ISSN 2616-5902 Vol. 3, Issue 10: 105-118, DOI: 10.25236/AJBM.2021.031019

The Operational and Coordinated Strategies of the low carbon Supply Chain with a Loss-reluctance Under the electronic business platform Financing Service

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Abstract: We investigate the operational and coordinated strategies of a low carbon supply chain in the carbon limit and exchange market, where the capital-constrained manufacturer exhibits loss-reluctance behavior due to the uncertainty of market demand. In this paper, we calculate the greatest loan interest rate for the electronic business platform, the greatest ordering amount for the manufacturer in the decentralized system, and the greatest ordering amount for the entire supply chain in the centralized system. We design a transfer payment contract to coordinate the emission-dependent supply under the electronic business platform financing service by comparing the manufacturer's greatest ordering amount in different systems. We conclude from theoretical analyses that when the critical value of the manufacturer's self-owned capital exceeds a certain point, the greatest ordering amount of the loss-reluctance manufacturer under the electronic business platform financing service is greater than that of the well-funded manufacturer. Furthermore, when the manufacturer's self-owned capital changes within a certain range, the electronic business platform financing service can cause both an electronic business platform and a loss-reluctant manufacturer to achieve Pareto improvement, even though the electronic business platform financing service does not coordinate the supply chain, which is regulated by a carbon limit and an exchange mechanism. Furthermore, when a certain condition is met by the transfer payment contract, the lack of capital and the low carbon supply chain can achieve complete coordination.

Keywords: business platform financing; capital-constrained; supply chain coordination; loss-reluctance; transfer payment contract.

1. Introduction

In wake of the global warming, air pollution, and other environmental problems, Carbon decrease technology has become an enormous challenge for many capital-constrained enterprises. In order to effectively control the emission of carbon dioxide and all kinds of greenhouse gas, the majority of countries have established corresponding carbon emission policies, and the carbon restriction and trading mechanism become one of the effective means to decrease carbon emission and improve carbon efficiency[1-3]. In carbon trading regulation, the government takes measures to restrict enterprises that exhaust carbon dioxide into the atmosphere and only allow these enterprises to have a certain amount of carbon emission[4]. In a certain period, If the enterprise’s carbon emissions are more than a certain value, the enterprise will buy an amount of corresponding carbon prescribed carbon number from the carbon trading marketplace. Besides, when enterprises emit carbon emissions below the prescribed carbon number, the surplus prescribed carbon number can be sold in the carbon trading market. Therefore, the rights of carbon emission have become an important factor and asset during enterprise operation[5]. Meanwhile, in wake of the green consumers' low-carbon conception gradually increasing, 68% of the investigated consumers will buy products or services due to the company's reputation for social responsibilities[6,7]. Increasingly, more consumers prefer paying a higher price for environmentally-friendly products, and the improvement of the environmental performance can effectively improve consumers' pay willingness[8]. In China, the ones focused on the ecological environment prefer to charge a higher price for green products. they are willing to pay an extra charge for green products[9]. In a word, the carbon limit and exchange regulation and the improvement of the consumers’ low-carbon awareness directly affect enterprises' costs, carbon emissions, and operational decisions.

However, the miniaturized and intermediate firms usually face the problem of fund shortage in the

ISSN 2616-5902 Vol. 3, Issue 10: 105-118, DOI: 10.25236/AJBM.2021.031019

low carbon supply chain. In recent years, new retail businesses based on the electronic business platform are rapidly emerging. Most of largescale manufacturers can directly sell products by electronic business platform. Meanwhile, considering buyer's green environmental awareness, manufacturers, such as, Huawei, Dell and Gree, have used the green environmental technology to control carbon emissions in the process of producing and selling products. Under new retail model and carbon restrict and exchange policy, the miniaturized and intermediate manufacturers are usually faced with the trouble of fund shortage and difficultly obtain the loan directly from some financial institutions because they not have a good credit [10-11]. Here, the electronic business platform, as a form of trade credit financing (TCF), can provide manufacturer with a new financing channel. Traditional TCF usually expands its reputation to the partners of the whole supply chain by lending short-term loan[12]. In this paper, the electronic business platform plays an important role in process of the manufacturer's sales. In China, such as Alibaba and Jingdong Mall either run a financing business or a leasing business in practice [13]. Here, the electronic business platform has only one sales channel which the manufacturer directly sells product to consumers, and he sets two suitable decision variables for pursuing maximal profit and coordinating supply chain.

In recent years, scholars have focused on the impact of firm's risk attitudes (loss reluctance) on supply chain operation and financing decision in the supply chain[14,15]. Particularly, with consumers' awareness of low-carbon preference increases, a few scholars pay attention to loss-reluctance participants in supply chain[16]. In order to appeal to low carbon economy, it's valuable to consider the problem that the capital constrained manufacturer possessing a loss-reluctance behavior directly sell products to consumer by the electronic business platform under carbon limit and exchange mechanism. In this scenario, what's the electronic business platform's greatest financing strategy under a decentralized decision-making? What's the loss-reluctance manufacturer's greatest ordering strategy? Carbon limit and exchange regulation whether or not to affect the electronic business platform and the manufacturer's greatest strategy?

In this section, we build a model of one capital constrained manufacturer and one manufacturer, the manufacturer is loss reluctance and the manufacturer is risk-neutral, who pursue themselves maximal expected profits. Under carbon limit and exchange regulation, the government firstly provide original free carbon emission quota to capital constrained manufacturer. If carbon emission has a shortage or a remainder, carbon market permit supply chain's participants bargain freely. According to backward induction, we firstly investigate the capital constrained manufacturer's greatest ordering strategy, and then analyze the electronic business platform's greatest loan interest rate in the decentralized system. Then, we discuss the entire supply chain's greatest ordering strategy in centralized system. In addition, under the electronic business platform financing service model, when the 3PL enterprise and the retailer sign an appropriate transfer payment contract, the supply chain can achieve entire coordination.

2. Literature Review

In this section, after reading a large number of literatures, we sort out the relative literatures from the following four aspects: loss reluctance, coordinated strategies on supply chain finance (SCF) and limit and exchange mechanism.

2.1 Loss reluctance in supply chain management

Loss reluctance behavior was investigated many years, but some researches apply this concept in supply chain in recent years. For example, Herweg et al.[17] introduce the Expectation Based Loss Reluctance into newsboy model and set the rational expected profit of decision maker as a reference point, which can better describe the loss reluctance behavior of the participant. Through analyzing the expected loss reluctance newsboy model, they find that the ordering amount of the expected loss-reluctance retailer is less than the order amount of the profit maximization paradigm. Hu et al. [14] conclude revenue sharing contract can make supplier, retailer and manufacturer to achieve Pareto improvements a three level supply chain. Xu et al. [18] introduce the conditional value-at-risk maximization of risk measurement criteria into the loss-reluctance newsvendor, and its fill-rate decision was influenced by shortage costs. When the scarcity cost is ignored, the loss-reluctance newsvendor reduces the fill rate. Yan et al. [15] analyze two financing means to loss-averse retailers: loan and investment, and find that both can contribute additional value to the loss-averse store and capital-constrained supplier, resulting in a win-win situation for both parties.

After reviewing a large amount of literature, we discovered that no previous research has addressed a two-stage supply chain that consists of a capital-constrained and loss-reluctant manufacturer selling items directly through an electronic business platform. This issue is investigated in this paper.

2.2 Coordination strategies for supply chain finance

In a dual-channel supply chain, some literatures explore coordinating mechanisms. for example, Cai et al. [19] compare the effects of channel form and coordination on suppliers, retailers, and the entire supply chain in two single channels and two dual channels. They quantify the unique contract formats in different supply chains through revenue sharing contracts, and show the impact of diverse supply chain forms on the negotiation ability between supplier and retailer in coordination conditions. Li et al. [20] Investigate a risk-neutral supplier who participates directly in the market through an electronic channel and a risk-averse retailer in a dual-channel supply chain, show how a better risk-sharing contract can coordinate a dual-channel supply chain, and two supply chains' participants can achieve a win-win situation.

Some studies focus on low-carbon supply chain coordination strategies as well. For example, Xu et al. [21] looks at how consumers' low-carbon preferences and channel substitution affect decision-making and cooperation in the dual-channel supply chain. Under the Carbon Cap and Trade Act, there is a restriction on the amount of carbon that can be Improve revenue-sharing contracts to help manufacturers and merchants work together more efficiently. A better contract is presented to accomplish Pareto optimization through revenue sharing. Bai et al. [22] uses a mean variance method to compare and solve the optimization problem with and without technology investment in a two-stage supply chain with a single risk-reluctance manufacturer and a single retailer under a carbon tax policy. Ma et al. [23] under carbon limit and exchange regulation, and investigate the most effective decision-making and coordination mechanism with a third-party logistics service's fresh-keeping work in a three-level cold supply chain. Using a coordination model, all supply chain participants can benefit from Pareto improvement.

As we all know, the majority of past studies have focused on the most effective operational decision-making and coordinating procedures in dual-channel or low-carbon supply chains. However, few researchers have looked into the issue of manufacturers selling their products directly through an electronic commerce platform.

2.3. limit-and-exchange mechanism in the supply chain management

The impact of carbon emissions on operational decision-making has been studied in certain publications. Benjaafar et al. [24] firstly integrated carbon quotas into the supply chain and built a supply chain that took into account the cost of carbon emissions. They also examined how carbon emission technology affects procurement, production, inventory decision-making, and cost in businesses. Toptal et al. [25] compare carbon quotas, carbon taxes, and carbon exchange policies to explore the investment challenge of reducing carbon emissions, and conclude that carbon exchange policy for emission reduction investment can successfully reduce enterprise operational costs and carbon emissions. Lamba et al.[26] establish a mixed integer nonlinear program model and address the supplier's problem of selecting and determining the appropriate lot sizes in order to reduce supply chain costs and carbon emissions. Guo et al.[27] makes a two-stage supply chain with a single manufacturer and retailer that takes into account three carbon emission reduction strategies, as well as the effects on consumer carbon sensitivity coefficient and carbon trading price on decision-making based on carbon emission reduction in the supply chain.

Limit and exchange mechanisms are also incorporated into production decisions and inventories by researchers. Zhang et al. [28] investigates the topic of production planning with carbon limits and exchange regulation, as well as the best production policy, carbon exchange strategy, and a method for linear computational complexity. Chang et al. [29] developed two profit-maximizing models and examined the effects of the carbon limit and exchange regulation on company production choices, finding that the carbon price is more responsive than the carbon cap in managing output and carbon emissions. Chai et al.[30] investigates a monopolistic manufacturer's make and remanufacture goods in order to maximize profit in both the ordinary and green markets while adhering to a carbon limit and an exchange mechanism. Liao et al. [31] creates an expanded EOQ model, demonstrates that the greatest quantities vary in two scenarios with a carbon limit and an exchange mechanism, and examines the effects of taxation policy on the greatest strategies from the government's viewpoint. Ren et al. [32] creates a novel multi-objective complicated integer nonlinear programming model and evaluates the effects of the carbon

ISSN 2616-5902 Vol. 3, Issue 10: 105-118, DOI: 10.25236/AJBM.2021.031019

limit and exchange mechanism on the model's solution. The preceding literatures examine supply chain operational management from the government's standpoint, but do not address customers' environmental preferences.

Pang et al. [33] explore the influence of carbon exchange price and consumers' low-carbon desire on carbon emissions using various kinds of manufacturer under the carbon quotas program. Seyfang et al. [34] investigate the influence of low-carbon preference behavior on market demand and pricing, and develop a scientific low-carbon impact demand function. Du et al. [35] construct a carbon-emission dependent demand function by introducing consumers' behavior into supply chain management, analyze the impact of consumers' low-carbon preference on carbon emissions and supply chain performance, and design revenue sharing contract and amount discount contract to coordinate the supply chain. Sun et al. [36] put up a Stackelberg differential game model, and examine the issue of carbon emission transfer and carbon emission reduction, and also address the lag time of emission decrease technology and consumers' the low-carbon choice.

Based on comprehensive literatures, some papers explore the benefit of carbon emission reduction, some works analyze the firms' operational decision-making with carbon limit and exchange regulation. others study the knowledge of customers' low carbon choice and the investment of carbon emission reduction. But they do not refer to the low carbon's supply chain consist of a capital-constrained and loss-reluctance manufacture via the electronic business platform sell items to customer. hence, it is significant for capital-constrained and loss-reluctance producer which may directly offered goods on electronic business platform.

3. Model description

Under the carbon limit and exchange regulation, we consider a two-level and emission-dependent supply chain consisting of a capital-constrained and loss-reluctant manufacturer (referred to as "she") who directly sells productions to consumers via the electronic business platform. The electronic business platform (referred to as "he") can provide either financing service or leasing business for the manufacturer, both of them aim to maximize profit. During the sales period, the supplier provides products to the capital-constrained manufacturer, who then sells products to consumers via the electronic business platform in the face of uncertain demand. The relationship between the electronic business platform and the manufacturer is modeled as a Stackelberg game, in which the electronic business platform is the leader, the manufacturer is the subleader, the electronic business platform is risk-neutral, and the manufacturer is loss averse. In recent years, the government has taken steps to reduce carbon emissions by imposing various carbon emission caps on manufacturers.

Figure 1 depicts the sequence of events and decision-making process associated with the electronic business platform finance service (see [37]).

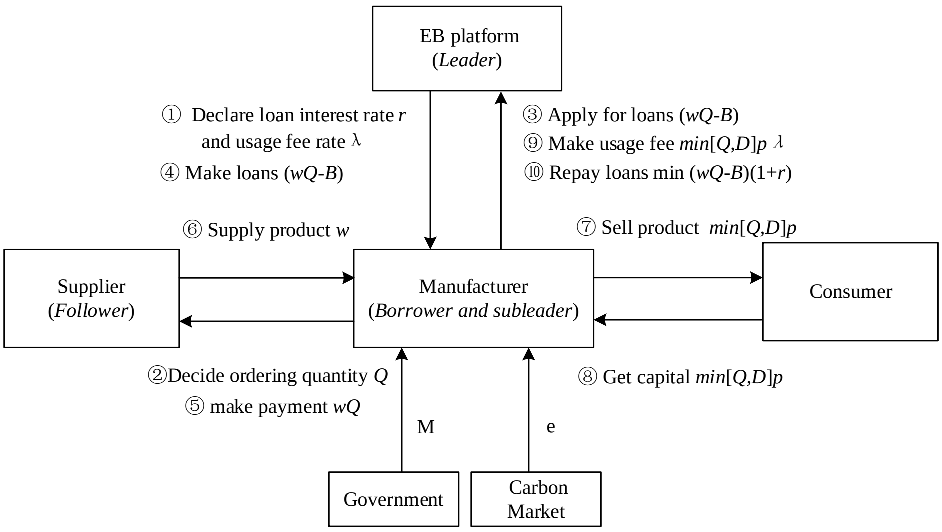

Figure 1 An emission-dependent SCF system with a capital constrained manufacturer under electronic business platform financing service

3.1 notion

In this post, we define and explain certain symbols connected to this paradigm in order to properly express it. Table 1 describes the notations.

Table 1 *List of notations*

Notation	Description
w	Dealer price per unit product decided by supplier
r	Loan interest rate for manufacturer (decision variable)
λ	electronic business platform's usage fee rate for the manufacturer, $\lambda \in [0,1]$
Q	manufacturer's order amount from the supplier (decision variable)
B	Original capital of the manufacturer
p	Retail price per unit product
C_m	The manufacturer's carbon cap
p_c	The carbon trading price
e_m	Carbon emissions per unit product of the manufacturer
ε	The salvage value of unit unsold products of manufacturer
θ	manufacturer's loss reluctance coefficient, $\theta > 1$
S	manufacturer pay to electronic business platform quota in transfer payment contract

In this paper, we ensure the model is consistent with the actual economic events, there are $\varepsilon < w$, $(1-\lambda)p > w(1+r) > \varepsilon$, $\lambda p + wr > 0$.

3.2 Assumptions

We will make the following hypotheses in this essay.

Assumption 1. The electronic business platform is risk-neutral, the manufacturer is loss-reluctance, and both of them pursue the maximal expected profits. ([38,39])

Assumption 2. Parameters in Table 1 are common knowledge to the manufacturer and the electronic business platform. ([40])

Assumption 3. The manufacturer has difficulty in obtaining bank loan and thus the electronic business platform is the only financing channel. ([11])

Assumption 4. the market demand D is random, and D is a nonnegative stochastic variable. $f(D)$ and $F(D)$ represent the market demand D's probability density function and cumulative distribution function respectively, $F(D)$ is continuous, differentiable and strictly increasing, $F(D=0)=0$, $f(D)>0$, the complementary cumulative distribution function of D is $\overline{F}(D)=1-F(D)$, and the demand distribution conforms to the characteristic of increasing failure rate (IFR). ([12])

Assumption 5. the capital market is perfectly competitive, that is, the risk-free interest rate of the market is 0, the electronic business platform is risk-neutral and completely rational, and the market risk is borne by the manufacturer. Simultaneously, the information between the manufacturer and the electronic business platform is symmetric during the operation of the low carbon supply chain. ([40])

4. The greatest strategies of emission-dependent supply chain's partners in decentralized system

At the beginning of the sales season, the electronic business platform firstly determines his loan interest rate r, and then the manufacturer sets her ordering amount is Q_1. In this paper, we consider manufacturer's original capital shortage, that is, the amount of funding gap is $(wQ_1 - B)$. At this moment, manufacturer needs to apply for loan from the electronic business platform. at the end of the sales season, the manufacturer's sales revenue is $(1-\lambda)p\min(Q_1, D)$ after subtracting the electronic business platform's usage fee, and she should repay the loan is $(wQ_1 - B)(1+r)$.

The manufacturer, the electronic business platform and the manufacturer's expected profits can be

ISSN 2616-5902 Vol. 3, Issue 10: 105-118, DOI: 10.25236/AJBM.2021.031019

derived as:

$$\pi^{e}\left(r\right)=\lambda pmin\left(D,Q_{1}\right)+\left(wQ_{1}-B\right)r \quad (1)$$

$$\pi^{m}(Q_{1})=\left(1-\lambda\right)pmin\left(Q_{1},D\right)+\varepsilon max\left(Q_{1}-D,0\right)+p_{c}\left(C_{m}-e_{m}Q_{1}\right)-wQ_{1}\left(1+r\right)+Br \quad (2)$$

4.1 The Greatest Ordering Amount of the Loss-reluctance manufacturer

According to Equation (3), we can find the demand threshold with no bankruptcy for manufacturers and get the following lemma.

Lemma 1. In order to ensure the profitability of the manufacturer,the market demand must be satisfied the condition : $D>\overline{D_{1}}$. When the capital-constrained manufacturer borrows from electronic business platform, the demand threshold $\overline{D_{1}}=\dfrac{\left(wQ_{1}-B\right)\left(1+r\right)-p_{c}\left(C_{m}-e_{m}Q_{1}\right)-\varepsilon Q_{1}+B}{\left(1-\lambda\right)p-\varepsilon}$.

Proof of Lemma 1 is in Appendix A.

Lemma 1 implies that manufacturer will face the loss risk for the uncertainty of market demand. When the actual market demand is sufficiently low, namely, $\left(Q_{1}-D\right)\leq 0$, the manufacturer has to keep a large backlog of inventory, and her profits decrease; then, when manufacturer's sales revenue after subtracting the electronic business platform's usage is sufficently low, namely, $min\left(Q_{1},D\right)\left(1-\lambda\right)P<\left(wQ_{1}-B\right)\left(1+r\right)$, the loan isn't repayed successffully. The manufacturer goes bankrupt and transfers all surplus sales revenue to the electronic business platform.

According to Equation (2) and Equation (3), we get the electronic business platform and the manufacturer's expected profit as follows

$$E\left[\pi^{e}\left(r\right)\right]=\lambda p\int_{0}^{Q_{1}}\overline{F}\left(D\right)dD+\left(wQ_{1}-B\right)r \quad (3)$$

$$E\left[\pi^{m}\left(Q_{1}\right)\right]=\left[\left(1-\lambda\right)p-\varepsilon\right]\int_{0}^{Q_{1}}\overline{F}\left(D\right)dD+p_{c}\left(C_{m}-e_{m}Q_{1}\right)+\varepsilon Q_{1}-wQ_{1}\left(1+r\right)+Br \quad (4)$$

Next, we identify the loss-reluctance manufacturer's utility function as Equation (5):

$$\mu\left(W\right)=\begin{cases}W-W_{0}, & W\geq W_{0}\\ \theta\left(W-W_{0}\right), & W<W_{0}\end{cases} \quad (5)$$

Where, W_{0} denotes the manufacturer's reference target profit. For calculative convention and without loss of generality, we assume the manufacturer's reference profit level is 0, i.e., $W_{0}=0$, which is consistent with [41,42]; θ is the coefficient of the manufacturer's loss reluctance, and $\theta>0$. when $\theta=1$, the manufacturer is risk-neutral, the utility function expresses a risk-neutral manufacturer's utility function; when $\theta>1$, the manufacturer is loss-reluctance, the lager the θ is, the more loss-reluctance the degree of manufacturers will be. in this paper, we only consider $\theta>1$.

According to Equation (3) and Lemma 1, we can get the capital-constrained manufacturer's profit, is as follows:

$$\pi^{m}(Q_{1})=\begin{cases}\left(1-\lambda\right)pD+\varepsilon\left(Q_{1}-D\right)+p_{c}\left(C_{m}-e_{m}Q_{1}\right)-wQ_{1}\left(1+r\right)+Br, 0<D<\overline{D_{1}}\\ \left(1-\lambda\right)pD+\varepsilon\left(Q_{1}-D\right)+p_{c}\left(C_{m}-e_{m}Q_{1}\right)-wQ_{1}\left(1+r\right)+Br, \overline{D_{1}}\leq D\leq Q_{1}\\ \left(1-\lambda\right)pQ_{1}+p_{c}\left(C_{m}-e_{m}Q_{1}\right)-wQ_{1}\left(1+r\right)+Br, Q_{1}<D\end{cases} \quad (6)$$

Based on Equation (5), the expected utility function for the manufacturer, which can be formulated as Equation (6).

$$E\left[\pi^{m}\left(Q_{1}\right)\right]=E\left[\pi^{m}\left(Q_{1}\right)\right]+E\left[\pi^{m}\left(Q_{1}\right)\right] \quad (7)$$

Here, $E\left(\pi^{m}\left(Q_{1}\right)\right)=-\left(\theta-1\right)\left[\left(1-\lambda\right)p-\varepsilon\right]\int_{0}^{\overline{D_{1}}}F\left(D\right)dD$, indicates the expected loss utility of manufacturers due to low market demand. Where, $\overline{D_1}=\dfrac{(wQ_1-B)(1+r)-p_c(C_m-e_mQ_1)-\varepsilon Q_1+B}{(1-\lambda)p-\varepsilon}$.

According to Equation (7), we can further describe the expected utility function of the manufacturer is given by

$$\begin{aligned}E[\mu(W)]&=\int_0^{\overline{D_1}}\theta\left[(1-\lambda)pD+\varepsilon(Q_1-D)+p_c(C_m-e_mQ_1)-wQ_1(1+r)+Br\right]f(D)dD\\&+\int_{\overline{D_1}}^{Q_1}\left[(1-\lambda)pD+\varepsilon(Q_1-D)+p_c(C_m-e_mQ_1)-wQ_1(1+r)+Br\right]f(D)dD\\&+\int_{Q_1}^{\infty}\left[(1-\lambda)pQ_1+p_c(C_m-e_mQ_1)-wQ_1(1+r)+Br\right]f(D)dD\end{aligned} \tag{8}$$

Which can be rewritten as

$$E[\mu(W)]=-(\theta-1)\left[(1-\lambda)p-\varepsilon\right]\int_0^{\overline{D_1}}F(D)dD+\left[(1-\lambda)p-\varepsilon\right]\int_0^{Q_1}\overline{F}(D)dD-\overline{D_1}\left[(1-\lambda)p-\varepsilon\right] \tag{9}$$

According to Equation (7), we can obtain some propositions as follow

Proposition 1. Under electronic business platform financing service mode, when electronic business platform's loan interest rate is known, the greatest amount of the loss-reluctance manufacturer is satisfied $\overline{F}(Q_1^*)=\Omega_1\left[1+(\theta-1)F(\overline{D_1})\right]$, where, $\Omega_1=\dfrac{w(1+r)+p_ce_m-\varepsilon}{(1-\lambda)p-\varepsilon}$.

According to Proposition 1, we have some corollary 1 as follow:

Corollary 1. Given the manufacturer's dealer price w, the electronic business platform's loan interest rate r, the carbon trading price per unit product p_c, the carbon emission per unit of the manufacturer e_m and the salvage value of unit unsold products of the manufacturer ε,we have $\dfrac{dQ_1^*}{d\theta}<0$.

Corollary 1 implies that under the electronic business platform financing service model, the greatest ordering amount of loss-reluctance manufacturer decreases as the degree of loss avoidance. the increasing loss-reluctance degree will cause manufacturer to adopt a conservative ordering strategy, thus manufacturer's ordering amount will decline.

Corollary 2. Given the manufacturer's dealer price w, the electronic business platform's loan interest rate r, the carbon trading price per unit product p_c, the carbon emission per unit of the manufacturer e_m and the salvage value of unit unsold products of the manufacturer ε, we have the following results:

(1) Given the manufacturer's loss reluctance coefficient θ, the loss-reluctance manufacturer's greatest order amount Q_1^* increases with its original capital B, namely, $\dfrac{dQ_1^*}{dB}>0$;

(2) The loss-reluctance manufacturer's greatest order amount Q_1^* increases with its salvage value of unit unsold products ε, namely, $\dfrac{dQ_1^*}{d\varepsilon}>0$.

(3) The loss-reluctance manufacturer's greatest order amount Q_1^* decreases with the electronic business platform's loan interest rate r, namely, $\dfrac{dQ_1^*}{dr}<0$;

(4) The loss-reluctance manufacturer's greatest order amount Q_1^* decreases with the Carbon emission per unit product of the manufacturer e, namely $\dfrac{dQ_1^*}{de_m}<0$.

Corollary 2 shows that the manufacturer's greatest order amount Q_1^* is directly proportional to the

ISSN 2616-5902 Vol. 3, Issue 10: 105-118, DOI: 10.25236/AJBM.2021.031019

original capital B and the salvage value of unit unsold products ε, but inversely proportional to the electronic business platform's financing interest rate r and the Carbon emission per unit product of the manufacturer e_m, The manufacturer's loan amount will be lower when the original capital is higher, that is financing cost will be lower. Thus, manufacturer will improve his ordering amount; the reason is that the high financing interest rate will increase manufacturer's financing cost and loss risk. Therefore, manufacturer will decrease his ordering amount; When the salvage value of the unit unsold products is higher, the manufacturer's risk of loss will be lower, so the manufacturer will increase his ordering amount; When

For analytical convention, Q_2^* denotes the greatest ordering amount of the loss-reluctance and well-funded manufacturer. According to Proposition 1, we obtain the following proposition.

Proposition 2. Given the manufacture's unit dealer price w, the well-funded and loss-reluctance manufacturer's greatest ordering amount satisfies $\overline{F}\left(Q_2^*\right)=\left[\Omega_2\left(1+(\theta-1)F\left(\overline{D_2}\right)\right)\right]$, where,

$$\Omega_2=\frac{w+p_c e_m-\varepsilon}{(1-\lambda)p-\varepsilon},\ \overline{D_2}=\Omega_2 Q_2. \tag{10}$$

According Proposition 2, we get the following Corollary.

Corollary 3. $\dfrac{dQ_2^*}{d\theta}<0$.

4.2 The greatest financing interest rate of the electronic business platform

According to Equation (10), we can obtain the following proposition.

Proposition 3. Under the electronic business platform financing service mode, the greatest financing interest rate of the electronic business platform satisfies

$$r^*=\frac{\Omega_1\left(wQ_1^*-B\right)\left[(1-\lambda)p-\varepsilon\right]\left[f\left(Q_1^*\right)+\Omega_1^{\ 2}(\theta-1)f\left(\overline{D_1}\right)\right]}{w\Omega_1^{\ 2}\left(wQ_1^*-B\right)(\theta-1)f\left(\overline{D_1}\right)+w^2\overline{F}\left(Q_1^*\right)}-\frac{\lambda p\overline{F}\left(Q_1^*\right)}{w}.$$

Where, $Q_1^*=\overline{F}^{-1}\left(\Omega_1\left(1+(\theta-1)F\left(\overline{D_1}\right)\right)\right)$.

Based on Proposition 1 and Proposition 2, by comparing the greatest ordering amount of the manufacturers under the electronic business platform financing service and well-fund manufacturer's greatest ordering amount, we can have the following proposition.

Proposition 4. When $0\le B\le\overline{B}$, $Q_1^*\le Q_2^*$; conversely, when $B>\overline{B}$, $Q_1^*>Q_2^*$, where,

$$\overline{B}=wQ_1^*-\frac{w\lambda p\varepsilon\overline{F}\left(Q_1^*\right)^2}{\Omega_1\left[(1-\lambda)p-\varepsilon\right]\left[f\left(Q_1^*\right)+\Omega_1^{\ 2}(\theta-1)f\left(\overline{D_1}\right)\right]-\lambda p\Omega^2(\theta-1)f\left(\overline{D_1}\right)\overline{F}\left(Q_1^*\right)}.$$

Proposition 4 shows that when the manufacturer's original capital is greater than a certain threshold, the manufacturer's ordering amount under the electronic business platform financing service model is greater than its ordering amount under sufficient funding. In other words, the electronic business platform financing service can effectively improve manufacturer's fund shortage and encourage them to increase order quantities. When the manufacturer's original capital is low, it means that its funding gap is large, that is, the financing cost is high, resulting in the manufacturer's order amount being lower than its order amount when the funds are sufficient. However, with the increase of manufacturers' original funds, their financing costs are decreasing. The electronic business platform will adjust the financing rate to decrease the manufacturer's ordering costs and encourage manufacturers to order more products.

5. The greatest order amount of emission-dependent supply chain in the centralized system

In the case of centralized decision-making, the electronic business platform and manufacturers are regarded as a risk-neutral unified economy, the purpose of which is to maximize the overall profit of the supply chain. Therefore, by adding formula (1) and formula (2), you can get the following form of supply

ISSN 2616-5902 Vol. 3, Issue 10: 105-118, DOI: 10.25236/AJBM.2021.031019

Chain overall profit function $\pi^s(Q_3) = pmin(Q_3, D) + \varepsilon max(Q_3 - D, 0) + p_c(C_m - e_m Q_3) - wQ_3$

Furtherly, the overall expected profit function of the supply chain can be written as follows: $E\left[\pi^s(Q_3)\right] = (p-\varepsilon)\int_0^{Q_3}\overline{F}(D)dD + (\varepsilon - p_c e_m - w)Q_3 + p_c C_m$ (11)

According to Equation (11), we can have the following Proposition

Proposition 5. Under centralized decision-making, the greatest ordering amount of supply chain system is $Q_3^* = \overline{F}^{-1}\left(\frac{p_c e_m + w - \varepsilon}{p-\varepsilon}\right)$.

According to Proposition 1, Proposition 2 and Proposition 5, we can obtain the following the Proposition by comparing the greatest order amount of manufacturers in different situations.

Proposition 6.

1) The greatest ordering amount of the loss-verse and well-fund manufacturer is less than supply chain system's greatest ordering amount, namely, $Q_2^* < Q_3^*$.

2) The greatest ordering amount of the loss-verse and capital-constrained manufacturer is less than supply chain system's greatest ordering amount, namely, $Q_1^* < Q_3^*$.

Proposition 6 shows that both the greatest ordering amount of the well-funded manufacturers and the greatest ordering amount of the manufacturers under the electronic business platform financing service are less than the greatest ordering amount of the entire supply chain system. The reason why exists the results is that whether the manufacturer has sufficient funds or finances by the electronic business platform financing service, the electronic business platform and the manufacturer in decentralized decision will have a double marginalization effect, resulting in the manufacturer's order amount in decentralized making-decision being less than the supply chain system's order amount.

6. Supply chain system coordination strategies analysis

In reality, the reason why the sum of manufacture's, manufacturer's and electronic business platform's profit is less than the total profit of the entire supply chain system under centralized decision is that supply chain participants usually pursue the biggest respective profits under decentralized decision. Next, for the electronic business platform financing service model, we analyze the effect of transfer payment contracts on the capital-constrained supply chain coordination. According to proposition 1 and proposition 5, we can have the following propositions.

Proposition 7

When the electronic business platform and the loss-reluctance manufacturer sign a transfer payment contract $(\overline{r}, S)$, where the electronic business platform's financing interest rate is $\overline{r} = \frac{(p_c e_m + w - \varepsilon)\left[(1-\lambda)p - \varepsilon\right]}{w(p-\varepsilon)\left[1+(\theta-1)F(\overline{D_1})\right]} - \frac{p_c e_m - \varepsilon}{w} - 1$, the manufacturer needs to transfer a fixed profit S to the electronic business platform and S should satisfied the inequality $\pi^m(Q_3^*) - \pi^m(Q_1^*) < S < \pi^e(Q_1^*) - \pi^e(Q_3^*)$. Thus, the transfer payment contract can enable the capital-constrained entire supply chain system to achieve coordination under the electronic business platform financing service.

Proposition 7 shows that when the electronic business platform and the manufacturer sign an appropriate transfer payment contract under the electronic business platform financing service model, the entire supply chain can achieve coordination. Both the electronic business platform's and the manufacturer's profits will improve, achieve Pareto improvements and get a win-win situation.

7. Conclusions

We investigate a supply chain finance system comprised of a capital-constrained manufacturer and an electronic business platform in this research. Under the electronic business platform financing model, we examine the operational and coordinated strategies of the loss-reluctance maker in the SCF. Specifically, under decentralized choice making, we receive the greatest ordering strategy of the manufacturer, while under centralized decision making, we obtain the greatest ordering strategy of the whole supply chain system. By comparing the highest ordering amounts in the two cases above, we may further examine the transfer payment contract, which can cause the whole supply chain to coordinate. The following are some of the primary conclusions:

Firstly, when the manufacturer's original capital exceeds a particular level, the manufacturer's greatest order amount under the electronic business platform financing service model will surpass the greatest order amount of a well-funded manufacturer.

Second, under the electronic business platform financing service model, when the manufacturer's original capital falls within a certain range, the profits of the electronic business platform and the manufacturer are greater than their respective profits when the manufacturer has sufficient original capital, resulting in Pareto improvement for the electronic business platform and the manufacturer.

Third, the capital-constrained supply chain cannot directly achieve coordination under the electronic business platform financing service; the entire supply chain can only achieve coordination if the electronic business platform and the manufacturer sign a transfer payment contract.

Based on the study findings of this work, the following management implications for the financing and operation choices of the capital-constrained supply chain in practice may be provided:

We will be able to pursue a variety of additional study avenues in the future. On the one hand, this study proves the existence of market information symmetry. In truth, manufacturers often understand market information better than computerized business platforms. As a result, the coordination problem of a capital-constrained supply chain in the presence of information asymmetry merits additional investigation. However, except for the manufacturer, this research does not examine the risk attitude of the electronic business platform; hence, it is required to further investigate supply chain operational and coordinated strategy concerns that consider the risk attitude of all firms.

Appendix A

A1 Proof of Lemma 1

Make sure that manufacturer make a profit, the expected profit of the manufacturer must be great than 0, and thus $\pi^m\left(Q_1\right)>0$. according to

$\pi^m\left(Q_1\right)=\left(1-\lambda\right)pmin\left(Q_1,D\right)+\varepsilon max\left(Q_1-D,0\right)+p_c\left(C_m-e_mQ_1\right)-wQ_1\left(1+r\right)+Br>0$,we obtain $D>\dfrac{\left(wQ_1-B\right)\left(1+r\right)-p_c\left(C_m-e_mQ_1\right)-\varepsilon Q_1+B}{\left(1-\lambda\right)p-\varepsilon}$ .hence, the demand threshold with no bankruptcy D should satisfy the condition $D>\overline{D_1}$, and thus, the demand threshold with no bankruptcy is $\overline{D_1}=\dfrac{\left(wQ_1-B\right)\left(1+r\right)-p_c\left(C_m-e_mQ_1\right)-\varepsilon Q_1+B}{\left(1-\lambda\right)p-\varepsilon}$.

A2 Proof of proposition1

According to Equation (9) of Lemma 1, after we drive the first and second derivative of $\mu\left(Q_1\right)$ with respect to Q_1 ,we obtain that $\dfrac{dE\left[\mu\left(Q_1\right)\right]}{dQ_1}=-\left(\theta-1\right)\left[w\left(1+r\right)+p_ce_m-\varepsilon\right]F\left(\overline{D_1}\right)+\left[\left(1-\lambda\right)p-\varepsilon\right]\overline{F}\left(Q_1\right)-w\left(1+r\right)-p_ce_m+\varepsilon$ and $\dfrac{d^2E\left[\mu\left(Q_1\right)\right]}{dQ_1^{\,2}}=-\left(\theta-1\right)\left[w\left(1+r\right)+p_ce_m-\varepsilon\right]f\left(\overline{D_1}\right)-\left[\left(1-\lambda\right)p-\varepsilon\right]f\left(Q_1\right)$. when $\dfrac{dE\left[\mu\left(Q_1\right)\right]}{dQ_1}=0$, we get $\overline{F}\left(Q_1^*\right)=\left[\left(\theta-1\right)F\left(\overline{D_1}\right)+1\right]\Omega_1$, where, $\Omega_1=\dfrac{w\left(1+r\right)+p_ce_m-\varepsilon}{\left(1-\lambda\right)p-\varepsilon}$. Since, $\theta>1$,

ISSN 2616-5902 Vol. 3, Issue 10: 105-118, DOI: 10.25236/AJBM.2021.031019

$(1-\lambda)p > w(1+r) > \varepsilon$, and the IFR assumption, we get $\frac{d^2E\left[\mu\left(Q_1^*\right)\right]}{dQ_1^{*2}} \le 0$. Then, the greatest order amount satisfies $\overline{F}\left(Q_1^*\right) = \left[(\theta-1)F\left(\overline{D_1}\right)+1\right]\Omega_1$.

A3 Proof of corollary 1

According to the implicit function theorem of $\overline{F}\left(Q_1^*\right) = \left[(\theta-1)F\left(\overline{D_1}\right)+1\right]\Omega_1$ and taking the first-order derivative of Q_1^* with respect to θ, we have $\frac{dQ_1^*}{d\theta} = -\frac{\Omega_1 F\left(\overline{D_1}\right)}{f\left(Q_1^*\right)+(\theta-1)\Omega_1^{\,2} f\left(\overline{D_1}\right)}$. Since, $\Omega_1 > 0$, $F(D) > 0$, $f(D) > 0$ and $\theta > 1$, we get $\frac{dQ_1^*}{d\theta} < 0$.

A4 Proof of corollary 2

(1) Based on proposition 1, according to the implicit function theorem of $\overline{F}\left(Q_1^*\right) = \left[(\theta-1)F\left(\overline{D_1}\right)+1\right]\Omega_1$ and taking the first-order derivative of Q_1^* with respect to B, we have $\frac{dQ_1^*}{dB} = \frac{r\Omega_1(\theta-1)f\left(\overline{D_1}\right)}{\left[(1-\lambda)p-\varepsilon\right]\left[f\left(Q_1^*\right)+\Omega_1^{\,2}(\theta-1)f\left(\overline{D_1}\right)\right]}$. Since, $\Omega_1 > 0$, $(1-\lambda)p > \varepsilon$, $f(D) > 0$ and $\theta > 1$, we get $\frac{dQ_1^*}{dB} > 0$.

(2) Similarly, we have $\frac{dQ_1^*}{dr} = -\frac{\Omega_1\left(wQ_1^*-B\right)(\theta-1)f\left(\overline{D_1}\right)+w\left[(\theta-1)F\left(\overline{D_1}\right)+1\right]}{\left[(1-\lambda)p-\varepsilon\right]\left[f\left(Q_1^*\right)+\Omega_1^{\,2}(\theta-1)f\left(\overline{D_1}\right)\right]}$. Since, $\Omega_1 > 0$, $(1-\lambda)p > \varepsilon$, $F(D) > 0$, $f(D) > 0$ and $\theta > 1$, we get $\frac{dQ_1^*}{dr} < 0$.

Similarly, we have $\frac{dQ_1^*}{d\varepsilon} = -\frac{\Omega_1(\theta-1)\left(\overline{D_1}-Q_1^*\right)f\left(\overline{D_1}\right)+(\Omega_1-1)\left[(\theta-1)F\left(\overline{D_1}\right)+1\right]}{\left[(1-\lambda)p-\varepsilon\right]^2\left[f\left(Q_1^*\right)+\Omega_1^{\,2}(\theta-1)f\left(\overline{D_1}\right)\right]}$. Since, $Q > \overline{D_1}$, $0 < \Omega_1 < 1$, $(1-\lambda)p > \varepsilon$, $F(D) > 0$, $f(D) > 0$ and $\theta > 1$, we get $\frac{dQ_1^*}{d\varepsilon} > 0$.

A5 Proof of proposition 3

In Equation (3), driving the first-order and the second-order derivative of $E\left[\pi^m(r)\right]$ with respect to r, we have $\frac{dE\left[\pi^m(r)\right]}{dr} = \frac{\partial E\left[\pi^m(r)\right]}{\partial Q_1^*}\frac{dQ_1^*}{dr} + \frac{\partial E\left[\pi^m(r)\right]}{\partial r} = \left[\lambda p\overline{F}\left(Q_1^*\right)+wr\right]\frac{dQ_1^*}{dr} + \left(wQ_1^*-B\right)$ and $\frac{d^2E\left[\pi^m(r)\right]}{dr^2} = -\lambda pf\left(Q_1^*\right)\left(\frac{dQ_1^*}{dr}\right)^2 + 2w\frac{dQ_1^*}{dr} + \left[\lambda p\overline{F}\left(Q_1^*\right)+wr\right]\frac{d^2Q_1^*}{dr^2}$, respectively. According to the above analysis, it is obvious that $\frac{d^2Q_1^*}{dr^2} = -\frac{2w(\theta-1)f\left(\overline{D_1}\right)\left[-\Omega_1^{\,2}\left(wQ_1^*-B\right)(\theta-1)f\left(\overline{D_1}\right)-\left(wQ_1^*-B\right)f\left(Q_1^*\right)+2w\overline{F}\left(Q_1^*\right)\right]}{\left[(1-\lambda)p-\varepsilon\right]^2\left[f\left(Q_1^*\right)+\Omega_1^{\,2}(\theta-1)f\left(\overline{D_1}\right)\right]^2} < 0$. Hence, we can conclude that $\frac{d^2E\left[\pi^m(r)\right]}{dr^2} < 0$, namely, the loss-reluctance manufacturer's expected profit

ISSN 2616-5902 Vol. 3, Issue 10: 105-118, DOI: 10.25236/AJBM.2021.031019

function is concave, and there exists a unique greatest solution r^*. The only greatest loan interest rate can be got by solving $\frac{dE\left[\pi^e(r)\right]}{dr}=0$, i.e., $r^*=-\frac{\left(wQ_1^*-B\right)}{wdQ_1^*/dr}-\frac{\lambda p\overline{F}\left(Q_1^*\right)}{w}=\frac{\Omega\left(wQ_1^*-B\right)\left[(1-\lambda)p-\varepsilon\right]\left[f\left(Q_1^*\right)+\Omega^2(\theta-1)f\left(\overline{D}\right)\right]}{w\Omega^2\left(wQ_1^*-B\right)(\theta-1)f\left(\overline{D}\right)+w^2\overline{F}\left(Q_1^*\right)}-\frac{\lambda p\overline{F}\left(Q_1^*\right)}{w}$.

A6 Proof of proposition 4

From corollary 2, we obtain $\frac{dQ_1^*}{dB}>0$. When the manufacturer's internal working capital satisfies $0\le B\le\overline{B}$, we get $\Omega_1\left[1+(\theta-1)F\left(\overline{D_1}\right)\right]\ge\left[\Omega_2\left(1+(\theta-1)F\left(\overline{D_2}\right)\right)\right]$, namely, $\overline{F}\left(Q_1^*\right)\ge\overline{F}\left(Q_2^*\right)$, because of $\Omega_1\ge\Omega_2$, $\overline{D_1}\ge\overline{D_2}$. And since $\overline{F}(D)$ is a strictly monotone decreasing function. Thus, we further deduce $Q_1^*\le Q_2^*$. According to $\Omega_1\left[1+(\theta-1)F\left(\overline{D_1}\right)\right]\ge\left[\Omega_2\left(1+(\theta-1)F\left(\overline{D_2}\right)\right)\right]$, we obtain $B\le wQ_1^*-\frac{w\lambda p\varepsilon\overline{F}\left(Q_1^*\right)^2}{\Omega_1\left[(1-\lambda)p-\varepsilon\right]\left[f\left(Q_1^*\right)+\Omega_1{}^2(\theta-1)f\left(\overline{D_1}\right)\right]-\lambda p\Omega^2(\theta-1)f\left(\overline{D_1}\right)\overline{F}\left(Q_1^*\right)}$, further deduce $\overline{B}=wQ_1^*-\frac{w\lambda p\varepsilon\overline{F}\left(Q_1^*\right)^2}{\Omega_1\left[(1-\lambda)p-\varepsilon\right]\left[f\left(Q_1^*\right)+\Omega_1{}^2(\theta-1)f\left(\overline{D_1}\right)\right]-\lambda p\Omega^2(\theta-1)f\left(\overline{D_1}\right)\overline{F}\left(Q_1^*\right)}$.

As the above describe, When the manufacturer's internal working capital satisfies $B>\overline{B}$, we get $Q_1^*>Q_2^*$.

A7 Proof of Proposition 5

In Equation (8), taking the first and second derivative of $E\left(\pi^s(Q_3)\right)$ with respect to Q_3, we get $\frac{dE\left(\pi^s(Q_3)\right)}{dQ_3}=(p-\varepsilon)\overline{F}(Q_3)+(\varepsilon-p_ce_r-w)$ and $\frac{d^2E\left(\pi^s(Q_3)\right)}{dQ_3{}^2}=-(p-\varepsilon)f(Q_3)$, respectively. According to the above analysis, Since $p>\varepsilon$, we can conclude that $\frac{d^2E\left(\pi^s(Q_3)\right)}{dQ_3{}^2}<0$, namely, the overall expected profit function of the supply chain is concave, and we get the greatest ordering amount of the supply chain system by solving $\frac{dE\left(\pi^s(Q_3)\right)}{dQ_3}=0$, i.e., $Q_3^*=\overline{F}^{-1}\left(\frac{p_ce_r+w-\varepsilon}{p-\varepsilon}\right)$.

A8 Proof of the proposition 6

From proposition 2 and 5, we known that $\overline{F}\left(Q_1^*\right)=\frac{w(1+r)+p_ce_r-\varepsilon}{(1-\lambda)p-\varepsilon}\left(1+(\theta-1)F\left(\overline{D_1}\right)\right)$, $\overline{F}\left(Q_2^*\right)=\frac{w+p_ce_r-\varepsilon}{(1-\lambda)p-\varepsilon}\left(1+(\theta-1)F\left(\overline{D_2}\right)\right)$ and $\overline{F}\left(Q_3^*\right)=\frac{p_ce_r+w-\varepsilon}{p-\varepsilon}$. It is obviously that $\overline{F}\left(Q_1^*\right)<\overline{F}\left(Q_3^*\right)$ and $\overline{F}\left(Q_2^*\right)>\overline{F}\left(Q_3^*\right)$. Since $\overline{F}(D)$ is a strictly monotone decreasing function, we get $Q_2^*<Q_3^*$ and $Q_1^*<Q_3^*$.

A9 Proof of proposition 7

According to Proposition 1 and 5, when electronic business platform declare the loan interest rate $\bar{r}$

to the capital-constrained manufacturer and $\bar{r}$ satisfied $Q_1^* = Q_3^*$. According to the supply chain coordination established by Cachon[45] , the complete supply chain may achieve coordination only if the earnings of the entire supply chain members have increased. Thus, the amount of transfer payment that the manufacturer sends to the electronic business platform under transfer payment contract has to fulfill the inequality $\pi^r\left(Q_3^*\right) - \pi^r\left(Q_1^*\right) < S < \pi^e\left(Q_1^*\right) - \pi^e\left(Q_3^*\right)$.

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