimal decisions in bank credit mode. The order quantity q_T, green innovation level g_T and wholesale price w_T are solved by backward induction. The excepted profits of firms in GSC are:

$$\pi_M^T = E\left[pq_T\chi - B - \left(w_T q_T - B\right)\left(1+r_T\right) - kg_T^2/2 \right] \tag{3}$$

$$\pi_S^T = E\left[B + \left(w_T q_T - B\right)\left(1+r_T\right) - cq_T \right] \tag{4}$$

Through the above solution process, the supplier first announces her wholesale price. Then the manufacturer decides order quantity and green innovation level. The optimal variables of the GSC under the trade credit mode are presented in Proposition 2.

Proposition 2. *When the manufacturer and supplier participate in GSC under the trade credit mode, the optimal order quantity* q_T^{**} *and green innovation level* g_T^{**} *of the manufacturer, the optimal wholesale price* w_T^{**} *of the supplier, and their expected profits are* $q_T^{**} = \dfrac{\left(a-c\right)k}{4\left(1+\sigma\right)k-2}$, $g_T^{**} = \dfrac{a-c}{4\left(1+\sigma\right)k-2}$, $w_T^{**} = \dfrac{a+c}{2\left(1+r_T\right)}$, $\pi_M^T\left(q_T^{**}, g_T^{**}\right) = \dfrac{\left(a-c\right)^2 k + 8\left[2\left(1+\sigma\right)k-1\right]Br_T}{16\left(1+\sigma\right)k-8}$ $\pi_S^T\left(w_T^{**}\right) = \dfrac{\left(a-c\right)^2 k + 4\left[2\left(1+\sigma\right)k-1\right]Br_T}{8\left(1+\sigma\right)k-4}$.

Moreover, to ensure that the green products can be produced and possessed by the manufacturer and supplier, the GSC must hold $2k\left(1+\sigma\right)-1>0$. Furthermore, the corollary can be obtained as follows.

Corollary 3. *Under the trade credit mode, the impacts of the interest rate of trade credit on the equilibrium decisions: (1)* $\dfrac{\partial q_T^{**}}{\partial r_T} = 0$, $\dfrac{\partial g_T^{**}}{\partial r_T} = 0$, $\dfrac{\partial w_T^{**}}{\partial r_T} < 0$*;*

(2) $\dfrac{\partial \pi_S^T\left(w_T^{**}\right)}{\partial r_T} < 0$, $\dfrac{\partial \pi_M^T\left(q_T^{**}, g_T^{**}\right)}{\partial r_T} > 0$.

Corollary 3 denotes that the manufacturer's optimal order quantity and green innovation level remain unaffected by the interest rate of trade credit, but the supplier's wholesale price is decreasing function of it. The intuition is that trade credit is only a capital transfer between the firms in the GSC. Thus, the manufacturer's optimal decisions are the same as the optimal decisions without capital constraint. However, the increasing interest rate of trade credit cannot increase and even hurts the profit of the supplier. The result implies that although the increase in interest rate of trade credit may bring enough payoffs to the supplier, she simultaneously formulates a low wholesale price to incentivise the manufacturer to purchase parts of green products. Under this circumstance, the incremental profit of a high interest rate under the trade credit never compensates for the loss caused by the sudden drop in wholesale price, so the supplier's profit also decreases with the interest rate of the trade credit. In contrast,

it is when the supplier fixes a higher interest rate of trade credit that the manufacturer can benefit from lower wholesale prices.

Corollary 4. *Under the trade credit mode, the impacts of other key factors on the equilibrium decisions: (1)* $\frac{\partial g_T^{**}}{\partial k}<0$, $\frac{\partial \pi_S^T\left(w_T^{**}\right)}{\partial k}<0$, $\frac{\partial \pi_M^T\left(q_T^{**},g_T^{**}\right)}{\partial k}<0$; *(2)* $\frac{\partial g_T^{**}}{\partial c}<0$, $\frac{\partial \pi_S^T\left(w_T^{**}\right)}{\partial c}<0$, $\frac{\partial \pi_M^T\left(q_T^{**},g_T^{**}\right)}{\partial c}<0$; *(3)* $\frac{\partial g_T^{**}}{\partial B}=0$, $\frac{\partial \pi_S^T\left(w_T^{**}\right)}{\partial B}<0$, $\frac{\partial \pi_M^T\left(q_T^{**},g_T^{**}\right)}{\partial B}>0$; *(4)* $\frac{\partial g_T^{**}}{\partial \sigma}<0$, $\frac{\partial \pi_S^T\left(w_T^{**}\right)}{\partial \sigma}<0$, $\frac{\partial \pi_M^T\left(q_T^{**},g_T^{**}\right)}{\partial \sigma}<0$.

Corollary 4 demonstrates the same as the impacts of the green innovation cost coefficient, the supplier's unit production cost and the production's fluctuating level on optimal decisions under the bank credit mode. Furthermore, the green innovation level is also independent of the manufacturer's initial capital. The expected profit of the manufacturer increases with his initial capital, but the expected profit of the supplier decreases with it, which demonstrates that the manufacturer's initial capital is critical for making optimal decisions in the GSC.

4. Comparative Analysis

In the field of supply chain finance, both bank credit and trade credit have been applied in practice. In order to improve the competitiveness of the GSC and promote sustainable development, we explore the optimal financing strategy of GSC with capital constraint and yield uncertainty. Based on the above analyses of the optimal decisions under the two financing credits of the manufacturer and supplier, the optimal financing strategies of the GSC are further discussed by comparing different interest rate relationships, where $B_1=kr_B\left[a^2-\left(1+r_B\right)c^2\right]\Big/\left\{4r_T\left(1+r_B\right)\left[2\left(1+\sigma\right)k-1\right]\right\}$, $B_2=ckr_B\left(2a-2c-r_B\right)\Big/\left\{8\left(r_B-r_T\right)\left[2\left(1+\sigma\right)k-1\right]\right\}$.

Proposition 3. *When two interest rates of bank credit and trade credit remain equal ($r_B=r_T$), (1) For the supplier, the optimal financing strategy is to enable trade credit when $B\le B_1$ and bank credit otherwise; (2) For the manufacturer, the optimal green innovation level and higher profit can be obtained under the trade credit than that under the bank credit.*

Proposition 3 highlights the optimal decisions and financing strategy of the firms in GSC when two interest rates of bank credit and trade credit are equal. Specifically, when the manufacturer's initial capital is on the low side ($B\le B_1$), the expected profit of the supplier under the trade credit mode remains higher than that under the bank credit mode. In contrast, the supplier can extract higher expected profit under the bank credit while the manufacturer holds sufficient initial capital ($B>B_1$). The intuition is that the low initial capital tends to be a strict capital constraint, and thus he has to fill

this funding gap through the financing strategy. This incremental profit under the trade credit mode can be captured by the supplier, so that it seems more beneficial for the supplier to operate under the trade credit at a low level of the initial capital. Furthermore, the manufacturer can improve higher green innovation level and obtain higher profits from green products under the trade credit mode. Compared to the bank credit, the manufacturer can purchase the parts from the supplier at a lower wholesale price because the trade credit can be seen as a capital transfer within the GSC.

Proposition 4. *When the interest rate of bank credit is greater than the interest rate of trade credit ($r_B > r_T$), (1) For the supplier, the optimal financing strategy is to enable trade credit when $B \le B_1$ and bank credit otherwise; (2) For the manufacturer, the optimal green innovation level can only be obtained under trade credit mode, whereas he tends to operate under trade credit mode only when $B \le B_2$ and bank credit otherwise.*

Proposition 4 demonstrates the optimal decisions and financing strategy of the firms in GSC when the interest rate of bank credit exceeds that of trade credit. Interestingly, it is similar conclusions as Proposition 3 that the optimal financing strategy of the supplier reflects. Additionally, there exists a higher green innovation level under the trade credit mode. However, the optimal financing strategy of the manufacturer has changed and depends on his initial capital. The low initial capital allows the manufacturer to extract higher profits under trade credit mode. These observed results can be attributed to the fact that the expected profit of the manufacturer decreases with the interest rate of bank credit when his initial capital is relatively low (see Corollary 1). Once the manufacturer has high initial capital to operate at a higher interest rate of bank credit, it decreases green products' wholesale price and thus enables the manufacturer to generate enough incremental profits.

Proposition 5. *When the interest rate of bank credit is less than the interest rate of trade credit ($r_B < r_T$), (1) For the supplier, the optimal financing strategy is to enable trade credit when $B \le B_1$ and bank credit otherwise; (2) For the manufacturer, the optimal green innovation level and higher profit can be achieved under the trade credit than that under the bank credit.*

Proposition 5 shows the optimal decisions and financing strategy of the firms in GSC when the interest rate of bank credit is lower than that of trade credit. Interestingly, all firms' financing strategy reflects similar conclusions as Proposition 3. The reason for these results is that the reduction of interest rate under bank credit mode reduces the operating cost of the manufacturer, but its incremental profit is not superior to that under the trade mode. On the one hand, the green innovation level can be optimised under trade credit mode in GSC. On the other hand, the incremental profit of a higher selling quantity cannot cover the higher ordering cost of green products for the manufacturer as the wholesale price of green products decreases with the interest rate of the bank credit, while the ordering quantity increases with it. In contrast, under trade credit mode, the manufacturer can generate enough profit at a low wholesale price although he has to bear a higher interest rate under this circumstance, where the selling quantity and green innovation level are independent of the interest rate of trade

credit. For the supplier, the trade-off between the interest rate of trade credit and her wholesale price weakens this association between the interest rate and the supplier's profit. Thus, the manufacturer's initial capital is essential for determining the supplier's optimal strategy in GSC. Specifically, the supplier tends to operate under the trade credit when the initial capital is on the low side and under the bank trade credit otherwise.

5. Numerical Analysis

In order to verify the feasibility of our model, a numerical analysis is introduced to explore the relationship between relevant parameters and optimal decisions in the GSC under both two credit modes. Management insights can be obtained by related companies in the GSC based on their statistics in practice. According to the quantization condition and actual situation (Cao et al., 2019; Cong et al., 2020; Huang et al., 2024), the specific parameters of the manufacturer and supplier in the GSC can be determined and set to $a=20$, $B=5$, $c=8$, $k=3$, $\sigma=2$, $r_B=r_T=0.3$.

Figure 3 reveals the sensitivity analyses of the green innovation level, the expected profit of the firms in GSC to the green innovation cost coefficient and unit production cost under bank credit and trade credit modes. It clearly illustrates that the green innovation level and the expected profits of the firms in the GSC decrease with green innovation cost and supplier's unit production cost, respectively. Moreover, the most effective measures for improving firms' behaviour and efficiency in GSC can be provided by comparing the results of two different credit modes. Although reducing green innovation cost can significantly improve the green innovation level, it has no significant boost on firms' profits. Therefore, the GSC focuses more on reducing the unit production cost of green products to extract more payoffs. In order to effectively promote sustainable development and GSC transformation, the exogenous green subsidy (e.g., government) should be implemented to incentivise firms including the manufacturer and supplier to update the green technology and produce products with a high green innovation level.

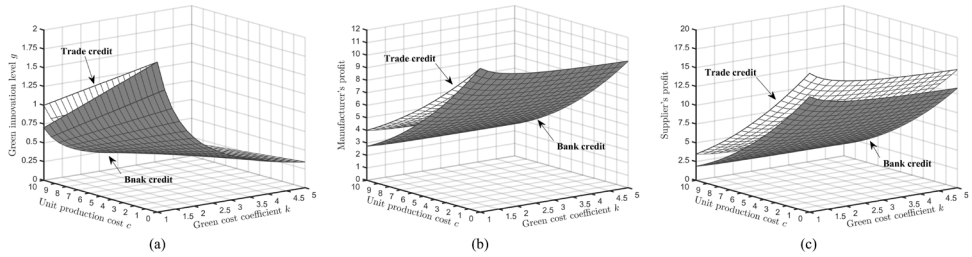

Figure 3. Impacts of green cost coefficient and unit production cost on (a) green innovation level, (b) manufacturer's profit, and (c) supplier's profit

Source: Authors' own creation.

Figure 4 illustrates the sensitivity analyses of the green innovation level, the expected profit of the firms in GSC to the manufacturer's initial capital and production's fluctuating level under two different credit modes. Specifically, the green innovation level remains independent of the initial capital but decreases with the fluctuating level of green products' production. The initial capital of the manufacturer reflects the financial capacity in the production of green products, which cannot affect their optimal decisions in the GSC. However, the high initial capital the manufacturer holds means that he borrows fewer loans to support his production, and thus the surplus that would otherwise be used to repay the interest of bank or trade credit can gain extra profits for the manufacturer. Therefore, the increase of initial capital exerts a negative influence on the expected profit of the manufacturer and supplier. Additionally, the green innovation level and the expected profits of the firms in GSC decrease with the production's fluctuating level, respectively. A lower production fluctuating level is beneficial for all firms in the GSC. Thus, the manufacturer should cooperate with the supplier in forecasting market fluctuations accurately to reduce the loss of their payoffs caused by high production's fluctuating level.

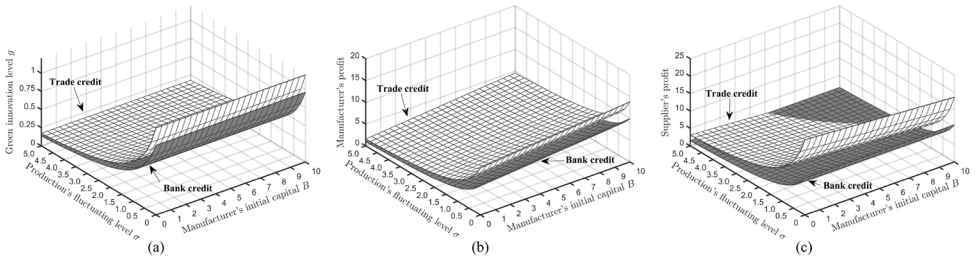

Figure 4. Impacts of initial capital and production's fluctuating level on (a) green innovation level, (b) manufacturer's profit, and (c) supplier's profit
Source: Authors' own creation.

Figure 5 verifies the optimal green innovation level and financing strategy of the firms in GSC with capital constraint and yield uncertainty. Correspondently, the green innovation level under trade credit mode is consistently higher than that under bank credit mode. However, firms' optimal financing strategies in GSC depend on the manufacturer's initial capital, the relationship between the interest rate of two credits. Specifically, when the interest rate of the bank credit remains lower than (equal to) that of trade credit, the manufacturer is inclined to operate under the trade credit mode regardless of his initial capital. Furthermore, when the interest rate of the bank credit exceeds that of trade credit, the manufacturer is inclined to operate under the trade credit mode only if his initial capital is on the low side. For the supplier, the manufacturer's initial capital serves as a key parameter for her financing strategy. Namely, it is rather than interest rates under two credit modes that the supplier's optimal financing strategy significantly depends on the manufacturer's initial capital, which only indirectly affects the threshold of the manufacturer's initial capital while it has little influence on the supplier's optimal decisions. Interestingly, we find that only

when the manufacturer's initial capital is relatively low (i.e., $B \le min\{B_1, B_2\}$), the optimal financing strategies of whole GSC can be naturally aligned and lead to a win-win situation, which means that all firms in the GSC not only achieve higher expected profits at an optimal green innovation level.

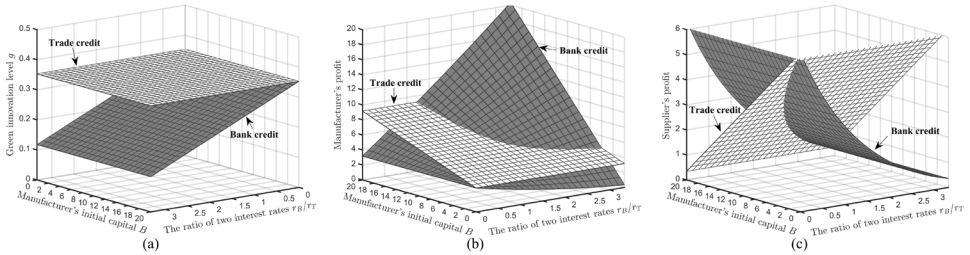

Figure 5. Impacts of the interest rate of bank credit and trade credit on (a) green innovation level, (b) manufacturer's profit, and (c) supplier's profit
Source: Authors' own creation.

6. Conclusions

Green transformation has been increasing to the strategic level of firms, whereas the introduction of green innovation technologies may lead to capital constraint and yield uncertainty in the GSC. This paper explores two different credit modes (i.e., bank credit and trade credit modes) in GSC that consists of a manufacturer and a supplier, where the manufacturer faces capital constraint and yield uncertainty, and he has to borrow from the bank or supplier with the interest rate of bank or trade credit to support his production of green products. The optimal financing strategies are obtained by comparing two different credit modes from the perspective of the manufacturer and the supplier, respectively. Moreover, the sensitivity analyses of the green innovation cost, unit production cost, manufacturer's initial capital and production's fluctuating level are confirmed to determine the impact of key parameters on GSC's optimal financing decisions.

This paper makes three main contributions by promoting sustainable development and GSC transformation: (1) This paper ascertains optimal financing decisions of the GSC under two different credit modes. Specifically, the green innovation level is consistently higher under trade credit than under bank credit mode. However, the financing strategies of the companies in GSC depend on the manufacturer's initial capital and the relationship between the interest of the bank and the trade credit. (2) This paper does pay attention to the impact of key parameters on optimal financing decisions of capital-constrained GSC with yield uncertainty. The green innovation level, the profits of the firms in GSC always decrease with the green innovation cost, unit production cost and production's fluctuating level. However, the impact of the manufacturer's initial capital on optimal decisions is different under two credit modes, which shows it is essential for determining firms' financing strategies in GSC. (3) The Pareto improvement for the whole GSC can be reached under the trade

credit mode. When the manufacturer's initial capital is relatively low, the optimal financing strategies of the firms in GSC under the trade credit mode are naturally aligned and lead to a win-win situation.

This paper also conveys several managerial insights as follows. With the increasing attention to sustainable development, green innovation has been the way for firms to improve resource efficiency and enhance own competitiveness. The manufacturer, especially small and medium-sized enterprises, should recognise the harm of yield uncertainty when investing in green innovation technologies. Furthermore, financing from the supplier within the GSC is also an effective way to address this financial challenge for the manufacturer facing capital constraint. Besides, all firms should strengthen cooperation within the supply chain finance and other areas, which contributes to overall performance improvement and ultimately benefits all stakeholders involved.

There also exist several limitations which are still valuable to be explored. For example, it is worth extending our model under the circumstance of both uncertain yield and demand, which may create more conflict and financial risks. Besides, this paper assumes that all firms are risk-neutral and the further research can analyse the optimal financing strategies in a GSC with risk aversion.

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