Annals of Operations Research (2022) 315:507–533
https://doi.org/10.1007/s10479-022-04691-7

ORIGINAL RESEARCH

Implications of credit default and yield uncertainty on supply chain's equilibrium financial strategy

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Accepted: 28 March 2022 / Published online: 17 April 2022
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Abstract
Two financial schemes, i.e., purchase order financing (POF) and buyer direct financing (BDF), have been proposed for small and medium-sized manufacturers. This study considers a supply chain consisting of a capital-constrained manufacturer who faces the random yield and has a probability of credit default, a well-capitalized retailer, and a bank. We find that the manufacturer prefers POF scheme if the unit production cost is high and the default risk is low, and BDF scheme otherwise. Whereas the retailer benefits from POF when the unit production cost is small. Thus, the retailer, as the leader, has an incentive to distort the purchase price to induce the manufacturer's financing strategy towards the retailer's preference. Furthermore, only BDF can achieve a Pareto improvement since the retailer plays a dual role (i.e., buyer and lender) under BDF.

Keywords Yield uncertainty · Capital constraint · Default risk · Purchase order financing

1 Introduction

Yield uncertainty, as a serious problem on the supply side, not only brings losses to manufacturers, but also affects the entire supply chain's efficiency (Tang & Kouvelis, 2011). For example, uncertain cotton output leads to great fluctuations in garment production (Adhikari et al., 2020), and small and medium-sized enterprises (SMEs) in the semiconductor and electronics industries generally can only achieve 50% output (Chen & Yang, 2014). Furthermore, the production of many products requires multiple production stages, which lead to potential yield uncertainty (Talay & Özdemir-Akyıldırım, 2019). Especially in the agricultural supply

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chain, agricultural products are obviously characterized by a random yield due to the impact of climate and other environmental factors (Allen & Schuster, 2004). A report released on February 17, 2020 by the United Nations Food and Agriculture Organization shows that locusts affected more than 1600 square kilometers of agricultural area and exacerbated food shortages for more than 22 million people in Ethiopia (Agri, 2020). Obviously, yield uncertainty not only brings losses to manufacturers, but also affects the national economy.

Furthermore, considering a fixed production cycle, the capital investment is needed much earlier than the product completion stage. The shortage of funds for upstream manufacturers progressively causes production interruptions, losses of entire supply chains, and even industry economic recession (Deng et al., 2018). For instance, the milk farmers, as Yili's upstream manufacturers, tend to lack of capital to invest in production, and often have problems with uncertain yield due to variable natural environment and inadequate technology (Ding & Wan, 2020). In addition, financing becomes a challenge due to the agricultural products' cyclicality (Varga & Sipiczki, 2015). SME manufacturers are always prone to a "capital gap" when involving a high capital demand. However, these manufacturers, who are lacking collaterals, credit records, and convincing profitability, can hardly finance directly from banks and other institutions (Fang & Xu, 2020; Lin & Xiao, 2018). Consequently, SME manufacturers must resort to other finance schemes.

Two financing schemes are widely applied in supply chains. One is purchase order financing (POF), which has been implemented in ShouGuang, ShanDong, China as early as 2012, with support of the banking institutions and supply chain core enterprises. Under POF scheme, a reputable buyer issues the purchase order to the manufacturer before products are produced, and then the manufacturer can finance from banks and other financial institutions according to this purchase order (Tang et al., 2017). Therefore, although the promised purchase order can broaden the manufacturer's financing channels, there still exists a certain risk given that the manufacturer may default (Reindorp et al., 2018). The other financing scheme is buyer direct financing (BDF), which is commonly adopted in the retail industry and helps the manufacturers or suppliers raise funds directly from the buyers (Zhen et al., 2020). Based on empirical research, Tunca and Zhu (2017) found a 13.05% increase in channel profit when applying buyer financing. Carrefour is the most prominent example, who put forward the "financing plan for supporting SMEs" as early as 2009 in China. This plan has been implemented in Europe for more than 20 years, with the outcomes of solving the financing problem of SME manufacturers and promoting the cooperative relationship between the participants. Moreover, many other retailers in the automotive, beverage and FMCG industries (i.e., PSA Peugeot Citroen, Coca-Cola, and Procter & Gamble) have offered advance payments to ease the capital constraints of upstream suppliers/manufacturers (Shen et al., 2021).

Neither of the aforementioned financing schemes requires tangible assets as collateral, so lenders obtain no complete guarantee that the loan can be repaid. Particularly, POF is mainly conducted on the orders of core enterprises that have high credit, and thus the main default risk of POF lies in whether the manufacturer can fulfill the delivery contract at the end of the financing period. As Wang et al. (2018) indicated, in the actual operations process, SMEs have the probability of defaulting and not repaying the loans. In exchange, the rational lenders will charge a higher loan interest rate and a premium to reduce the loss caused by the higher default risk (Babich et al., 2013; Chod et al., 2019). Especially, when a bank provides financing, it takes into account both the borrower's default probability and possible losses caused by default (Chun & Lejeune, 2020). Therefore, default risk will affect lenders' interest rate decisions and borrowers' financing strategies.

In recent years, scholars who consider capital-constrained manufacturers mainly focus on the comparison of financing schemes. For example, BDF and bank financing have been

widely compared (Gupta & Chen, 2019; Tang & Yang, 2020), and POF as a new financing scheme has also been compared with BDF (Tang et al., 2017). However, the manufacturer's uncertain yield and credit default risk as a SME, which are crucial to financing decisions, are rarely taken into account. In addition, the impact of the well-funded retailer's dominant role on the manufacturer's financing strategy has also not been fully discussed. This study is devoted to fill these research gaps. To our best knowledge, we are the first to introduce two variables to capture yield uncertainty and credit default risk, and consider the interest rate premium charged by banks for this default risk simultaneously. It not only provides a new mathematical model for discussing the manufacturer's optimal financing strategy, but also makes the research more realistic.

Combining with the above considerations, we investigate a supply chain consisting of one manufacturer who is constrained by capital, one retailer who has sufficient capital, and one bank. The manufacturer can borrow money from either the retailer (BDF) or the bank (POF) based on the corresponding purchase contracts given by the retailer. In view of the relatively low reliability of the SME manufacturer, its default risk is taken into account when we explore the optimal financial strategy. Furthermore, yield uncertainty is also a key influencing factor of the optimal financial strategy, since it prevents the manufacturer from delivering enough products to pay the loan. The present paper mainly addresses the following questions:

(i) How do the manufacturer's default risk and unit production cost affect the optimal profits under POF and BDF respectively?
(ii) When does the retailer have an incentive to guide the manufacturer's financing preferences by distorting the purchase price?
(iii) What's the equilibrium financing strategy when both BDF and POF are available? And which financing strategy can achieve Pareto improvement?

The main findings of this paper are threefold. First, the analysis of the model shows that a higher default risk of the manufacturer, indicating a less stable supply chain, will damage the profits and output quantities of entire supply chain under both financing schemes. Furthermore, a high unit production cost which makes purchasing and financing more expensive, finally results in zero profit of the manufacturer regardless of which financing scheme. Moreover, under POF, when the unit production cost is low, the manufacturer presents a low financing pressure and can profit via the increasing wholesale revenue. With the increase of this cost, the reduced production quantity may lead to the wholesale revenue cannot offset the financing cost, thus damaging the manufacturer's profit.

Second, we find out that the retailer doesn't distort the purchase price only when the unit production cost is moderate. Particularly, when this cost is low, the retailer can obtain a higher profit under POF, so the wholesale price under POF will be set at the optimal level, while that under BDF at a sufficiently high level to make POF more attractive to the manufacturer. When this cost is high, the manufacturer prefers POF which is more reliable, even if there is no difference in its profits under two financing schemes. While the retailer, who benefits from both sales and financing revenues under BDF, has an incentive to distort the purchase price under POF to the lowest feasible level, thus forcing the manufacturer to choose BDF.

Third, the equilibrium financing scheme is POF if the unit production cost is below a certain threshold, and BDF otherwise. Given that this low cost indicates the low loss of yield uncertainty and default risk, the bank is more willing to finance the manufacturer. As this cost increases, financing becomes more expensive, and thus POF is no longer attractive. Similarly, a higher default risk also results in a higher interest rate and lower profit of the retailer under POF. Consequently, BDF can tolerate the higher default risk and higher yield uncertainty.

Moreover, we find that only BDF can achieve Pareto improvement due to that the retailer plays a dual role (i.e., buyer and lender) under BDF.

The rest of this paper is organized as follows. We review the relevant literature in Sect. 2, and present the model in Sect. 3. Section 4 provides the optimal solutions when only POF or BDF is available. Then, we discuss the impact of default risk and unit production cost on the optimal solutions under POF and BDF respectively, and provide the financing equilibrium when both the schemes are available in Sect. 5. Section 6 draws the conclusion. Main results under two financing schemes and all proofs are available in Appendix.

2 Literature review

In this section, we compare the difference between our study and previous ones in terms of three related streams, namely, yield uncertainty, supply chain finance, and default risk. Then, we summarize the existing research limitations and highlight our study's contribution.

2.1 Yield uncertainty

Yield uncertainty, as a feature of the unstable supply side, has received an increasing attention of specialists and practitioners. Among them, several researchers investigated the effect of this feature on production planning and pricing decisions (Kazaz, 2004; Kazaz & Webster, 2011), some researchers proposed multi-source procurement as a solution to reduce the supply side's yield uncertainty (Chao et al., 2016; Li, 2017). Some other scholars focused on the relationship between the random yield and investment decisions (Allen & Schuster, 2004; Talay & Özdemir-Akyıldırım, 2019). For instance, Anderson and Monjardino (2019) investigated how manufacturers could reduce yield uncertainty based on fertilizer input decisions in a three-tier supply chain. Considering the uncertain output of high-end products, Lu et al. (2018) found that when the yield uncertainty is high, enterprises tend to reduce the output of high-end products and switch to the production of low-end products. In addition, how to design risk-sharing contracts to cover the risk of yield uncertainty and achieve supply chain coordination has also become a research issue (Inderfurth & Clemens, 2014; Peng & Pang, 2020). On this basis, Zare et al. (2019) and Cai et al. (2019) considered uncertainty of yield and demand together, and explored the impact of contracts on input decision-making and supply chain performance.

Most of the aforementioned studies aim to balance the risks of random yield by making decisions on input investment, and contract designing, to improve efficiency and thus achieve coordination of supply chains. However, production yield uncertainty cannot be neglected in conjunction with financing strategies nowadays, since suppliers with random yield are perceived as unreliable (Yuan et al., 2021). There exists few literature that combines production yield uncertainty with financing strategies. Among them, Ding and Wan (2020) discussed how a supplier with uncertain output makes its optimal financing decision. Dong et al. (2020) built a two-stage model to deduce the equilibrium financing strategy of the battery manufacturer when both yield and demand are random. Cong et al. (2020) explored the impact of yield uncertainty on the selection of green financial subsidy and low-carbon subsidy strategies in a low-carbon supply chain. The authors revealed that yield uncertainty would weaken the positive impact of green finance on carbon emission reduction. Similarly, Zou et al. (2021) found that the optimal supply chain financing strategies and the carbon emission reduction level were related to yield uncertainty in an emission-dependent supply

chain. Moreover, the influence of yield uncertainty on strategy selection between advance payment and bank financing in a coal-electricity supply chain was explored by Guo et al. (2018). In contrast, besides random yield, we also consider the borrower's default risk that presents a great influence on financing strategies.

2.2 Supply chain finance

In supply chains, trade credit financing is available and popular for buyers (i.e., the demand side) when they are short of funds. This financing scheme is also considered as a risk-sharing role (Yang & Birge, 2017). Furthermore, due to the limited liability, the capital-constrained retailer prefers to order more under this financing scheme (Chen & Wang, 2012). A number of scholars have studied the borrowers' preference between trade credit financing and bank financing. For instance, Chod (2016) pointed out that the debt financing from suppliers can alleviate the distorting effect on retailers' inventory decisions when compared with that from banks. Jing et al. (2012) discovered that the option of retailers' financing strategy between trade credit and bank financing depends on manufacturers' production costs. Kouvelis and Zhao (2012) analyzed why retailers always prefer trade credit to bank loans with competitive prices when credit ratings are not considered.

In contrast with the abovementioned studies, this paper considers capital constraints of the supply side's manufacturers, for whom POF and BDF schemes are more applicable and attract more attention recently. For instance, Reindorp et al. (2018) studied the influence of supplier's credit and information transparency on POF decisions and profits. Tunca and Zhu (2017) demonstrated that financing with the buyer that acts as an intermediary between the supplier and the bank can increase the entire supply chain's profit. Lin and Xiao (2018) explored the impact of the ordering contract (push or pull contract) on the manufacturer's financing decision when the retailer provides credit guarantee financing. Based on demand uncertainty and bankruptcy costs, Zhen et al. (2020) found that the retailer will benefit from the buyer lending if he is risk-neutral or risk-seeking. Tang and Yang (2020) considered the capital-constrained manufacturer's optimal financing strategy (finance from the bank or the capital-abundant retailer). Differently, since the retailer is the game leader, we also explore the role of its purchase price decision in inducing the manufacturer's financing preference. Several other scholars also deduced more attractive financing schemes, such as retailer direct financing or bank financing under consignment (Gupta & Chen, 2019), and a mixed financing combining prepayment and green credit financing in a green supply chain (Fang & Xu, 2020).

Our study is similar to the study conducted by Tang et al. (2017), who considered whether suppliers with performance risk would choose POF or BDF. This risk determines default probability, which can be improved by the supplier's effort (i.e., the internal decision). However, we pay more attention to the risk of credit default, which is exogenous in our model. And the manufacturer's optimal production and financing preferences are explored by combining the random yield and credit default.

2.3 Default risk

In the traditional research of supply chains, default risk is generally related to the supplier's delivery capability, which may result in supply interruption. Existing studies related to this impact factor mainly focus on the impact on supply chain coordination and contract design, such as Swinney and Netessine (2009), who found that dynamic long-term contract can better coordinate the supply chain under default risk. Through the analysis of variable and fixed

default costs, Kouvelis and Zhao (2015) concluded the optimal contracts that coordinate the supply chain under different default costs. Huang et al. (2015) explored how suppliers with default risk build a stable alliance and realize the sharing of capital resources in the alliance.

Furthermore, the default risk of borrowers can also be considered as a critical impact factor in supply chain financing that may cause the losses to lenders or even the entire supply chain. For instance, default risk is first taken by Shi and Zhang (2010) as the judgment basis for whether suppliers provide trade credit and how to design this financing term. Trade credit insurance was proposed by Li et al. (2016) as an important tool to reduce default risk. Wang et al. (2018) studied how suppliers should reasonably design contracts to reduce the default risk via providing trade credit when the credit rating of retailers is a private information. Shi et al. (2020) explored how the buyback contract coordinated the SCF system when the retailer defaults, whereas Lin and He (2019) focused on the influence of supplier's asset structure on the financing strategies with the probability of the supplier defaults. The research about how to design trade credit scheme and credit period when considering default risk was also discussed (Tsao, 2018, 2019). In addition, Wang et al. (2020) considered when facing the asymmetric default risk of logistics service providers, how should suppliers set up trade credit to expand sales and balance the default risk.

Similar to Kouvelis and Zhao (2017), who studied the influence of the credit ratings on operations and financing decisions with demand uncertainty, we also explore how the credit default risk influences financing strategies. While the difference is that, we shift the research focus from downstream to upstream of the supply chain, and discuss the impacts of manufacturer's default risk and yield uncertainty on financing strategies.

2.4 Paper's difference and contribution statement

Through the above review, the differences between this paper and the existing literature are illustrated in Table 1. Specifically, the limitations of the existing relevant works are threefold. First, the existing literature about yield uncertainty mostly explored the impact of random yield on production input decisions, but not the option for financing strategy, especially for the comparison between POF and BDF. Second, the literature considering manufacturers' capital constraints mainly focused on the comparison of financing strategies. However, most of these works ignored the characteristics of manufacturers (i.e., uncertain yield, and credit default risk of SMEs), which have a crucial impact on financing decisions. Third, a large part of literature related to supply chain financing took retailers as borrowers to explore their default risk. Thus, the research on the default situation of capital-constrained enterprises on the supply side is lacking. These research gaps are filled by our study.

Consequently, the main contributions of our study can be summarized as follows. First, to our best knowledge, we are the first to study supply chain financing between POF and BDF by considering yield uncertainty and default risk. These two factors respectively depict the situation of passive and active default of borrowers in real-world practice, and have a significant impact on financing decisions, as described in the background. Second, by introducing two variables to capture yield uncertainty and credit default risk and considering the interest rate premium charged by banks for the default risk, this paper provides a new mathematical model to explore the manufacturer's optimal financing strategy. Finally, we explore the supply chain financing from the perspective of capital-constrained upstream enterprises, and consider the guiding role of a well-funded retailer as the dominant player to the manufacturer's financing strategy. Therefore, our study not only supplements the existing literature, but also brings managerial insights on operations and financing decisions for relevant practitioners.

Table 1 Literature comparison

	Yield uncertainty	Capital-constrained manufacturer	Purchase order financing	Buyer direct financing	Credit default
Ding and Wan (2020)	√			√	
Dong et al. (2020)	√	√			
Guo et al. (2018)	√			√	
Gupta and Chen (2019)				√	
Kouvelis and Zhao (2017)					√
Lin and He (2019)					√
Lin and Xiao (2018)		√	√		√
Reindorp et al. (2018)			√		√
Tang and Yang (2020)		√		√	
Tang et al. (2017)			√	√	
Yuan et al. (2021)	√			√	
Zhen et al. (2020)		√		√	
Zou et al. (2021)	√	√			
This paper	√	√	√	√	√

3 Model preliminary

Notations of parameters, random and decision variables in our model are listed in Table 2.

The following assumptions are provided to build our mathematical model of the equilibrium financing scheme for the manufacturer with uncertain yield and credit default.

First, given that the production process is inevitably affected by environmental factors or natural variation of the production technology, the yield of the production is usually uncertain. Following Henig and Gerchak (1990), and Song and Wang (2017), we use a random variable $x \sim U(0, 1)$ to capture the uncertainty of yield in our model. Moreover, to focus on the supply side uncertainty, the market demand D is assumed to be known and normalized to be one (Tang et al., 2017).

Second, SMEs feature a high probability of credit default, since their default will only leave them with no income in the end and will have little impact on their reputation. Similar to Kouvelis and Zhao (2017), we also use $\rho \in [0, 1]$ to denote the default probability of the

Table 2 Notations

D	Demand of the product (assuming $D = 1$)
p	Retail price of the unit product
c	Production cost of the unit product
r_f	Risk-free interest rate (assuming $r_f = 0$)
ρ	Manufacturer's default probability,$0 < \rho < 1$
ε	Bank's interest rate premium, and $\varepsilon = \rho(1 + r_f)/(1 - \rho)$
x	Random variable, obeying the uniform distribution from 0 to 1
w^j	Decision variable for the retailer, denoting unit purchase price of the product, and $0 < c \le w^j \le p$, $j = P, B$
q^j	Decision variable for the manufacturer, denoting the production quantity of the product, and $q^j \ge 1$, $j = P, B$
i^P	Decision variable for the bank, denoting the interest rate under POF
i^B	Decision variable for the retailer, denoting the interest rate under BDF

Table 3 The equilibrium results

Case	Optimal purchase price	Equilibrium financing scheme
$0 < c \le \widehat{c}^P$ (Region I)	$w^{P*} = \widehat{w}$, $w^{B*} > w_0$	POF
$\widehat{c}^P < c \le c^B$ (Region II)	$w^{P*} = \widehat{w}$, $w^{B*} = w_0$	BDF
$c^B < c \le \overline{c}$ (Region III)	$w^{P*} < 2c/(1-\rho)^2$, $w^{B*} = c$	BDF

manufacturer, which is a common knowledge in the supply chain. A larger ρ represents that the manufacturer is more likely to default, namely, a lower reliability of the manufacturer.

Third, the interest rate premium ε set by the bank is related to the default probability. According to the Reduced-Form Approach (Jarrow & Turnbull, 1995), the relationship between interest rate premium and the manufacturer's default probability can be represented as $\varepsilon = \rho(1 + r_f)/(1 - \rho)$. r_f is the risk-free rate of return on capital markets and without loss of generality, normalized to be zero in our model (Jing et al., 2012).

Given the above assumptions, this study considers a supply chain consisting of a retailer (she), a manufacturer (he), and a bank. Based on the known market demand, the retailer orders a product in quantity of D and announces the purchase price w to the market. When observing the retailer's decisions, the manufacturer determines the production quantity q and delivers the order correspondingly. Given the yield uncertainty, the actual output quantity will be qx, and the manufacturer finally obtains $w\min\{qx, 1\}$ at the end of sales season. After accepting the order, the retailer sells the product to the market at price p.

In this supply chain, the manufacturer doesn't have any cash on hand, but he can choose to borrow money from either the bank or the fully-funded retailer. We use the superscript P and B to denote the two financing modes POF and BDF, respectively. The sequence of events under two financing schemes is shown in Fig. 1.

Under POF scheme: (i) The manufacturer can take the purchase order to the bank and obtain a loan to start organizing production after he has received an order from the retailer with purchase price w^P. (ii) According to the manufacturer's default probability, the bank decides

Table 4 Main results

Outcome	POF				BDF			
	$0 < c \le \tilde{c}^P$	$\tilde{c}^P < c \le c^P$	$\rho\uparrow$	$c\uparrow$	$0 < c \le c^B$	$c^B < c \le \bar{c}$	$\rho\uparrow$	$c\uparrow$
w^*	$\widehat{w}$	$\frac{2c}{(1-\rho)^2}$	$\uparrow$	$\uparrow$	w_0	c	$\downarrow$	$\downarrow$
i^*	$\sqrt{\frac{\widehat{w}(1-\rho)^2}{2c}}$	1	$\uparrow$	$\uparrow$	0	0	–	–
q^*	$\frac{\widehat{w}-c-\sqrt{\widehat{w}^2-2\widehat{w}c/(1-\rho)^2}}{c}$	$\frac{2\rho-\rho^2+1}{(1-\rho)^2}$	$\downarrow$	$\downarrow$	$\sqrt{\frac{(p-2w_0)(1-\rho)}{2c}}$	1	$\downarrow$	$\downarrow$
π_M^*	$\widehat{w}(1-\rho)(1-\sqrt{\frac{2c}{\widehat{w}(1-\rho)^2}})$	0	$\downarrow$	first $\uparrow$ then $\downarrow$	$w_0(1-\rho)\big(1-\sqrt{2c/(p-2w_0)(1-\rho)}\big)$	0	$\downarrow$	$\downarrow$
π_R^*	$(1-\rho)(p-\widehat{w})\Big(1-\sqrt{\frac{c}{2\widehat{w}(1-\rho)^2}}\Big)$	$\frac{1}{2}\Big(p(1-\rho)-\frac{2c}{1-\rho}\Big)$	$\downarrow$	$\downarrow$	$(1-\rho)(p-w_0)-\sqrt{2c(p-2w_0)(1-\rho)}$	$\frac{1}{2}(p(1-\rho)-2c)$	$\downarrow$	$\downarrow$

$\uparrow$ denotes "increase", $\downarrow$ denotes "decrease", and – denotes "remain unchanged"

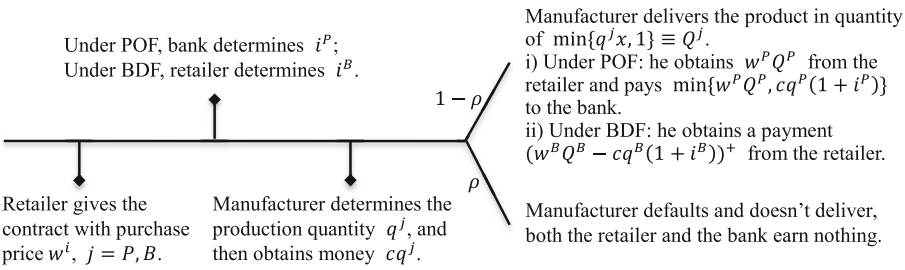


Fig. 1 Sequence of events

the interest rate i^P. (iii) Afterwards, the manufacturer decides the production quantity q^P when considering the yield uncertainty, and obtains cq^P from the bank. iv) At the end of the selling season, if the manufacturer doesn't default, he will obtain a payment $w^P \min\{q^P x, 1\}$ from the retailer and pay $\min\{w^P \min\{q^P x, 1\}, cq^P(1+i^P)\}$ to the bank; otherwise, following Kouvelis and Zhao (2017), the manufacturer will default and not deliver the product, and thus the bank earns nothing.

Similarly, under BDF scheme: (i) The retailer initially decides the wholesale price w^B and the loan interest rate i^B. (ii) If the manufacturer accepts the contract, he will obtain a loan from the retailer and decide the production quantity q^B correspondingly. (iii) Finally, if the manufacturer doesn't default, he can obtain a payment $(w^B \min\{q^B x, 1\} - cq^B(1+i^B))^+$ from the retailer; otherwise, the retailer will pay nothing.

4 Financing with POF or BDF

In this section, we solve the optimal solutions by backward induction when only one financing scheme (POF or BDF) is viable.

4.1 Purchase order financing

Under the POF scheme, the manufacturer takes the order to the bank and obtains the money to organize production. Consequently, the manufacturer's profit function can be expressed as follows:

$$\max_{q^P} \pi_M^P = \max_{q^P} (1-\rho)\left(E_x w^P \min\left\{q^P x, 1\right\} - \left(1+i^P\right)cq^P\right)^+, \tag{1}$$

where $1-\rho$ denotes that the manufacturer does not default, and $(\bullet)^+$ means that $(\bullet)^+ = (\bullet)$ if $(\bullet) > 0$, and $(\bullet)^+ = 0$ otherwise. That is, without default, if the output quantity $q^P x$ is so low that the manufacturer's wholesale revenue is insufficient to repay the bank loan, the manufacturer only needs to repay his entire revenue to the bank due to his limited responsibility.

Under this financing scheme, the bank needs to initially release cq^P to the manufacturer. When the production yield is realized, the bank will get payment $\min\left\{w^P min\{q^P x, 1\}, \left(1+i^P\right)cq^P\right\}$ if the manufacturer doesn't default, whereas it will receive nothing if the manufacturer defaults. Thus, the bank will charge an interest rate premium on the basis of risk-free interest rate to reduce the loss caused by the default risk.

Following Kouvelis and Zhao (2017), we assume that the interest rate market is completely competitive, where i^P satisfies the following equation:

$$cq^P\left(1+r_f+\varepsilon\right)=(1-\rho)E_x\min\left\{w^P min\left\{q^P x,1\right\},\left(1+i^P\right)cq^P\right\}. \tag{2}$$

Given that $r_f=0$ and $\varepsilon=\rho\left(1+r_f\right)/(1-\rho)$, from Eqs. (1) and (2), the profit function of the manufacturer can be expressed as

$$\max_{q^P}\pi_M^P=\max_{q^P}(1-\rho)\left(E_x w^P min\left\{q^P x,1\right\}-\frac{cq^P}{(1-\rho)^2}\right),$$

which shows a higher cost due to his default risk compared with the situation when he involves no financial constraint. This expression indicates a similar theory with Jing et al. (2012), who revealed that under bank credit financing, the profit of a capital-constrained borrower is the same as that without capital constraints. This is because the limited liability of the borrower (i.e., the manufacturer in our model) will not obtain a negative profit even if the actual output quantity is too low to repay the loan. Thus, he will expand his production quantity as much as possible to maximize his profit, just as he has no capital constraints. The different from Jing et al. (2012) is that, our study considers the manufacturer's default risk, which causes the bank to charge a risk premium, and accordingly a higher cost for the manufacturer.

We first solve the manufacturer's decision on production quantity, and then determine the bank's interest rate to obtain the solutions under POF. The results are demonstrated in Lemma 1.

Lemma 1 *Under POF, for any given purchase price that satisfies* $w^P\geq 2c/(1-\rho)^2$,

(i) *the manufacturer's optimal production quantity is* $q^P(w^P)=\sqrt{\frac{w^P(1-\rho)^2}{2c}}$, *and the bank's optimal interest rate is* $i^P(w^P)=\frac{w^P-c-\sqrt{w^{P2}-2w^Pc/(1-\rho)^2}}{c}$;

(ii) *the expected profits of the manufacturer and the retailer are* $E\pi_M^P\left(w^P\right)=w^P(1-\rho)\left(1-\sqrt{\frac{2c}{w^P(1-\rho)^2}}\right)$ *and* $E\pi_R^P\left(w^P\right)=(1-\rho)\left(p-w^P\right)\left(1-\sqrt{\frac{c}{2w^P(1-\rho)^2}}\right)$.

From Lemma 1, we can easily deduce that $dq^P(w^P)/dw^P>0$ and $di^P(w^P)/dw^P<0$. Intuitively, in the case of a higher purchase price, the manufacturer prefers to increase the production quantity to pursue a higher wholesale income, and the bank can survive in the completely competitive market at a lower interest rate. Thus, the manufacturer will benefit from a higher purchase price since such a higher wholesale income leads to a lower loan interest (i.e., $dE\pi_M^P\left(w^P\right)/dw^P>0$). On the contrary, the retailer, whose marginal cost is consistent with the purchase price, tends to set a lower w^P. However, a lower purchase price may result in a lower production quantity that can't meet the market demand, thus reducing the retailer's profit. Therefore, in practice, a quite low purchase price that will damage both profits of the retailer and the manufacturer is not always a good choice for the retailer.

Next, we deduce the retailer's optimal decision on purchase price. In the event that the manufacturer doesn't default, the retailer will pay $w^P min\left\{q^P x,1\right\}$ to the manufacturer and sell the product to the market at price p. Thus, the retailer's expected profit is given by the following:

$$\max_{w^P}\pi_R^P=\max_{w^P}(1-\rho)E_x\left(p-w^P\right)min\left\{q^P x,1\right\}. \tag{3}$$

Define $\widehat{w}$ as the solution of $\frac{dE\pi_R^P(w^P)}{dw^P} = 0$, $\tilde{c}^P \equiv \frac{p(1-\rho)^2}{6}$ and $c^P \equiv \frac{p(1-\rho)^2}{2}$, and then we can obtain Proposition 1.

Proposition 1 *When only POF is available for the manufacturer:*

(i) *if* $0 < c \le \tilde{c}^P$, $w^{P*} = \widehat{w}$, $q^{P*} = \sqrt{\frac{\widehat{w}(1-\rho)^2}{2c}}$, $i^{P*} = \frac{\widehat{w}-c-\sqrt{\widehat{w}^2-2\widehat{w}c/(1-\rho)^2}}{c}$, $\pi_M^{P*} = \widehat{w}(1-\rho)(1-\sqrt{\frac{2c}{\widehat{w}(1-\rho)^2}})$,*and* $\pi_R^{P*} = (1-\rho)(p-\widehat{w})(1-\sqrt{\frac{c}{2\widehat{w}(1-\rho)^2}})$;

(ii) *if* $\tilde{c}^P < c \le c^P$, $w^{P*} = \frac{2c}{(1-\rho)^2}$, $q^{P*} = 1$, $i^{P*} = \frac{2\rho-\rho^2+1}{(1-\rho)^2}$,$\pi_M^{P*} = 0$, *and* $\pi_R^{P*} = \frac{1}{2}(p(1-\rho) - \frac{2c}{1-\rho})$.

From Eq. (3), we can conclude that the retailer's purchase price decision is not influenced by whether the manufacturer is capital constrained, because the manufacturer and the bank can be regarded as a whole with sufficient funds. When the unit production cost is low (i.e., Proposition 1(i)), the retailer tends to increase the purchase price to induce the manufacturer to maintain the production quantity at a higher level than the market demand. Consequently, the retailer can obtain the highest net sales revenue by setting the optimal purchase price at $\widehat{w}$, which is higher than the minimum threshold (i.e., $2c/(1-\rho)^2$).

Corollary 1 *Under POF scheme, when the unit production cost is high (i.e.,* $\tilde{c}^P < c \le c^P$*), the retailer always extracts the entire profit of the manufacturer.*

While when the unit production cost is high (i.e., Proposition 1(ii), which further results in Corollary 1), the retailer no longer profits from a high purchase price and thus a minimum purchase price is set to maximize her profit. This price also ensures that the production quantity is at least equal to the demand and the bank is willing to provide POF. In this case, the manufacturer obtains no profit and the retailer occupies all channel profit. Similar to Jing et al. (2012), given the assumption that the manufacturer is a Pareto or good-willed participant, he is still willing to finance and manufacture although the marginal profit is zero. This finding is similar with Tang et al. (2017), in which the upstream supplier also earns nothing in POF under certain conditions. In real life, giant retailers are able to negotiate the purchase price at the lowest level for profit-seeking. For example, Walmart makes a purchase deal only when it is convinced that it will not buy the products at a lower price elsewhere. Once the purchase relationship is established, manufacturers can hardly raise the price. Recently, a large number of SME manufacturers in China reportedly profit less gradually as the cost of raw materials increases under the influence of COVID-19. The reason is that these SMEs have a weak bargaining power, especially when they can only obtain funds through a sole financing scheme (Noting that in the next subsection that explores the BDF scheme, we also find that the manufacturer will earn nothing under certain conditions).

In summary, Proposition 1 indicates that when the production cost is low, the retailer can motivate the manufacturer to produce more by raising the purchase price so that the whole supply chain can obtain higher profits. Otherwise, there is no need for the retailer to raise the purchase price in vain, given that this raising only increases her own cost.

4.2 Buyer direct financing

Under the BDF scheme, the manufacturer borrows money from the retailer to organize production. Correspondingly, the retailer declares the purchase price and the interest rate sequentially. Then, the manufacturer decides the production quantity and obtains the loan

cq^B from the retailer. Finally, the yield is realized. If the manufacturer doesn't default, he will get payment $\left(E_x w^B \min\left\{q^B x, 1\right\} - \left(1+i^B\right)cq^B\right)^+$ from the retailer, and the retailer could obtain the sales revenue $p\min\left\{q^B x, 1\right\}$; otherwise, the retailer will receive nothing and need not pay to the manufacturer. The expected profit functions of the manufacturer and the retailer under BDF are given as follows:

$$\max_{q^B} \pi_M^B = \max_{q^B} (1-\rho)\left(E_x w^B \min\left\{q^B x, 1\right\} - \left(1+i^B\right)cq^B\right)^+, \tag{4}$$

$$\max_{i^B} \pi_R^B = \max_{i^B} (1-\rho)E_x\left[p\min\left\{q^B x, 1\right\} - \left(w^B \min\left\{q^B x, 1\right\} - \left(1+i^B\right)cq^B\right)^+\right] - cq^B. \tag{5}$$

Define $c^B \equiv \frac{p(1-\rho)}{2(2-\rho)}$, $\bar{c} \equiv \frac{p(1-\rho)}{2}$, $i_1^B(w^B) \equiv \frac{w^B}{c}\left(1 - \sqrt{\frac{(p-2w^B)(1-\rho)-2c}{(p-2w^B)(1-\rho)}}\right) - 1$, and w_0 as the larger solution of $i_1^B\left(w^B\right) = 0$. Consequently, we can obtain the optimal solutions under BDF, as demonstrated in Lemma 2.

Lemma 2 *Under BDF, for a given purchase price:*

(i) *if* $0 < c \le c^B \cap w_0 \le w < \frac{p}{2} - \frac{c}{1-\rho}$, $i^B\left(w^B\right) = i_1^B(w^B)$, $q^B\left(w^B\right) = \sqrt{\frac{(p-2w^B)(1-\rho)}{2c}}$, $\pi_M^B\left(w^B\right) = w^B(1-\rho)\left(1 - \sqrt{\frac{2c}{(p-2w^B)(1-\rho)}}\right)$, *and* $\pi_R^B\left(w^B\right) = (1-\rho)\left(p-w^B\right) - \sqrt{2c\left(p-2w^B\right)(1-\rho)}$;

(ii) *if* $c^B < c \le \bar{c} \cap c \le w < p$, $i^B\left(w^B\right) = \frac{w^B}{c} - 1$, $q^B = 1$, $\pi_M^B = 0$, *and* $\pi_R^B = \frac{1}{2}(p(1-\rho) - 2c)$.

When the unit production cost is low (i.e., Lemma 2(i)), $dq^B(w^B)/dw^B < 0$ and $di^B(w^B)/dw^B > 0$ can be easily derived. That is, with the increase of the purchase price, the retailer will set a higher interest rate to compensate for the increased procurement cost. As a result, although the marginal wholesale revenue is higher, the manufacturer must reduce the production quantity due to the more expensive financing. Therefore, the profit of the retailer suffers from a higher purchase price (i.e., $d\pi_R^B\left(w^B\right)/dw^B < 0$). This finding indicates that the manufacturer should not only focus on the purchase price, but also consider the interest rate comprehensively when deciding the optimal production quantity.

Recalling that under the POF scheme, the loan risk is taken by the bank and the interest rate market is completely competitive. As a result, the manufacturer can simultaneously raise the production quantity and obtain a decreased interest rate as the purchase price increases, thereby benefiting himself more. However, under the BDF scheme, the loan risk is taken by the retailer, who determines the loan cost of the manufacturer. As the purchase price increases, the retailer will raise the interest rate to make up for the loss of sales revenue. The manufacturer anticipates this increase of loan cost and consequently, will finally cut down production.

Corollary 2 *When the unit production cost is high (i.e.,* $c^B < c \le \bar{c}$*), the retailer's optimal decision under BDF will shrink the manufacturer's profit to be zero.*

Particularly, when the unit production cost is high (i.e., Lemma 2(ii), which further results in Corollary 2), the retailer will extract the manufacturer's entire profit via setting the purchase price and interest rate to satisfy $c\left(1+i^B\right) = w^B$. Then, the manufacturer, as a rational decision-maker, will not expand its yield in vain, and hence $q^B = 1$ always holds.

Next, given the retailer's profit function $\pi_R^B(w^B) = (1-\rho)(p-w^B) - \sqrt{2c(p-2w^B)(1-\rho)}$, the optimal purchase price and equilibrium solution under BDF can be deduced in the following proposition.

Proposition 2 *When only BDF is available for the manufacturer:*

(i) *if* $0 < c \le c^B$, $w^{B*} = w_0$, $i^{B*} = 0$, $q^{B*} = \sqrt{(p-2w_0)(1-\rho)/2c}$, $\pi_M^{B*} = w_0(1-\rho)\left(1-\sqrt{2c/(p-2w_0)(1-\rho)}\right)$, *and* $\pi_R^{B*} = (1-\rho)(p-w_0) - \sqrt{2c(p-2w_0)(1-\rho)}$;

(ii) *if* $c^B < c \le \bar{c}$, $w^{B*} = c$ *and* $i^{B*} = 0$, *which satisfies* $w^{B*} = c(1+i^{B*})$, $q^{B*} = 1$, $\pi_M^{B*} = 0$, *and* $\pi_R^{B*} = \frac{1}{2}(p(1-\rho)-2c)$.

Under BDF, the retailer not only engages in distribution, but also finances the manufacturer's production. In other words, the retailer performs as a buyer and a lender. However, Proposition 2 shows an interesting finding that the interest rate is always shrunk to zero, thereby indicating that the entire retailer's profit is generated from net product sales. This finding is consistent with prepayment, a trade credit financing, in which the manufacturer obtains payment from the retailer at the beginning to organize production activities, while at the expensive of a lower purchase price. Consequently, $w/(1+i)$ can be regarded as the discounted purchase price under the prepayment mechanism. Proposition 2 suggests that the retailer who plays the dual roles of buyer and lender, can achieve a higher profit by giving up the benefits of interest rate and paying a lower purchase price instead.

5 Sensitivity analysis and managerial discussion

This section investigates how changes in the default risk and the unit production cost will affect the optimal solutions under two financing schemes, respectively, and then obtains the equilibrium solutions and the resulting managerial implications.

5.1 Impact of the default risk

In our model, the manufacturer's default risk is represented by his default probability. That is, the manufacturer will be considered to have a high default risk, if he defaults (i.e., refusing to deliver orders at the end of production season). Thus, we use the default probability to explore the impact of the default risk, and conclude in Proposition 3.

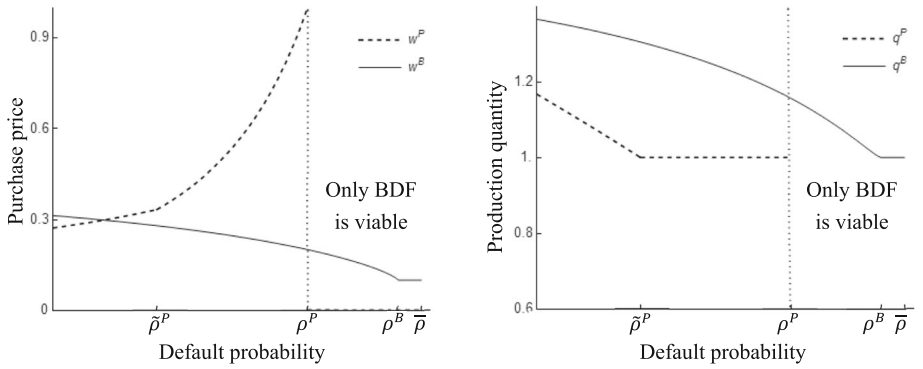
Proposition 3 *As the default probability* ρ *increases:*

(i) *the purchase price under POF* (w^{P*}) *increases, and that under BDF* (w^{B*}) *decreases;*

(ii) *the interest rate under POF* (i^{P*}) *increases, and that under BDF* (i^{B*}) *is independent of* ρ;

(iii) *both the production quantities and the profits of the manufacturer and the retailer under POF* (q^{P*}, π_M^{P*}) *and BDF* (q^{B*}, π_M^{B*}) *decrease.*

Under POF, when the default probability increases, the bank must charge an additional amount of interest rate i^{P*} to offset the default risk. This rate also increases the financing pressure on the manufacturer, and then he will reduce the production quantity q^{P*} to alleviate the pressure. Meanwhile, to satisfy the market demand, the retailer, aiming to maximize her own profit, will increase the purchase price w^{P*} to encourage the manufacturer to maintain production quantity above the market demand.



(a) Purchase price **(b)** Production quantity

Fig. 2 Impact of default probability on the decisions under POF and BDF ($c = 0.1$)

Given that the retailer obtains profit solely from net sales of the product (i.e., $i^{B*} = 0$) under BDF, she tends to reduce the marginal purchase cost w^{B*} to maximize her profit, and then the rational manufacturer is unwilling to increase the production quantity q^{B*}. In other words, under BDF, the retailer is forced to share default risk and yield uncertainty, thus charging a lower purchase price when the default risk increases (i.e., $w^{B*} < w^{P*}$) as shown in Fig. 2a). Therefore, Proposition 3 also indicates that the retailer has different attitudes towards the manufacturer's default risk when playing different roles. Specifically, as the default probability increases: (i) since the retailer only acts as the buyer under POF, it is more sensible to increase the purchase price and thus meet the market demand; (ii) while under BDF, it is more profitable to reduce the purchase price to mitigate the risk given that the retailer also plays as the borrower.

Furthermore, recall that the manufacturer must invest in production before the yield uncertainty is realized. The bank or the retailer must take more risk in order to produce more products to meet market demand, and the low interest rate under BDF allows it to mitigate this uncertainty risk better than POF. Thus, just as shown in Fig. 2b), a higher production quantity can be achieved under BDF. Moreover, noting that only BDF is viable when the default probability is high, this finding also reflects that BDF can bear a higher default risk.

From the perspective of the whole supply chain, neither the manufacturer nor the retailer can benefit from an increasing default probability, thereby indicating a more volatile supply chain. Furthermore, the supply chain's output will also be at a lower level when the default risk is higher. Thus, we can conclude that the supply chain with a high default risk is an inefficient one.

5.2 Impact of the unit production cost

This subsection examines how the manufacturer's unit production cost affects the optimal decisions and the entire supply chain's profit under both financing schemes.

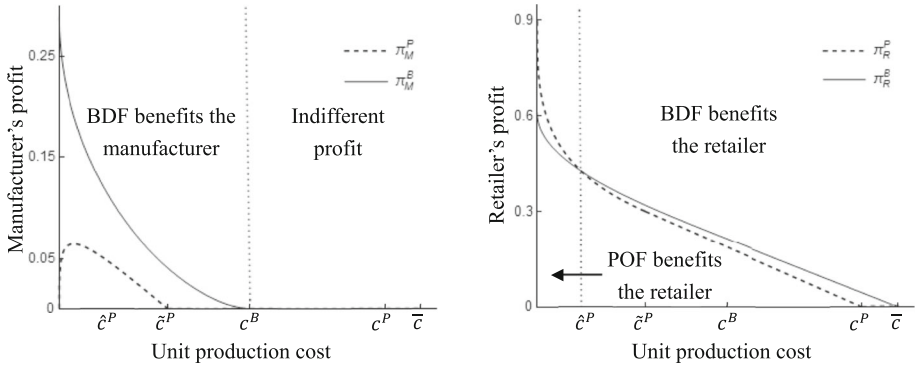
Proposition 4 *As the manufacturer's unit production cost c increases:*

(i) *the changes in all optimal decisions are consistent with the situation when ρ increases;*

(ii) *the manufacturer's profit under POF (π_M^{P*}) first increases and then decreases, and that under BDF (π_M^{B*}) monotonically decreases;*
(iii) *both the retailer's profits under POF (π_R^{P*}) and BDF (π_R^{B*}) decrease;*
(iv) *both the entire supply chain's profits under POF and BDF decrease.*

As the unit production cost increases, the capital-constrained manufacturer needs to borrow an increasing amount of money from the bank or the retailer to produce. Consequently, if the manufacturer defaults, the lender's loss will be higher. Thus, all the optimal decisions are consistent with those as the default probability increases (i.e., Proposition 4(i)). In particular, under POF, when the unit production cost is low, the purchase price offered by the retailer can stimulate the manufacturer to finance and produce, thereby resulting in a higher profit. However, with the further increase of unit production cost, the additional income from the increased purchase price cannot make up for the increase of capital pressure due to the higher interest rate charged by the bank (i.e., Proposition 4(ii)). In addition, it is intuitive that the increase of unit production cost leads to a corresponding increase in the purchase price, thereby ultimately resulting in the reduction of output quantity and low profits of the supply chain (i.e., Propositions (iii) and (iv)).

Unlike Tang et al. (2017), who concluded that POF and BDF present no difference in profits for suppliers and manufacturers when the supplier's performance risk is symmetrical, we find that the manufacturer and the retailer may benefit from different financing schemes when considering yield uncertainty and credit default. Figure 3 shows the comparison of the retailer's and the manufacturer's profits under two financing schemes. From Fig. 3b), a threshold $\widehat{c}^P \in \left(0, \tilde{c}^P\right]$ that ensures $\pi_R^P(\widehat{w}) = \pi_R^B(w_0)$ can be found. In the case of a low unit production cost (i.e., $0 < c \leq \widehat{c}^P$), the loss caused by yield uncertainty is minor, and thus the interest rate charged by the bank under POF is low. Consequently, the retailer does not need to increase the purchase price to encourage the manufacturer to produce more products. Therefore, the lower purchase price under POF can make the retailer more profitable. Whereas, the manufacturer's marginal wholesale income must be reduced, and thus his profit is always worse under POF, as shown in Fig. 3a). This also provides insights for the manufacturer to choose the optimal financing scheme; that is, it is necessary to consider not only the interest rate factor, but also his own production cost level.



(a) Manufacturer's profit **(b)** Retailer's profit

Fig. 3 Impact of unit production cost on profits under POF and BDF ($\rho = 0.1$)

5.3 Manufacturer's preferable financing scheme between POF and BDF

In this subsection, we deduce the manufacturer's preferable financing scheme when both POF and BDF are available. That is, given the contracts with different purchase price (i.e., w^{P*} and w^{B*}), the manufacturer prefers the financing scheme that makes him more profitable. The results are concluded in Corollary 3.

Corollary 3 *For the manufacturer, more profitable financing scheme is POF when* $c^B < c \leq c^P$ *and* $0 < \rho < \overline{\rho}$ *(Region I in* Fig. 4*), and BDF otherwise (Regions II and III in* Fig. 4*).*

From Corollary 3 and Fig. 4, it is easy to draw conclusions as the following: (i) BDF always makes the manufacturer more profitable when the unit production cost is low (i.e., $c \leq c^B$), as shown in Fig. 3a); (ii) otherwise, although both the manufacturer's profit under POF and BDF are equal to zero, he prefers POF when his default risk is relatively low and the unit production cost is moderate (i.e., $0 < \rho < \overline{\rho} \cap c^B < c \leq c^P$), and BDF when the unit production cost is high (i.e., $\max\{c^B, c^P\} < c \leq \overline{c}$). Particularly, we focus on the situation where the manufacturer's profit is zero (i.e., $c > c^B$). Similar to Jing et al. (2012), we assume that financing from the bank is more reliable and attractive to the manufacturer when there is no difference in his profits between POF and BDF. Thus, POF is always more preferable when both POF and BDF are available (i.e., Region I in Fig. 4).

Furthermore, a high unit production cost (i.e., Region III in Fig. 4) not only increases the loss of uncertain output, but also forces the bank to bear the high default loss due to the high borrowing cost. Thus, the bank is reluctant to finance the manufacturer. However, the retailer, not only acting as a lender, can still extract all profit of the manufacturer by setting $c\left(1+i^B\right) = w$. Therefore, only BDF is optional for the manufacturer in this case (i.e., Region III in Fig. 4). In other words, BDF can tolerate higher risk of default and yield uncertainty than POF. This finding is similar to Lu et al. (2019), who deduced that compared with the third-party guarantee model, the supplier still has an incentive to guarantee even if the market risk is high and the retailer is poor.

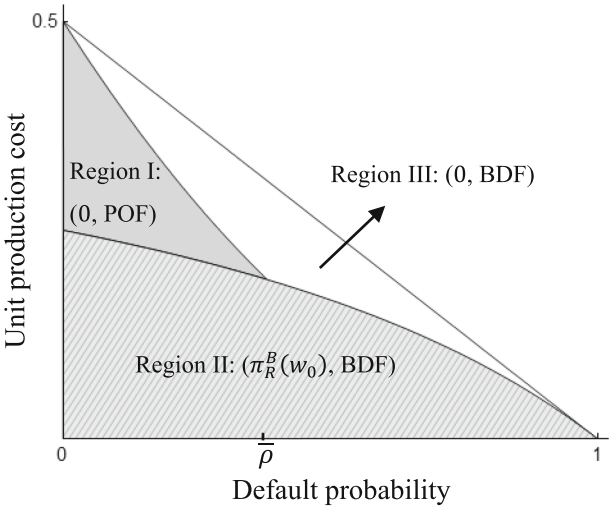


Fig. 4 Manufacturer's preferable financing scheme

5.4 Financing equilibrium between POF and BDF

Similar to Jing et al. (2012) and Jiang et al. (2021), we also discuss the impact of supply chain leadership on the equilibrium financing strategy. The retailer, as the leader in the Stackelberg game, has the right to induce the manufacturer to choose the financing scheme that is beneficial to her by adjusting the purchase price. Thus, in this subsection, we analyze the optimal strategy from the perspective of the retailer, and discuss how unit production cost and default risk affect the financing equilibrium.

When POF (BDF) offers a higher profit for the retailer, she will maintain the optimal purchase price decisions under both financing schemes if the manufacturer prefers the same financing scheme. If their preferences are inconsistent, the retailer will adjust the purchase price under BDF (POF) to deviate from the optimal decision w^{B*} (w^{P*}), thus making POF (BDF) more attractive to the manufacturer. On this basis, we obtain the equilibrium solutions in Proposition 5.

Proposition 5 *The retailer's optimal purchase price and the equilibrium financing scheme can be concluded in* Table 3 and Fig. 5.

Proposition 5 indicates that only when the unit production cost is moderate does the retailer not distort the purchase price; otherwise, she tends to induce the manufacturer to choose a more profitable financing scheme of her. Particularly, recalling Fig. 3b), the retailer can obtain a higher profit under POF due to the lower purchase cost when the unit production cost is low (i.e., Region I in Fig. 5). Thus, the purchase price under POF is maintained at the optimal level w^{P*}, whereas that under BDF is distorted to a sufficiently high level since $d\pi_M^B(w^B)/dw^B < 0$ when w^B is high. Then, the manufacturer is induced to choose POF that ensures him more profitable. Furthermore, the retailer only acts as the buyer and obtains the net sales revenue under POF. However, as analyzed in Sect. 4.2, when the unit production cost is high (i.e., Region III in Fig. 5), the retailer, as a buyer and a lender, can maximize her profit under BDF by compressing the marginal purchase cost to the unit production cost. Thus, BDF makes the retailer more profitable in this case, and a lower purchase price is set

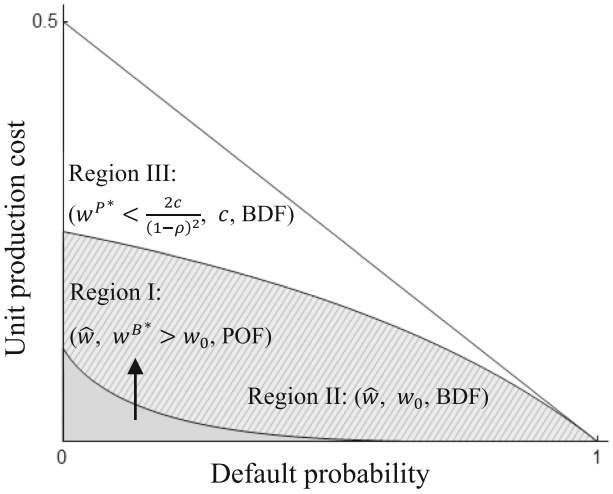


Fig. 5 Equilibrium solutions when both POF and BDF are available

under POF since $d\pi_M^P\left(w^P\right)/dw^P > 0$. In addition, this distorted purchase price is below the minimum threshold that ensures POF available, and then only BDF can provide financing for the manufacturer in this case.

Therefore, Proposition 5 provides the following management enlightenments for the retailer: (i) when the unit production cost is low, the retailer can benefit from a low purchase cost under POF, and thus the purchase price under BDF should be distorted upward to induce the manufacturer to choose POF; (ii) when the unit production cost is high, the high interest rate charged by the bank under POF will cause the manufacturer to reduce its willingness to produce, thus hurting the retailer. Then, the purchase price under POF should be distorted downward to induce the manufacturer to choose BDF.

From Proposition 5, we can conclude that the equilibrium financing scheme is POF when the unit production cost is low (i.e., $0 < c \leq \widehat{c}^P$), and BDF otherwise. This is because the bank is more willing to finance the manufacturer due to that this low cost implies less loss in default risk and output uncertainty. Given $d\widehat{c}^P/d\rho < 0$ and $dc^B/d\rho < 0$, Corollary 4 can be obtained.

Corollary 4 *A higher default risk results in a lower probability of manufacturer's positive profit and a lower probability of choosing POF.*

Recall that the manufacturer has limited liability, indicating that his worst outcome is zero. Moreover, given a high unit production cost, the lender's loss of financing is high when the manufacturer defaults. Therefore, the retailer and the bank tend to shrink the manufacturer's profit to be zero if the default risk is higher. In addition, in the case of a higher default risk, since a higher interest rate must be charged under POF, the retailer must set a relatively high purchase price to ensure that the manufacturer is willing to produce more to meet the market demand. Therefore, it is less likely for the retailer to profit more under POF. This finding also indicates that BDF can tolerate a higher default risk and make the manufacturer and the retailer more profitable.

5.5 Pareto improvement

The Pareto region can be depicted in Proposition 6 and Fig. 6 by comparing preferable financing schemes of the manufacturer and the retailer.

Proposition 6 *When $\widehat{c}^P < c \leq c^B \cup max\{c^B, c^P\} < c \leq \overline{c}$, Pareto improvement achieves; in this Pareto region, BDF is always the better choice.*

From Proposition 6, we find that only BDF achieves Pareto improvement. Especially, when the unit production cost is moderate (i.e., $\widehat{c}^P < c \leq c^B$), both the production quantity and total channel profit are higher under BDF. This is because, the retailer cannot obtain financing income under POF, and then her profit is lower due to the higher purchase cost, compared to that under BDF; while the manufacturer still need to bear the pressure of paying loan interest, thus being reluctant to increase the production quantity and obtaining a lower profit. Moreover, according to the previous analysis, we find that only BDF, which can tolerate a higher risk, is available in the case of a high unit production cost (i.e., $max\{c^B, c^P\} < c \leq \overline{c}$), thus achieving Pareto improvement. While in other cases (i.e., $0 < c \leq \widehat{c}^P \cup c^B < c \leq c^P$), the retailer tends to distort the purchase price to induce the manufacturer's financing strategy. Proposition 6 illustrates that BDF is a better financing scheme for the supply chain since it can achieve Pareto improvement due to the retailer's dual roles.

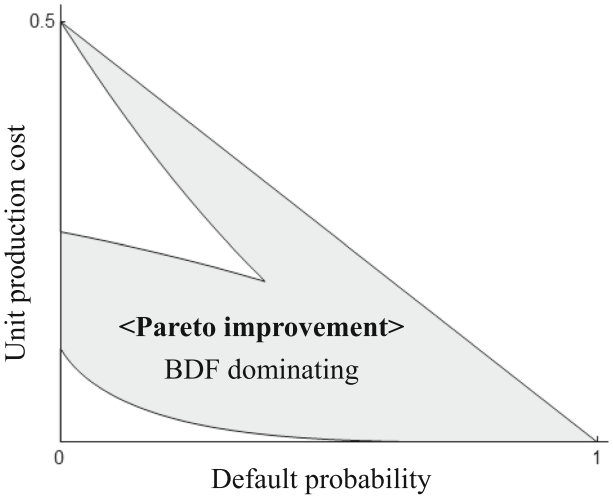


Fig. 6 Pareto region

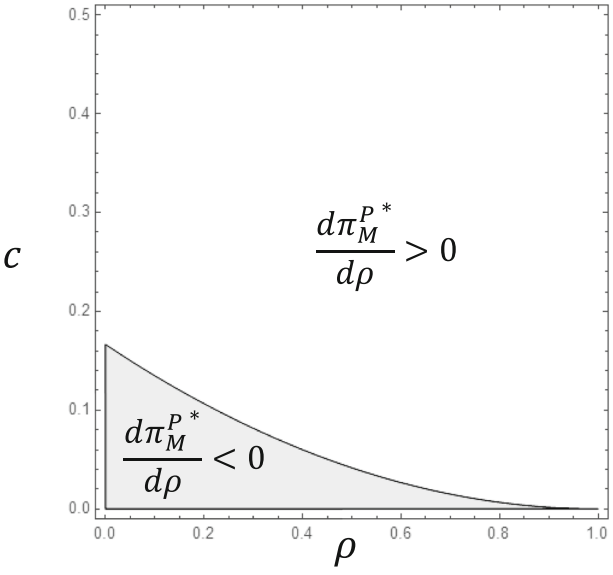


Fig. 7 Region of $\frac{d\pi_M^{P*}}{d\rho} < 0$

5.6 Managerial implications

The managerial implications of this study are fourfold. First, we provide enlightenment of optimal financing scheme (POF or BDF) for capital-constrained manufacturers when considering their yield uncertainty and default risk. Especially, when the unit production cost is high, the manufacturer's profit is shrunk to zero regardless of the financing scheme.

Therefore, in this case, manufacturers are advised to reduce their own default risk to obtain a higher purchase price and hence positive profit.

Second, we explain why in practice, buying firms (i.e., retailers) are willing to offer a lower interest rate than banks. Surprisingly, the optimal interest rate is zero in our model, meaning that BDF is equivalent to prepayment mechanism. In other words, manufacturers can maximize profits by simply setting a discounted purchase price $w/(1 + i)$ to reduce purchase costs. Furthermore, only BDF can achieve Pareto improvement due to retailers' dual roles.

Third, we provide banks with how and whether to provide financing. Particularly, because a higher unit production cost indicates a higher borrowing cost, banks must bear the higher loss of yield uncertainty and default risk. Thus, it is irrational to provide POF for banks. However, retailers, who have the flexibility to set purchase prices and interest rates, can still benefit from BDF. That is, BDF can tolerate a higher risk.

Fourth, we explain why the setting of retailers' purchase price has a guiding effect on manufacturers' financing preference and indicate what kind of guiding effect this setting has. This is consistent with reality, since retailers as the game leaders, have right to set the purchase price under the unfavorable financing scheme to deviate from the optimal level, thus making this scheme unprofitable for manufacturers.

6 Conclusion

This paper investigates the optimal financing strategy of a capital-constrained manufacturer by establishing a game model with random yield and default risk. The comparison analysis between BDF and POF schemes concludes that given a high cost of unit production, if the default risk is low, the manufacturer prefers POF which is more reliable, although his profits under POF and BDF are indifferent. The retailer, who benefits from BDF, has an incentive to distort the purchase price under POF to induce the manufacturer to choose BDF. If the default risk is high, only BDF is viable due to it can better tolerate default risk and yield uncertainty. In the case of the moderate unit production cost, BDF is always preferable for both participants since it can achieve Pareto improvement. Especially when this cost is below a certain threshold, the retailer tends to deviate the purchase price under BDF from the optimal level, and thus the manufacturer will choose POF. On this basis, we explore how changes in the unit production cost and the default risk will affect the optimal decisions and channel profits. The results reveal that the efficiency of the entire supply chain suffers from a higher unit production cost and default risk.

In our model, we assume that the information is perfectly symmetrical, namely, the default probability of the manufacturer is public knowledge. In practice, this probability may not be known to all participants of the supply chain. The asymmetry default probability will affect the willingness of the bank and the retailer to provide financing, and thus influence the equilibrium financing strategy. Therefore, information asymmetry can be an interesting and meaningful direction for the future expansion of this paper.

Acknowledgments The authors sincerely thank the editor and the reviewers for their constructive comments and suggestions that improve the paper. This work is supported by the National Natural Science Foundation of China (Grant No. 72102163), and the Humanities and Social Sciences Youth Foundation, Ministry of Education of China (Grant No. 20YJC630037).

Funding Funding were provided by The Ministry of education of Humanities and Social Science project (20YJC630037) and National Natural Science Foundation of China (Grant No. 72102163).

Appendix

Summary of main results

The optimal outcomes and their sensitivity analysis under two financing schemes are summarized in Table 4.

Proof of Lemma 1 and Proposition 1

Given $(a-b)^+ = a - \min\{a,b\}$, $r_f = 0$, $\varepsilon = \rho/(1-\rho)$ and Eq. (2), we can obtain that

$$\begin{aligned}
\max_{q^P} \pi_M^P &= (1-\rho)\left(E_x w^P min\left\{q^P x, 1\right\} - \left(1+i^P\right) cq^P\right)^+ \\
&= (1-\rho)\, E_x\left(w^P min\left\{q^P x, 1\right\} - \min\left\{w^P min\left\{q^P x, 1\right\}, \left(1+i^P\right) cq^P\right\}\right) \\
&= (1-\rho)\,(E_x w^P min\left\{q^P x, 1\right\} - \frac{cq^P}{(1-\rho)^2}) \\
&= (1-\rho)\,(w^P(\int_0^{\frac{1}{q^P}} q^P x dx + \int_{\frac{1}{q^P}}^1 1 dx) - \frac{cq^P}{(1-\rho)^2}) \\
&= (1-\rho)\left(w^P(1-\frac{1}{2q^P}) - \frac{cq^P}{(1-\rho)^2}\right).
\end{aligned}$$

Then, we can obtain that $\frac{d\pi_M^P}{dq^P} = (1-\rho)\left(\frac{w^P}{2(q^P)^2} - \frac{c}{(1-\rho)^2}\right)$, and $\frac{d^2\pi_M^P}{dq^{P2}} = -\frac{(1-\rho)w^P}{(q^P)^3} < 0$. Thus, π_M^P is concave in q^P, and the optimal production decision $q^P(w^P) = \sqrt{\frac{w^P(1-\rho)^2}{2c}}$, which is the solution of $\frac{d\pi_M^P}{dq^P} = 0$. Furthermore, when $1/q^P \le x \le 1$, $min\{q^P x, 1\} = 1$, and there must exist $w^P > \left(1+i^P\right)cq^P$, which equals to $1/q^P > \left(1+i^P\right)c/w^P$. Thus,

$$\min\left\{w^P min\left\{q^P x, 1\right\}, \left(1+i^P\right)cq^P\right\} = \begin{cases} \left(1+i^P\right)cq^P, \frac{(1+i^P)c}{w} \le x \le 1 \\ wq^P x, 0 \le x < \frac{(1+i^P)c}{w} \end{cases},$$

and Eq. (2) can be simplified as $\frac{c}{(1-\rho)^2} = \left(1+i^P\right)c - \frac{\left(1+i^P\right)^2 c^2}{2w^P}$. Therefore, we can deduce to $i^P(w^P) = \frac{w^P - c - \sqrt{w^{P2} - 2w^P c/(1-\rho)^2}}{c}$, where $w^P \ge 2c/(1-\rho)^2$ must be satisfied so that $i^P(w^P)$ can make sense.

The retailer needs to maximize her profit as the following:

$$\begin{aligned}
&\max_{w^P} E\pi_R^P = \max_{w^P}(1-\rho)\left(p - w^P\right)\left(1 - \sqrt{\frac{c}{2w^P(1-\rho)^2}}\right), \\
&s.t. 2c/(1-\rho)^2 \le w < p, \\
&0 < c \le p(1-\rho)^2/2.
\end{aligned}$$

Given $\frac{d^2 E\pi_R^P(w^P)}{dw^{P2}} = -\frac{(3p+w^P)}{4w^{P2}}\sqrt{\frac{c}{2w^P}} < 0$, then $\widehat{w}$, the solution of $\frac{dE\pi_R^P}{dw^P} = 0$, must satisfy $G(w) \equiv 8w^3 - c(p+w)^2/(1-\rho)^2 = 0$. Given that $c \le w(1-\rho)^2/2 < 2p(1-\rho)^2$, then $G(c) < 0$ and $G(p) > 0$ hold, meaning that $G(w)$ has a unique solution when $c < \widehat{w} < p$. Since $dE\pi_R^P/dw^P > 0$ is equal to $G(x) < 0$. Thus, as w increases, $E\pi_R^P$ increases when $w < \widehat{w}$, and decreases otherwise.

When $0 < c \le \frac{p(1-\rho)^2}{6}, G\left(\frac{2c}{(1-\rho)^2}\right) < 0$ holds, and thus $\widehat{w} > \frac{2c}{(1-\rho)^2}$ and $w^{P*} = \widehat{w}$; when $\frac{p(1-\rho)^2}{6} < c \le \frac{(1-\rho)^2}{2}, G\left(\frac{2c}{(1-\rho)^2}\right) > 0$ holds, and thus $w^{P*} = \frac{2c}{(1-\rho)^2}$ since $\frac{2c}{(1-\rho)^2} \le w < p$. ■

Proof of Lemma 2

Given.

$$\left(E_x w^B \min\left\{q^B x, 1\right\} - \left(1+i^B\right)cq^B\right)^+ = \begin{cases} 0, 0 \le x \le \frac{c\left(1+i^B\right)}{w^B} \\ w^B q^B x - \left(1+i^B\right)cq^B, \frac{c\left(1+i^B\right)}{w^B} < x \le \frac{1}{q^B}, \\ w^B - \left(1+i^B\right)cq^B, \frac{1}{q^B} < x \le 1 \end{cases}$$

Equation (4) can be simplified as.

$$\max_{q^B} \pi_M^B = (1-\rho)\left(w^B - \frac{w^B}{2q^B} + \frac{q^B c^2\left(1+i^B\right)^2}{2w^B} - \left(1+i^B\right)cq^B\right).$$

$\frac{d\pi_M^B}{dq^B} = (1-\rho)(\frac{w^B}{2(q^B)^2} + \frac{c^2(1+i^B)^2}{2w^B} - c\left(1+i^B\right))$, and $\frac{d^2\pi_M^B}{dq^{B2}} = -\frac{(1-\rho)w^B}{(q^B)^3} < 0$. Thus, π_M^B is concave in q^B, and $q^B(i^B, w^B) = \frac{w^B}{\sqrt{2w^B c(1+i^B) - c^2(1+i^B)^2}}$. By substituting $q^B(i^B, w^B)$ into Eq. (5), the retailer's expected profit can be simplified as.

$$\max_{i^B} \pi_R^B = (1-\rho)\left((p-w^B)\left(1 - \frac{1}{2q^B(i^B, w^B)}\right) - \frac{q^B(i^B, w^B)c^2\left(1+i^B\right)^2}{2w^B} + \left(1+i^B\right)cq^B(i^B, w^B)\right) - cq^B\left(i^B, w^B\right).$$

Case 1 When $c < w^B < \frac{p}{2} - \frac{c}{1-\rho}$, $i_1^B(w^B) = \frac{w^B}{c}\left(1 - \sqrt{\frac{(p-2w^B)(1-\rho)-2c}{(p-2w^B)(1-\rho)}}\right) - 1$ and $i_2^B(w) = \frac{w^B}{c}\left(1 + \sqrt{\frac{(p-2w^B)(1-\rho)-2c}{(p-2w^B)(1-\rho)}}\right) - 1$, both of which satisfy $\frac{d^2\pi_R^B}{di^{B2}} < 0$, are solutions of $\frac{d\pi_R^B}{di^B} = 0$. Moreover, $\pi_R^B\left(i_1^B, w^B\right) = \pi_R^B\left(i_2^B, w^B\right)$ also holds. Then, we need to judge if both i_1^B and i_2^B are greater than 0. First, we can find that $i_2^B > 0$ always holds due to $w^B > c$. Second, define $F(w) \equiv 2(3-2\rho)w^2 - 2(1-\rho)(p+c)w + cp(1-\rho)$, and w_1, w_2 are two solutions of $F(w) = 0$ and $w_1 < w_2$. Then, it is easy to prove that $F\left(\frac{p}{2} - \frac{c}{1-\rho}\right) = (p(1-\rho) - 2(2-\rho)c)^2/2(1-\rho)^2 \ge 0$ and $F(c) < 0$ always hold when $c < \frac{p(1-\rho)}{2(2-\rho)}$. Since $i_1^B > 0$ is equal to $F(w) > 0$, $i_1^B > 0$ holds when $w_0 < w < \frac{p}{2} - \frac{c}{1-\rho}$ and $0 < c < \frac{(1-\rho)p}{2(2-\rho)}$, where $w_0 \equiv w_2 = \frac{(p+c)(1-\rho) + \sqrt{\left((p-c)^2(1-\rho) - 2cp\right)(1-\rho)}}{6-4\rho}$.

Furthermore, although the retailer's profits generated by these two interest rates (i.e., i_1^B,i_2^B) are indifferent, she prefers to set a lower interest rate that looks more attractive to the manufacturer. Thus, $i^B\left(w^B\right) = i_1^B$ when $0 < c \le \frac{(1-\rho)p}{2(2-\rho)}$. Then, $q^B\left(w^B\right) = \sqrt{\frac{(p-2w^B)(1-\rho)}{2c}}$, and $E\pi_R^B\left(w^B\right) = (1-\rho)\left(p-w^B\right) - \sqrt{2c\left(p-2w^B\right)(1-\rho)}$.

Case 2 When $\max\{c, \frac{p}{2} - \frac{c}{1-\rho}\} < w < p$ and $0 < c \le \frac{p(1-\rho)}{2}$, we can obtain that $i^B\left(w^B\right) = \frac{w^B}{c} - 1$ and $\frac{d^2\pi_R^B}{di^{B^2}} = \frac{c^2\left((p-2w^B)(1-\rho)-2c\right)}{2w^{B^2}} < 0$. In this case, $q^B = 1$, $E\pi_R^B = \frac{1}{2}(p(1-\rho)-2c)$, and $E\pi_M^B = 0$.

By comparing the retailer's profits under two cases when $0 < c \le \frac{p(1-\rho)}{2(2-\rho)}$, we find that $(1-\rho)\left(p-w^B\right) - \sqrt{2c\left(p-2w^B\right)(1-\rho)} \ge \frac{1}{2}(p(1-\rho)-2c)$ always holds, and thus $i^B\left(w^B\right) = i_1^B$. ■

Proof of Proposition 2

When $0 < c \le \frac{p(1-\rho)}{2(2-\rho)}$, the retailer needs to maximize her profit under BDF. This optimization problem is given by the following:

$$\max_{w^B} E\pi_R^B = \max_{w^B}\left[(1-\rho)\left(p-w^B\right) - \sqrt{2c\left(p-2w^B\right)(1-\rho)}\right],$$
$$s.t. w_0 \le w^B \le \frac{p}{2} - \frac{c}{1-\rho},\ 0 < c \le \frac{p(1-\rho)}{2(2-\rho)}.$$

Since $\frac{dE\pi_R^B}{dw^B} = \sqrt{\frac{2c(1-\rho)}{p-2w^B}} - (1-\rho)$ and $\frac{d^2E\pi_R^B}{dw^{B^2}} = \sqrt{\frac{2c(1-\rho)}{\left(p-2w^B\right)^3}} > 0$, π_R^B decreases in w^B when $w^B < \frac{p}{2} - \frac{c}{1-\rho}$. Consequently, we can easily deduce the retailer's optimal purchase price $w^* = w_0$.

When $\frac{p(1-\rho)}{2(2-\rho)} < c \le \frac{p(1-\rho)}{2}$, given $i^B\left(w^B\right) = \frac{w^B}{c} - 1$ and $\pi_R^B = \frac{1}{2}(p(1-\rho)-2c)$, the retailer will set $w^{B*} = c$ and $i^{B*} = 0$ so that she obtains all profit from net sales revenue. ■

Proof of Propositions 3 and 4

For example, given the optimal decisions and profits under POF when $0 < c \le \tilde{c}^P$, Fig. 7 shows the region of $\frac{d\pi_M^{P*}}{d\rho} < 0$, which completely coincides with the region of $0 < c \le \tilde{c}^P$. Thus, we can conclude that π_M^P always decreases with respect to ρ. In the same way, we can easily prove the change trend of other decision variables and optimal profits with respect to c and ρ. Then, Propositions 3 and 4 can be drawn. ■

Proof of Propositions 5 and 6

From Propositions 1 and 2, we have obtained the optimal solutions under POF and BDF. Then, by comparing the retailer's expected profits under these two financing schemes, we can simply conclude that $\pi_R^{P*} > \pi_R^{B*}$ holds when $0 < c \le \widehat{c}^P$, and $\pi_R^{P*} < \pi_R^{B*}$ holds otherwise.

When $0 < c \le \widehat{c}^P$, the retailer prefers POF. Then, we explore how the retailer should set the wholesale price under BDF to induce the manufacturer to choose POF. Given that $\frac{d^2\pi_M^B(w^B)}{dw^{B^2}} < 0$ and $\frac{d\pi_M^B(w^B)}{dw^B}\left(w^B = \frac{p}{2} - \frac{c}{1-\rho}\right) < 0$, we can deduce that if the retailer sets w^B to be much higher than w_0, the manufacturer's profit will suffer, especially when $w^B \ge \frac{p}{2} - \frac{c}{1-\rho}$.

When $c^B < c \le c^P$, given that $\pi_M^{B*} = 0$ and $\frac{d\pi_M^P(w^P)}{dw^P} > 0$ since $w^P \ge \frac{2c}{(1-\rho)^2}$, the retailer will set $w^P < \frac{2c}{(1-\rho)^2}$ to make POF not profitable for the manufacturer. ■

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