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LOSS-AVERSE SUPPLY CHAIN DECISIONS WITH A CAPITAL CONSTRAINED RETAILER

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Abstract. In real-world transactions, capital constraints restrict the rapid development of the enterprises in the supply chain. The loss aversion behaviors of enterprises directly affect the decision making. This paper investigates the optimal decisions of both the supplier and the capital constrained retailer being loss aversion decision makers under different financing strategies. The capital constrained retailer may borrow from a bank or use the supplier's trade credit to satisfy uncertain demand. With a wholesale price contract, we analytically solve the unique Stackelberg equilibrium under two financing schemes. We derive the critical wholesale price that determines the retailer's financing preference. We identify the impacts of the loss aversion coefficients and initial capital level on the operational and financing decisions. Numerical examples reveal that there exists a Pareto improvement zone regarding the retailer's loss aversion coefficient and initial capital level.

1. **Introduction.** In today's competitive business environments, small and medium-sized enterprises (SMEs) play a vital role. However, limited capital constrains SMEs to make efficient decisions [23, 37, 41]. To mitigate the capital pressure, SMEs often appeal to financial institutions, e.g., banks or supply chain players,

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e.g., a dominant player with full capital. Surveys from the China's Ministry of Commerce showed that approximately 25% of SMEs secured bank loans in 2013 [31]. In Australia, the amount of trade credit owed by Australian businesses was estimated to exceed 80 billion in March 2013 [9]. In addition, according to the report of the Aberdeen Group, approximately 56% of the surveyed companies used trade credit to deal with their insufficient capital problem [44].

Currently, many studies explore the capital-constrained supply chain's operational and financing decisions. Specifically, [1] first incorporated asset financing into a multi-period production decision model. They studied the joint operational and financing decisions for a supply chain with a capital-constrained retailer. Extending [1], [32] investigated the production and financing decisions of capital-constrained firms in the presence of demand uncertainty and market imperfection. In the same vein, [8] analyzed the interactions between a capital-constrained retailer and a profit maximizing bank. They proposed a nonlinear loan contract to coordinate the supply chain. In addition, [19] analytically derived the Stackelberg game equilibrium in a supply chain in which a capital-constrained retailer borrowed from a bank and bankruptcy costs are considered. [35] formulated a multi-level Stackelberg game and found that a suitable financing scheme motivated the capital-constrained retailer to order more products. [34] considered a bi-level Stackelberg game in which the bank acted as a leader and designed a partial trade credit guarantee contract for the supply chain financing. They combined the bank credit financing with the supplier's trade-credit guarantee to characterize the supply chain coordination conditions. At the same time, many scholars also have begun to focus on joint decisions for a capital-constrained supply chain under trade credit financing. For example, [11] first considered that the supplier allowed the retailer to delay payment and further constructed an EOQ model under trade credit financing. Motivated by this pioneer work, many studies analyzed supply chain players' decisions from different perspectives including deteriorate products [9, 14], allowable shortage [11, 16], and order quantity-dependent trade credit [3, 4]. Most previous studies showed that employing trade credit improved the overall efficiency of the supply chain compared with bank-credit financing [18, 22, 41]. This is because trade credit financing realizes risk sharing among the supply chain players. Further, the retailer has incentives to order more items than the order quantity in a traditional newsvendor model with full capital [7, 21, 23, 25]. To be more specific, [2] compared the impacts of trade credit financing and bank credit financing on the supply chain player's decisions. Their results revealed that in most scenarios, the supplier and the retailer were better off using trade credit financing than using bank credit financing.

The studies mentioned above mainly focused on maximizing the expected profits of the players in the traditional newsvendor model [24, 44, 52]. However, in practice, the order quantity decision is not made simply by maximizing the player's expected profit. There exists an actual "decision bias" [32], since the supply chain players often face many kinds of risk, such as uncertain production cost, demand and material procurement. Such risks could lead to player loss. To reduce the loss of risk, the player makes decisions distinct from those to maximize expected profit. More currently, several experiments and surveys show that the people commonly are more averse to losses compared to equal-sized gains [38, 46]. In the prospect theory, [20] effectively and precisely depicted such loss-aversion behaviors. Thereafter, many scholars investigated the impact of loss aversion on decision making. Specifically, [32] first introduced loss aversion into the supply chain and discussed the impact of loss aversion on the newsvendor's order quantity. Their results indicated that the loss-averse newsvendor's order quantity is less than that of the loss-neutral newsvendor. Extending [32], [34] examined ordering decisions in the supply chain with shortage costs. They found that the order quantity of the loss-averse newsvendor might be greater than that of a risk-neutral newsvendor. [6] studied the loss-averse retailer's and the risk-neutral supplier's optimal policies under option contracts. They found that the loss-averse retailer's order quantity might be less than, equal to, or greater than that of the traditional risk-neutral newsvendor. [16] showed that the loss-averse retailer earned less profits than did the loss-neutral retailer. [51] found that, compared with the loss-neutral case, retailers' loss-averse behaviors benefited the retailers and the supply chain and hurt the manufactures. [28] explored the case in which the loss-averse firm purchased from two suppliers when one supplier had potential disruption under uncertain demand. They showed that the unreliable supplier always had positive order quantities, while the reliable supplier might be useless under certain conditions. [29] showed that the loss-averse preference did not always affect the decisions of the supply chain members. The logistics service integrator benefited from its loss-averse preference under certain conditions. Previous studies included a common assumption because a supply chain system consisted of one risk-averse decision maker and a loss-neutral decision maker. This paper is distinct from the above settings because both the supplier and the retailer are loss-averse decision makers, and the retailer is capital constrained.

To capture more-generalized situations, some studies considered the models with a loss-averse supplier. For example, with an option contract, the supplier likely lost part of production costs if the retailer reduced exercise quantity [30, 49]. [30] investigated the optimal decisions of loss-averse suppliers and risk-neutral retailers under an option contract and an advance-purchase discount contract. Following this vein, after examined the buyback contract and the revenue sharing contract, some scholars identified the loss-averse supplier's influence on optimal decisions. [47] disclosed the decision difference of a loss-averse supplier between the buyback contract and the revenue-sharing contract.

This paper studies a supply chain system consisting of a risk-averse supplier and a risk-averse retailer facing uncertain demand. This paper is distinct from the above literature in that with a wholesale price, both the supplier and the retailer are simultaneously considered loss-averse decision makers. The capital-constrained retailer may borrow from a bank or use the supplier's trade credit to fund his business. Those generalized considerations are in sharp contrast to the traditional wholesale price contract with full capital, in which the supplier is always a risk-neutral player. We construct the loss-averse newsvendor model under bank-credit financing (BCF) and trade credit financing (TCF) to characterize the conditions under which the retailer prefers BCF or TCF. The proposed newsvendor model with two financing schemes and two loss-averse players obviously differs from that with a single BCF and a loss-averse retailer presented by [46] and that with a single TCF and a loss-averse retailer presented by [39]. Table 1 summarizes the differences among three models with loss aversion.

The main contributions of this paper are twofold. First, to the best of our knowledge, this paper is among the first to study a scenario in which both supply chain players are loss-averse decision makers. Second, by analytically solving for the critical wholesale price, we clarify the conditions under which the retailer prefers

Table 1. Comparisons of three models with loss aversion

Literature	Financing scheme	Loss-averse player	Decision objective	
			Upstream	Downstream
Zhang et al.(2016)	BCF	Retailer	EPM	EUM
Yan et al.(2018)	TCF or SI	Retailer	EPM	EUM
This paper	BCF or TCF	Retailer and Supplier	EUM	EUM

to choose a financing scheme. At the same time, we also identify that trade credit financing is not a unique financing equilibrium when both players are loss-averse. We find that whether the supplier is willing to offer trade credit depends on the loss-aversion coefficients and the retailer's initial capital level. Numerical examples show that there exists a Pareto improvement zone regarding the retailer's loss-aversion coefficient or the retailer's initial capital level. This finding is in sharp contrast to some papers because trade credit financing always benefits both players [2, 21].

The remainder of the paper is organized as follows. Section 2 describes the basic model, notations and assumptions. Section 3 and Section 4 analytically derive the unique equilibrium under BCF and TCF, respectively. Section 5 presents numerical examples. Section 6 concludes and provides management insights. All proofs are given in the appendix.

2. Model description.

We consider a two-echelon supply chain consisting of a loss-averse supplier and a loss averse and capital-constrained retailer. The retailer may borrow from a bank or use the supplier's trade credit to fund his business. As a Stackelberg leader, the supplier decides the wholesale price w per unit purchased with a fixed production cost c. As a follower, the retailer decides order quantity and sells the products at a fixed retail price p to customers. Let $F(X)$ and $f(X)$ be the distribution and density functions of the nonnegative random demand X. Let $z(x) = \frac{f(x)}{\bar{F}(x)}$ be the failure rate, where $\bar{F}(x) = 1 - F(X)$ is the complementary distribution function of X. Assume $z(X)$ is increasing in X [18, 21]. For a clear interpretation, we list the main notation in Table 2.

We use the prospect theory introduced by [20] to describe the loss-aversion behaviors of the supplier and the retailer. Following the settings in [32] and [34], the loss-averse decision-maker utility function can be expressed as

$$U(\pi) = \begin{cases} \lambda(\pi - \pi_0) & \pi < \pi_0, \\ \pi - \pi_0 & \pi \geq \pi_0, \end{cases} \tag{1}$$

where π_0 is the reference profit, π is the loss-averse decision-maker profit, and $\lambda \geq 1$ is the loss-aversion coefficient. Specifically, if $\lambda = 1$, the decision maker is risk-neutral. If $\lambda > 1$, the decision maker is risk-averse. For simplification, assume $\pi_0 = 0$.

3. Bank credit financing.

3.1. Retailer's decisions.

In this section, the capital-constrained retailer borrows from a bank to satisfy uncertain demand. The bank loans are competitively priced. Before the sales season, with a wholesale price contract, the supplier charges a wholesale price w_B. Based on w_B, the retailer with initial capital level Ω decides order quantity q_B. If the initial capital level is not enough to cover orders, then the retailer borrows loans $w_B q_B - \Omega$ from a bank at interest rate r_B. At the end of the sales season, the retailer accumulates sales income $pmin\{q_B, x\}$. The uncertain

Table 2. Notation

Notation	Definition
p	Retail price
c	Production cost
w_j	Wholesale price, where $j = B, T$ denotes bank credit financing or trade credit financing, respectively (the supplier's decision variable)
X	Random demand, defined over continuous interval$[0, +\infty)$
$f(X)$	Probability density function of X
$F(X)$	Cumulative distribution function of X
$z(X)$	Failure rate of the demand distribution, $z(x) = \frac{f(x)}{\bar{F}(x)}$
q_j	Order quantity, where $j = B, T$ (the retailer's decision variable)
λ_i	Loss-aversion coefficient, where $i = S, R$ denotes the supplier or retailer, respectively
π_{ij}	Profit of player i under financing scheme j, where $i = S, R$ and $j = B, T$
$U(\pi)$	Utility function
$EU(\pi_{ij})$	Expected utility function
Ω	Retailer's initial capital level
r_f	Risk-free interest rate
r_B	Interest rate of bank loans
r_T	Interest rate of trade credit (the supplier's decision variable)

For notation purposes, we use the symbols "BCF" and "TCF" to represent "bank credit financing" and "trade credit financing", respectively. In addition, for convenience, we refer to the supplier as "she" and the retailer as "he".

demand leads to two crucial demand thresholds regarding the retailer's bankruptcy, $k_{B1} = (w_B q_B - \Omega)(1+r_B)/p$, and loss aversion, $k_{B2} = ((w_B q_B - \Omega)(1+r_B)+\Omega)/p$. When $x < k_{B1}$, the retailer's sales income is not enough to pay his loans. The retailer goes bankrupt and has to pay all sales income to the bank. When $x = k_{B1}$, the retailer's sales income just makes up for the loans. When $k_{B1} < x < k_{B2}$, the retailer obtains profit of $px - (w_B q_B - \Omega)(1 + r_B) - \Omega < 0$. When $k_{B2} < x < q_B$, the retailer obtains profit of $px - (w_B q_B - \Omega)(1 + r_B) - \Omega > 0$. When $x \geq q_B$, the retailer's profit is $pq_B - (w_B q_B - \Omega)(1 + r_B) - \Omega > 0$. Based on Equation (1), the retailer's expected utility function is

$$
\begin{aligned}
& EU(\pi_{RB}) \\
= \; & \lambda_R \int_0^{k_{B1}} -\Omega f(x)\mathrm{d}x + \lambda_R \int_{k_{B1}}^{k_{B2}} (px - (w_B q_B - \Omega)(1 + r_B) - \Omega) f(x)\mathrm{d}x + \\
& \int_{k_{B2}}^{q_B} (px - (w_B q_B - \Omega)(1 + r_B) - \Omega) f(x)\mathrm{d}x + \int_{q_B}^{+\infty} (pq_B - (w_B q_B - \Omega) \\
& (1 + r_B) - \Omega) f(x)\mathrm{d}x \qquad (2)
\end{aligned}
$$

Since the bank loans are competitively priced, the interest rate r_B equates the expected return from the loans to its costs. Therefore, $(w_B q_B - \Omega)(1 + r_f) = E\left[min\{pminq_B, x, (w_B q_B - \ \Omega)(1 + r_B)\}\right]$. Now, the retailer's expected utility function is rewritten as

$$
\begin{aligned}
EU(\pi_{RB}) = & \int_0^{q_B} p\bar{F}(x)\mathrm{d}x + (\lambda_R - 1) \int_{k_{B1}}^{k_{B2}} p\bar{F}(x)\mathrm{d}x \\
& - (w_B q_B - \Omega)(1 + r_f) - \lambda_R \Omega \qquad (3)
\end{aligned}
$$

Proposition 1. *Under BCF, (i) the retailer's optimal order quantity is given by* $p\bar{F}(q_B) - \frac{w_B(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) + (1-\lambda_R)\bar{F}(k_{B2})) = 0$*; (ii)* q_B *is decreasing in* w_B*,* λ_R *and* Ω*.*

As λ_R increases, the more loss-averse retailer employs more-conservative order strategies to mitigate the risk of loss. The retailer with a higher initial capital level often borrows less from banks. The retailer bears greater risk when facing uncertain demand. To mitigate risk, the retailer therefore decreases order quantity. Note that when $\Omega = 0$, the retailer's order quantity is independent of λ_R. In this situation, the retailer actually transfers his risk to the bank. When $\lambda_R > 1$, the loss-averse retailer's order quantity is less than risk-neutral, i.e., $p\bar{F}(q_B) < w_B(1 + r_f)$. The retailer's loss aversion negatively affects his ordering decisions. When $\lambda_R = 1$, the retailer's order quantity is given by $p\bar{F}(q_B) = w_B(1+r_f)$. The result in Proposition 1(i) is in sharp contrast to the result in [46], because as the Stackelberg leader, the bank maximizes its profits.

3.2. **Supplier's decisions.** With a wholesale price contract, as a Stackelberg leader, the supplier charges the retailer w_B per unit purchased. At the beginning of the sales season, the supplier receives the upfront payment w_Bq_B and spends cq_B for production. At the end of the sales season, the supplier's profit is given by

$$\pi_{SB} = (w_B - c)q_B(1 + r_f) \tag{4}$$

From the supplier's perspective, the retailer borrowing bank loans is equivalent to a player with sufficient initial capital. Under BCF, the supplier is risk-free. Even though the retailer goes bankrupt, the supplier incurs no loss. Therefore, the supplier's utility function is $EU(\pi_{SB}) = \pi_{SB}$.

Proposition 2. *Under BCF, the supplier's optimal wholesale price satisfies* $\bar{F}(q_B)(q_Bz(q_B)-1)-c\frac{(1+r_f)}{\bar{F}(k_{B1})}[(\lambda_R-1)\frac{w_Bq_B(1+r_f)\bar{F}(k_{B2})}{p\bar{F}(k_{B1})}(z(k_{B2})-z(k_{B1}))+\lambda_R\bar{F}(k_{B1}) + (1-\lambda_R)\bar{F}(k_{B2})] = 0$*.*

Specifically, when $\Omega = 0$, the retailer's order quantity is independent of λ_R. The supplier's wholesale price is also independent of λ_R. When $\Omega > 0$, the supplier's wholesale price depends on Ω and λ_R.

4. **Trade credit financing.**

4.1. **Retailer's decisions.** At the begin of the sales season, the supplier charges the retailer w_T. Then, the retailer orders q_T according to w_T. Since the initial capital level Ω is insufficient to pay for the orders, the supplier offers the retailer trade credit of $w_Tq_T - \Omega$. At the end of the sales season, the retailer accumulates sales income $pmin\{q_T, x\}$ and pays $(w_Tq_T - \Omega)(1+r_T)$ to the supplier. Otherwise, the retailer goes bankrupt and has to pay full sales income $pmin\{q_T, x\}$ to the supplier. Under TCF, the retailer's bankruptcy likely leads to the supplier's bankruptcy. Lemma 1 establishes two critical demand thresholds regarding the retailer's and supplier's bankruptcies.

Lemma 1. *Under TCF, (i) the retailer's critical market demand threshold* $k_{RT1} = \frac{(w_Tq_T-\Omega)(1+r_f)}{p}$*; (ii) if* $\Omega < cq_T$*, then the supplier's critical market demand threshold* $k_{ST} = \frac{(cq_T-\Omega)(1+r_f)}{p}$ *and; if* $\Omega \geq cq_T$*, then the supplier does not go bankrupt.*

When $x < k_{RT1}$, the retailer goes bankrupt. Under TCF, the retailer's loss-aversion threshold $k_{RT2} = ((w_T q_T - \Omega)(1 + r_T) + \Omega)/p$. When $k_{RT1} \leq x < k_{RT2}$, the retailer's profit is $px - (w_T q_T - \Omega)(1 + r_T) - \Omega < 0$. When $k_{RT2} \leq x < q_T$, the retailer's profit is $px - (w_T q_T - \Omega)(1 + r_T) - \Omega > 0$. When $x \geq q_T$, the retailer's profit is $pq_T - (w_T q_T - \Omega)(1 + r_T) - \Omega > 0$. Based on Equation (1), the retailer's expected utility function is given by

$$\begin{aligned} & EU(\pi_{RT}) \\ = \; & \lambda_R \int_0^{k_{RT1}} -\Omega f(x)\mathrm{d}x + \lambda_R \int_{k_{RT1}}^{k_{RT2}} (px - (w_T q_T - \Omega)(1 + r_T) - \Omega) f(x)\mathrm{d}x + \\ & \int_{k_{RT2}}^{q_T} (px - (w_T q_T - \Omega)(1 + r_T) - \Omega) f(x)\mathrm{d}x + \int_{q_T}^{+\infty} (pq_T - (w_T q_T - \Omega) \\ & (1 + r_T) - \Omega) f(x)\mathrm{d}x \end{aligned} \tag{5}$$

Proposition 3. *Under TCF, (i) the retailer's optimal order quantity is given by* $p\bar{F}(q_T) - w_T(1 + r_T)(\lambda_R \bar{F}(k_{RT1}) + (1 - \lambda_R)\bar{F}(k_{RT2})) = 0$*; (ii)* q_T *is decreasing in* w_T*,* λ_R *and* Ω*.*

Under BCF, the bank partially bears the retailer's default risk. Due to the fully competitive pricing, the bank does not obtain an additional risk premium. The retailer transfers the partial risk to the bank without providing extra costs. Comparatively, under TCF, the supplier partially bears the retailer's default risk but charges an additional risk premium via setting the delayed wholesale price. This gap causes the retailer's order under TCF to differ from under BCF.

4.2. **Supplier's decisions.** From Lemma 1, we note that whether the supplier goes bankrupt depends on the retailer's initial capital level and accumulated sales income. If $\Omega \geq cq_T$, the supplier does not go bankrupt. When $x \leq k_{RT1}$, the supplier's profit is $px - (cq_T - \Omega)(1 + r_f) > 0$. When $x > k_{RT1}$, the supplier's profit is $(w_T q_T - \Omega)(1 + r_T) - (cq_T - \Omega)(1 + r_f) > 0$. Based on Equation (1), the supplier's expected utility function is

$$\begin{aligned} & EU(\pi_{ST}) \\ = \; & \int_0^{k_{RT1}} (px - (cq_T - \Omega)(1 + r_f)) f(x)\mathrm{d}x + \int_{k_{RT1}}^{+\infty} ((w_T q_T - \Omega)(1 + r_T) - \\ & (cq_T - \Omega)(1 + r_f)) f(x)\mathrm{d}x + \end{aligned} \tag{6}$$

If $\Omega < cq_T$, whether the supplier goes bankrupt depends on the retailer's accumulated sales income. When $x \leq k_{ST}$, the supplier goes bankrupt. When $k_{ST} < x \leq k_{RT1}$, the supplier's profit is $px - (cq_T - \Omega)(1 + r_f) > 0$. When $x > k_{RT1}$, the supplier's profit is $(w_T q_T - \Omega)(1 + r_T) - (cq_T - \Omega)(1 + r_f) > 0$. Based on Equation (1), the supplier's expected utility function is

$$\begin{aligned} EU(\pi_{ST}) \; = \; & \lambda_S \int_0^{k_{ST1}} (px - (cq_T - \Omega)(1 + r_f)) f(x)\mathrm{d}x + \int_{k_{ST1}}^{k_{RT1}} (px - (cq_T - \Omega) \\ & (1 + r_f)) f(x)\mathrm{d}x + \int_{k_{RT1}}^{+\infty} ((w_T q_T - \Omega)(1 + r_T) - (cq_T - \Omega)(1 + r_f)) \\ & f(x)\mathrm{d}x \end{aligned} \tag{7}$$

Proposition 4. *Under TCF, (i) if* $\Omega \geq cq_T$*, the supplier's optimal wholesale price satisfies* $\bar{F}(k_{RT1})\bar{F}(q_T)(1 - q_T z(q_T)) - c(1 + r_f)(\lambda_R \bar{F}(k_{RT1})(1 - \frac{w_T q_T (1 + r_T)}{p} z(k_{RT1})) +$

$(1-\lambda_R)\bar{F}(k_{RT2})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT2}))) = 0$;*if* $\Omega < cq_T$, *the supplier's optimal wholesale price satisfies* $\bar{F}(k_{RT1})\bar{F}(q_T)(1-q_T z(q_T)) - c(1+r_f)[1+(\lambda_S - 1)F(\frac{(cq_T-\Omega)(1+r_f)}{p})](\lambda_R\bar{F}(k_{RT1})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT1})) + (1-\lambda_R)\bar{F}(k_{RT2})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT2}))) = 0$;*(ii) the supplier's optimal interest rate* $r_T = r_f$.

Under TCF, when $\Omega \geq cq_T$, the supplier does not go bankrupt. The supplier's wholesale price is independent of λ_S. When $\Omega < cq_T$ and $x \leq k_{ST}$, the supplier goes bankrupt. The supplier's wholesale price depends on λ_S. This finding is in contrast to the situation under BCF in which the supplier is a risk-free party. Proposition 4(ii) indicates that the supplier's optimal interest rate equals the risk-free interest rate. This finding is identical to the result in [21] in that both parties are risk-neutral. For example, [13] investigated 3498 SMEs in the United States in 1998 and found that most companies accepted the interest rate of TCF cheaper than BCF, and many suppliers even offered zero interest rate to the downstream enterprises.

The following proposition establishes the critical wholesale price that the capital-constrained retailer prefers which financing scheme.

Proposition 5. *Under TCF,when* $w_T < \bar{w}_T$, *the retailer prefers TCF; (ii) when* $w_T > \bar{w}_T$, *the retailer prefers BCF; and (iii) when* $w_T = \bar{w}_T$, *TCF and BCF are equivalent for the retailer, where* $\bar{w}_T$ *satisfies* $EU(\pi_{RT}(\bar{w}_T)) = EU(\pi_{RB}(w_B))$.

As a Stackelberg follower, the retailer makes a tradeoff between BCF and TCF to maximize his own expected utility. From the proofs of Proposition 5, the retailer's utility is monotonically decreasing in the wholesale price under TCF. There always exists the unique critical wholesale price $\bar{w}_T$ such that $EU(\pi_{RT}(\bar{w}_T)) = EU(\pi_{RB}(w_B))$. When $w_T < \bar{w}_T$, the loss-averse retailer prefers TCF. In this situation, the retailer enjoys the lower wholesale price and obtains greater expected utility. When $w_T > \bar{w}_T$, the retailer prefers BCF. In this situation, the retailer pays lower financing costs than under TCF. The findings are different from the results in [21] in that the capital constrained and risk-neutral retailer always prefers TCF.

5. Numerical analysis.

The numerical examples are provided to illustrate the impacts of both parties' loss-aversion coefficients and the retailer's initial capital level on the optimal decisions and expected utilities. We utilize Matlab 2017a to conduct the numerical analysis to verify our theoretical results.

5.1. Impact of the loss-aversion coefficient.

We use the two basic settings over the simulations: (1) The demand X follows a uniform distribution $U(0, 250)$, $p = 100$, $c = 15$ and $r_f = 0.03$ [35, 52]; and (2) The demand X follows a normal distribution $N(100, 60)$, $p = 1$, $c = 0.2$ and $r_f = 0.03$ [5]. Figures 1 and 2 illustrate that the retailer's order quantity is decreasing in λ_R under BCF and TCF with $\lambda_S = 1.5$(Proposition 1(ii) and Proposition 3(ii)). When Ω is relatively high, the retailer's order quantity under TCF is greater than under BCF.

Based on the settings in Figures 1 and 2, Figures 3 and 4 disclose that the retailer's order quantity is decreasing in λ_S under BCF and TCF. When Ω is relatively low and the supplier's loss-aversion coefficient is not sufficiently large, the retailer's order quantity under TCF is greater than under BCF. Otherwise, the retailer's order quantity under TCF is less than under BCF because when Ω is low, the supplier's loss aversion negatively affects the retailer's quantity decision. Under TCF, both players bear risk. The supplier sets a high wholesale price to obtain greater profit and compensate for the risk. Correspondingly, the retailer reduces orders to

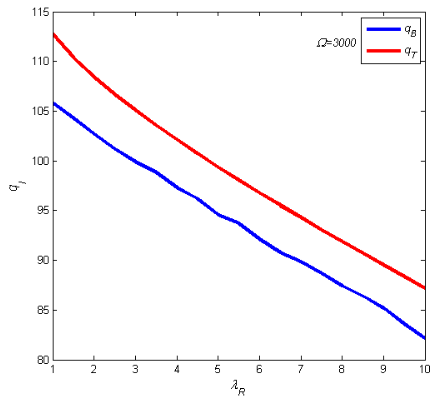

Figure 1. The retailer's order quantity changes with λ_R under $U(0, 250)$

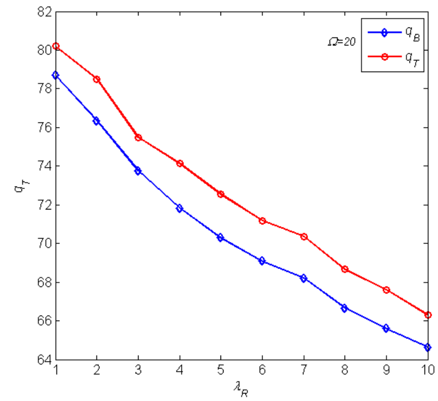

Figure 2. The retailer's order quantity changes with λ_R under $N(100, 60)$

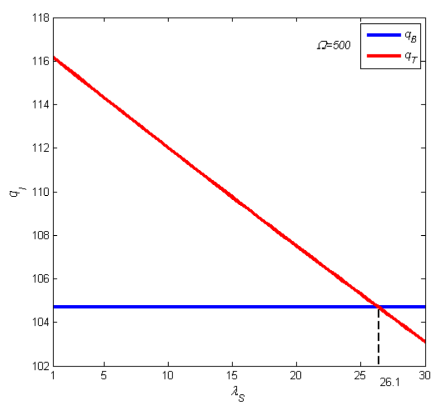

Figure 3. The retailer's order quantity changes with λ_S under $U(0, 250)$ with $\lambda_R = 2$

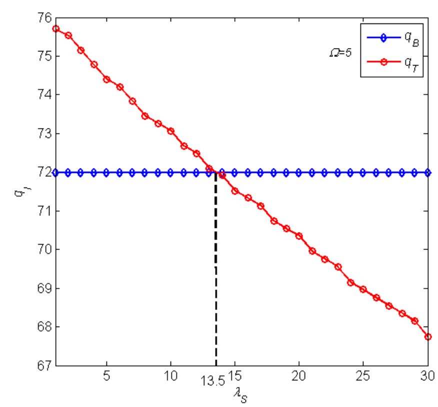

Figure 4. The retailer's order quantity changes with λ_S under $N(100, 60)$with $\lambda_R = 10$

avoid risk. In comparison, the supplier under BCF does not bear risk; therefore, the setting of the wholesale price is dependent on λ_S, which leads to the retailer's order quantity being dependent on λ_S.

Based on the settings of Figures 1 and 3, Figures 5 and 6 illustrate the player's expected utility under BCF and TCF, where $\Delta EU(\pi_{Sj}) = EU(\pi_{ST}) - EU(\pi_{SB})$, and $\Delta EU(\pi_{Rj}) = EU(\pi_{RT}) - EU(\pi_{RB})$. Figure 5 indicates that the difference between the supplier's expected utility under BCF and TCF is decreasing, with

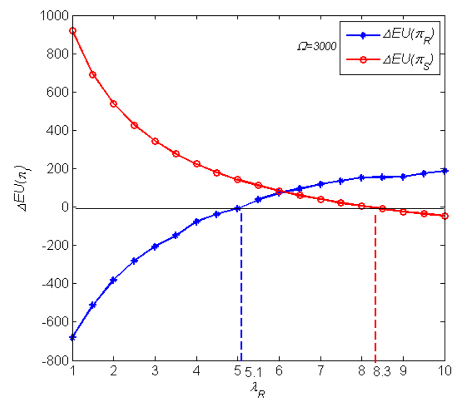

FIGURE 5. The difference of player's expected utility changes with λ_R under $U(0, 250)$

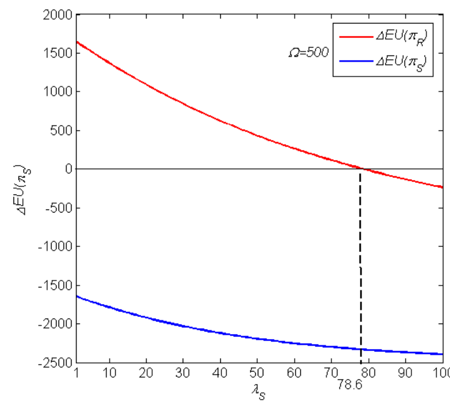

FIGURE 6. The difference of player's expected utility changes with λ_S under $U(0, 250)$

the retailer's loss-aversion degree increasing. When $\lambda_R < 8.3$, the supplier's expected utility under TCF is greater than that under BCF. When $\lambda_R > 8.3$, the supplier's expected utility under TCF is less than that under BCF. As the retailer's loss-aversion degree increases, the supplier reduces the wholesale price to induce more orders. At the same time, the difference between the supplier's wholesale price under BCF and TCF is decreasing, with the retailer's loss-aversion degree increasing. However, the difference between the retailer's expected utility under BCF and TCF is decreasing, with the retailer's loss-aversion degree increasing. Compare with BCF, the supplier partially bears the risk under TCF, and the retailer's risk correspondingly decreases. It is beneficial for the retailer to raise his order quantity. As the retailer's loss-aversion degree increases, the benefits are more obvious. When $\lambda_R > 5.1$, the retailer's expected utility under TCF is greater than that under BCF. Therefore, when $\lambda_R \leq 5.1$, the supplier is willing to provide TCF to the retailer, while the retailer prefers BCF. When $5.1 < \lambda_R < 8.3$, both players obtain greater expected utility under TCF than that under BCF. In this condition, the supplier is willing to provide TCF, and the retailer also prefers TCF. Therefore, when $5.1 < \lambda_R < 8.3$, TCF is the unique financing equilibrium. Hence, when Ω is relatively high, there exists a Pareto improvement zone regarding λ_R that lures both players to take TCF. Table 3 illustrates how the changes of λ_R affect the equilibrium in the Stackelberg game. The results in Table 3 show that the supplier's wholesale price is decreasing with the retailer's loss-aversion degree under BCF and TCF. As the retailer's loss-aversion degree increases, the retailer reduces his order quantity. To motivate the retailer to place more orders, the supplier reduces the wholesale price under both financing modes. The supplier's wholesale price under TCF is greater than that under BCF. This is because the supplier bears the risk under TCF. Through raising the wholesale price, the supplier obtains greater profit to compensate for her risk.

From Figure 6, when Ω is relatively low, BCF always benefits the retailer. The supplier's preference depends on her loss-aversion coefficient. When $\lambda_S > 78.6$,

Table 3. Sensitivity analysis with respect to λ_R

λ_R	w_B	w_T	q_B	q_T	$\Delta EU(\pi_R)$	$\Delta EU(\pi_S)$	$\Delta EU(\pi_{SC})$
1.0	56.0	64.7	105.8	112.9	-681.9	921.6	239.7
1.5	53.1	59.3	104.3	110.4	-512.6	690.1	177.5
2.0	50.5	55.1	102.7	108.5	-379.6	536.9	157.3
2.5	48.3	51.7	101.2	106.7	-280.4	426.7	146.3
3.0	46.3	48.8	99.9	105.2	-207.1	343.6	136.5
3.5	44.5	46.4	98.8	103.6	-149.3	277.3	128.0
4.0	43.0	44.2	97.3	102.4	-75.8	224.0	148.2
4.5	41.6	42.4	95.9	100.7	-37.0	180.0	143.0
5.0	40.3	40.7	94.6	99.0	-8.5	142.9	134.3
5.5	39.1	39.2	93.4	98.1	38.4	111.3	149.7
6.0	38.0	37.8	92.1	96.9	73.4	84.1	157.5
6.5	37.0	36.6	90.8	95.5	95.0	60.3	155.3
7.0	36.0	35.5	89.9	94.0	118.3	39.9	158.2
7.5	35.1	34.4	88.7	93.1	135.3	21.2	156.5
8.0	34.3	33.4	87.3	91.9	153.1	4.6	157.7
8.5	33.5	32.5	86.4	90.8	155.4	-10.4	145.0
9.0	32.8	31.7	85.2	89.5	157.0	-23.8	133.2
9.5	32.2	30.9	83.6	88.4	175.9	-35.9	140.0
10.0	31.6	30.2	82.3	87.3	187.2	-47.1	140.1

the supplier's expected utility under TCF is less than that under BCF. The results show that when the supplier is extremely loss-averse, she is not willing to offer TCF. Under this condition of $\lambda_S > 78.6$, the supplier and the retailer both prefer BCF. Therefore, BCF is the unique financing equilibrium. When Ω is relatively low, there exists a Pareto improvement zone regarding λ_S that lures both players to take BCF. When $\lambda_S < 78.6$, the supplier's expected utility under TCF is greater than that under BCF. The supplier prefers to provide TCF, while the retailer prefers BCF. Note that the supply chain expected utility under BCF is greater than that under TCF. The retailer can offer an incentive, such as revenue sharing, to induce the supplier to set the appropriate wholesale price under BCF. The supplier and the retailer therefore may prefer BCF under the retailer's incentive mechanism. Table 4 illustrates how the changes of λ_S affect the equilibrium in the Stackelberg game. The results in Table 4 show that the supplier's wholesale price is increasing, with the supplier's loss-aversion degree increasing under TCF. As the supplier's loss-aversion degree increases, the supplier raises the wholesale price to mitigate her risk; further, the retailer reduces his order quantity. Under BCF, the supplier does not bear the risk. The expected profits of the supplier and the retailer are dependent on λ_S. The difference between the supplier's and the retailer's expected utility under both financing modes is decreasing, with the supplier's loss-aversion degree increasing.

5.2. **Impact of retailer's initial capital.** Based on the settings in Figure 1, Figure 7 illustrates how the supplier's expected utility changes with the wholesale price under TCF and BCF. Figure 7(a) shows that when $\Omega = 3000$ and $\lambda_R = 3$, $w_B = 46.3$ and $w_T = 48.8$. Further, we have $EU(\pi_{SB}) = 3223.3$ and $EU(\pi_{ST}) = 3566.9$. Obviously, the supplier is willing to provide TCF. Based on Proposition 5, we obtain the critical wholesale price $\bar{w}_T = 47.1$. If $w_T < 47.1$, the retailer

Table 4. Sensitivity analysis with respect to λ_S

λ_S	w_B	w_T	q_B	q_T	$\Delta EU(\pi_R)$	$\Delta EU(\pi_S)$	$\Delta EU(\pi_{SC})$
1	65.2	77.8	104.7	116.2	-1642.9	1649.4	6.5
5	65.2	78.6	104.7	114.3	-1711.1	1521.3	-189.8
10	65.2	79.6	104.7	112.0	-1788.8	1369.2	-419.6
15	65.2	80.5	104.7	109.7	-1859.1	1225.7	-633.4
20	65.2	81.3	104.7	107.5	-1922.8	1090.5	-832.3
25	65.2	82.1	104.7	105.3	-1980.4	963.1	-1017.3
30	65.2	82.8	104.7	103.1	-2032.5	843.3	-1189.2
35	65.2	83.4	104.7	100.9	-2079.6	730.6	-1349.0
40	65.2	84.1	104.7	98.9	-2122.0	624.8	-1497.2
45	65.2	84.6	104.7	96.8	-2160.3	525.5	-1634.8
50	65.2	85.1	104.7	94.8	-2194.6	432.3	-1762.3
55	65.2	85.6	104.7	92.9	-2225.5	344.8	-1880.7
60	65.2	86.0	104.7	91.0	-2253.2	262.8	-1990.4
65	65.2	86.3	104.7	89.2	-2278.1	185.9	-2092.2
70	65.2	86.7	104.7	87.5	-2300.4	113.6	-2186.8
75	65.2	87.0	104.7	85.8	-2320.5	45.8	-2274.7
80	65.2	87.3	104.7	84.2	-2338.6	-17.9	-2356.5
85	65.2	87.5	104.7	82.7	-2354.9	-77.9	-2432.8
90	65.2	87.7	104.7	81.2	-2369.6	-134.3	-2503.9
95	65.2	88.0	104.7	79.8	-2382.9	-187.5	-2570.4
100	65.2	88.2	104.7	78.5	-2394.9	-237.7	-2632.6

prefers TCF. Otherwise, the retailer prefers BCF. When $38.9 \leq w_T \leq 57.3$, the supplier is willing to provide TCF. Therefore, when the wholesale price falls within $38.9 \leq w_T \leq 47.1$, TCF becomes the financing equilibrium.

Note that the supplier's optimal wholesale price is $49.1 > \bar{w}_T = 47.1$. As a Stackelberg leader, when the supplier determines the wholesale price under TCF, she needs to consider the retailer's expected utility under BCF. The capital-constrained retailer can utilize the two financing modes to increase his game power and further obtains a low wholesale price. The optimal wholesale price depends on each member's bargaining power. Using the normal distribution with $\Omega = 20$ and $\lambda_R = 3$, Figure 8(a) shows that the supplier is willing to provide TCF.

Figure 7(b) shows that when $\Omega = 500$, $\lambda_R = 25$ and $\lambda_S = 30$, $w_B = 39.2$ and $w_T = 50.0$. Further, we have $EU(\pi_{SB}) = 2325.0$ and $EU(\pi_{ST}) = 2278.8$. Obviously, the supplier is not willing to provide TCF. Based on Proposition 5, we obtain the critical wholesale price $\bar{w}_T = 39.8$. The supplier's optimal wholesale price is $w_T = 50.0 > \bar{w}_T$ under TCF. The retailer is not willing to choose TCF. Figure 7(b) shows that when $35.7 < w_B < 42.9$, the supplier prefers the retailer to choose BCF. Note that when $w_B < 49.0$, the retailer prefers BCF. In this condition, BCF may become the unique financing equilibrium. When the retailer's initial capital level is relatively low, the loss-averse supplier sets the appropriate wholesale price to induce the retailer to choose BCF. Under normal distribution with $\Omega = 5$, $\lambda_R = 25$ and $\lambda_S = 30$, Figure 8(b) shows that the supplier is not willing to provide TCF.

Based on the settings in Figures 1 and 4, Figures 9 and 10 present how the retailer's order quantity changes with Ω. Obviously, the retailer's order quantity

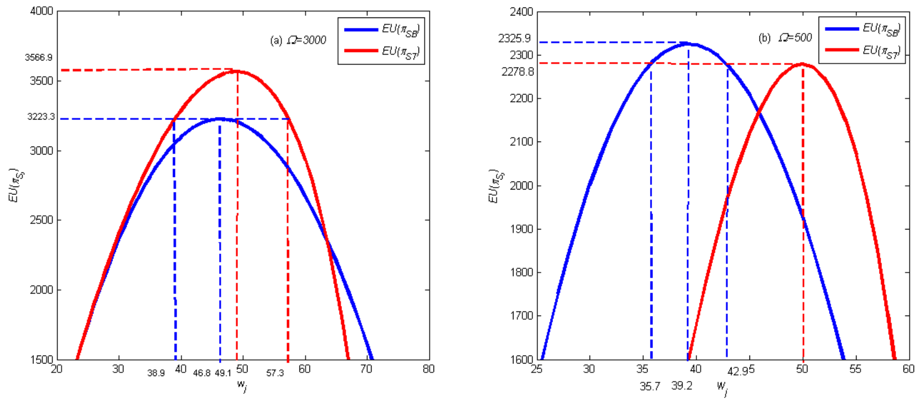

FIGURE 7. The supplier's expected utility changes with w_j under $U(0, 250)$

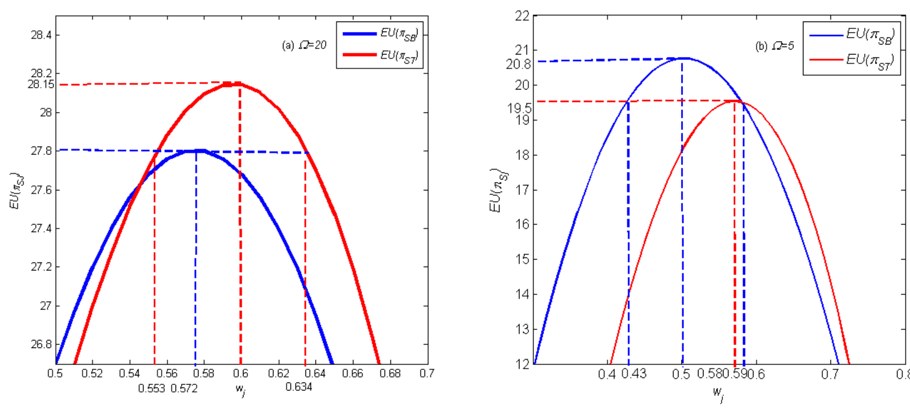

FIGURE 8. The supplier's expected utility changes with w_j under $N(100, 60)$

decreases with Ω under TCF and BCF. As the retailer's initial capital level increases, the retailer reduces the loans either from the bank or from the supplier. However, this reduction causes the retailer to bear high risk. The retailer therefore adopts more-conservative order strategies to mitigate the risk of loss.

Based on the settings in Figure 9, Figure 11 compares the player's expected utility under BCF with that under TCF under the uniform distribution. Figure 11 shows that $\Delta EU(\pi_{Sj})$ is decreasing and $\Delta EU(\pi_{Rj})$ is increasing with the retailer's initial capital level. At the same time, as the retailer's initial capital level increases, the supplier reduces the wholesale price. The supplier reduces the wholesale prices under TCF more than under BCF. Compared with BCF, the supplier's expected utility is substantially reduced, while the retailer's expected utility significantly increases under TCF. When $\Omega < 4920.8$, the supplier's expected utility under TCF is greater than that under BCF. When $\Omega > 4190.5$, the retailer's expected utility

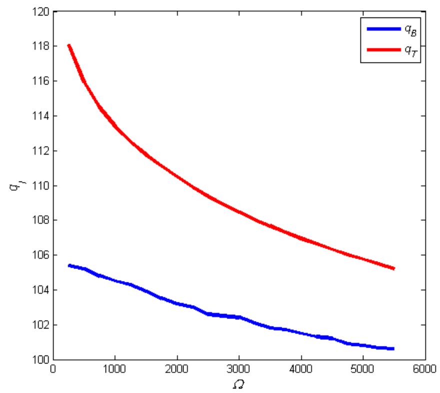

FIGURE 9. The retailer's order quantity changes with Ω under $U(0, 250)$ with $\lambda_R = 2$, $\lambda_S = 1.5$

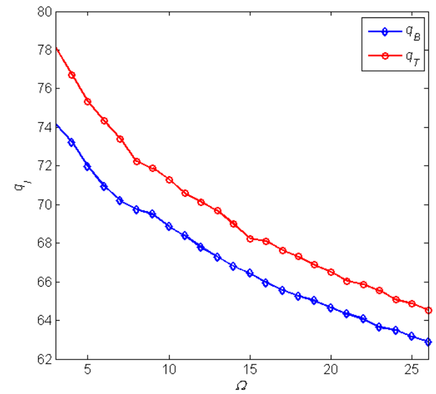

FIGURE 10. The retailer's order quantity changes with Ω under $N(100, 60)$with $\lambda_R = 10$, $\lambda_S = 2$

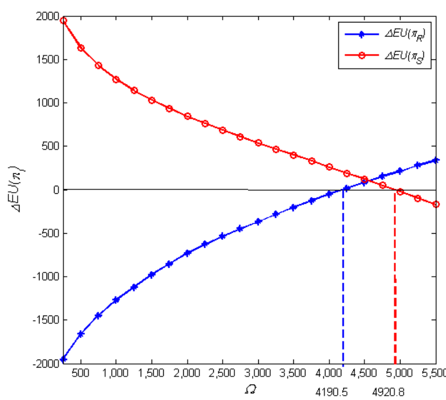

FIGURE 11. The difference of player's expected utility changes with Ω under $U(0, 250)$

under TCF is greater than that under BCF. Therefore, when $4190.5 < \Omega < 4920.8$, both players obtain greater expected utility under TCF than under BCF. Therefore, when $4190.5 < \Omega < 4920.8$, TCF is the unique financing equilibrium. There exists a Pareto improvement zone regarding Ω that entices both players to take TCF. Table 4 illustrates how the changes of Ω affect the equilibrium in the Stackelberg game. The results in Table 4 show that the supplier's wholesale price is decreasing in the initial capital level under both financing modes. As the initial capital level increases, the retailer reduces order quantity. To motivate the retailer to place more orders, the supplier reduces the wholesale price under both financing modes.

Table 4. Sensitivity analysis with respect to Ω

Ω	w_B	w_T	q_B	q_T	$\Delta EU(\pi_R)$	$\Delta EU(\pi_S)$	$\Delta EU(\pi_{SC})$
250	55.4	83.3	105.5	118.1	-1974.3	1942.9	-31.4
500	54.8	77.9	105.2	115.9	-1684.5	1633.0	-51.5
750	54.3	73.9	104.8	114.5	1465.5	1427.0	-38.5
1000	53.8	70.6	104.5	113.4	-1288.9	1270.3	-18.6
1250	53.4	67.8	104.0	112.5	-1127.3	1142.0	14.7
1500	52.9	65.4	103.9	111.8	-997.1	1031.6	34.5
1750	52.5	63.3	103.6	111.1	-870.5	933.1	62.6
2000	52.1	61.4	103.3	110.5	757.6	843.8	86.2
2250	51.7	59.6	103.0	109.9	-654.8	761.1	106.3
2500	51.3	58.0	102.9	109.4	-560.4	683.3	122.9
2750	50.9	56.5	102.8	108.9	-473.1	608.9	135.8
3000	50.6	55.1	102.4	108.5	-379.9	536.9	157.0
3250	50.3	53.8	102.1	108.1	-292.4	466.5	174.1
3500	49.9	52.6	101.9	107.7	-213.6	397.1	183.5
3750	49.6	51.5	101.7	107.3	-144.0	328.1	184.1
4000	49.3	50.4	101.5	107.0	-70.2	258.1	187.9
4250	49.1	49.3	101.4	106.6	16.3	189.8	206.1
4500	48.8	48.4	101.3	106.3	81.3	119.8	201.1
4750	48.5	47.4	101.2	106.0	143.2	49.0	192.2
5000	48.2	46.6	101.1	105.7	202.0	-22.8	179.2
5250	48.0	45.7	100.9	105.5	270.0	-95.8	174.2
5500	47.7	44.9	100.6	105.2	323.3	-170.4	152.9

6. **Conclusion.** This paper considers a two-echelon supply chain consisting of a loss-averse supplier and a loss-averse and capital-constrained retailer. The retailer may borrow from a bank or use the supplier's trade credit. Based on the expected utility, we analytically derive the unique Stackelberg equilibrium regarding the wholesale price and interest rate for the supplier and order quantity for the retailer. The retailer's order quantity decreases with the loss-aversion coefficients and initial capital level. A more loss-averse retailer employs more-conservative order strategies to mitigate the risk of loss. The supplier's wholesale price depends on the loss-aversion coefficients and initial capital level. The more loss-averse supplier often sets higher wholesale prices to compensate for the risk of loss. In general, the greater the initial capital level, the less the retailer orders. We obtain the critical wholesale price that the capital-constrained retailer prefers which financing scheme. Numerical examples reveal that when the retailer's initial capital level is relatively large and the retailer's loss-aversion coefficient falls within certain intervals, TCF is the unique financing equilibrium. There exists a Pareto improvement zone regarding the retailer's loss-aversion coefficient or the retailer's initial capital level that lures both players to take TCF to obtain greater expected utility.

This research work points to two important managerial insights. First, by setting the appropriate wholesale price, the loss-averse supplier can induce the retailer to choose the financing scheme that makes her benefitted. When the retailer's initial capital level is relatively high, setting a low wholesale price can induce the retailer to choose TCF so that the supplier obtains more profit. When the retailer's initial capital level is relatively low, the supplier may charge a high wholesale price to induce the retailer to choose BCF, thus eliminating her risk. Second, the capital-constrained retailer can utilize the financing scheme to increase his game power to obtain a low wholesale price. For example, when the supplier sets the wholesale price under TCF, she needs to consider the retailer's expected utility under BCF. If the retailer's expected utility under BCF is greater than under TCF, the retailer will choose BCF, which leads to a lower expected utility for the supplier.

This paper can be expanded in the following directions. First, in our model, the retailer is capital constrained, and the supplier is endowed with full capital. However, in reality, the supplier may also be financially constrained. It would be interesting to incorporate the financially constrained supplier into a two-echelon supply chain with loss-averse consideration. Second, we assume the risk-aversion thresholds are common knowledge to both players. In practical business environments, risk-aversion information is commonly asymmetric. Considering asymmetric risk aversion in a future extension would yield different and interesting results in the Stackelberg equilibrium analysis.

Appendixes.

Appendix A (Proof of proposition 1). (i) Taking the first-order condition of $EU(\pi_{RB})$ with respect to q_B yields $\frac{\partial EU(\pi_{RB})}{\partial q_B} = p\bar{F}(q_B) - (\lambda_R - 1)(\bar{F}(k_{B2}) - \bar{F}(k_{B1}))\frac{\partial k_{B1}}{\partial q_B} - w_B(1 + r_f)$. $(w_Bq_B - \Omega)(1 + r_f) = E\,[min\{pmin\{q_B, x\}, (w_Bq_B - \Omega)(1 + r_B)\}]$, $\bar{F}(k_{B1})\frac{\partial k_{B1}}{\partial q_B} = w_B(1+r_f)$. Therefore, $\frac{\partial EU(\pi_{RB})}{\partial q_B} = p\bar{F}(q_B) - \frac{w_B(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) + (1 - \lambda_R)\bar{F}(k_{B2}))$. Taking the second-order condition of $EU(\pi_{RB})$ with respect to q_B yields $\frac{\partial^2 EU(\pi_{RB})}{\partial q_B^2} = -pf(q_B) - (\lambda_R - 1)\frac{w_B(1+r_f)}{\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1})))$. Since $z(q)$ is increasing in q and $k_{B2} > k_{B1}$, $z(k_{B2}) - z(k_{B1}) > 0$. Further, $\frac{\partial^2 EU(\pi_{RB})}{\partial q_B^2} < 0$. Therefore, $EU(\pi_{RB})$ is concave. From $\frac{\partial EU(\pi_{RB})}{\partial q_B} = 0$, q_B satisfies $p\bar{F}(q_B) - \frac{w_B(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) + (1 - \lambda_R)\bar{F}(k_{B2})) = 0$.

(ii)Taking the first-order condition of ;q_B with respect to w_B yields $-pf(q_B)\frac{\partial q_B}{\partial w_B} - (\lambda_R - 1)\frac{w_B(1+r_f)\bar{F}(k_{B2})}{\bar{F}(k_{B1})}(z(k_{B2}) - z(k_{B1}))\frac{\partial k_{B1}}{\partial w_B} - \frac{(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) - (1 - \lambda_R)\bar{F}(k_{B2})) = 0$. Since $(w_Bq_B - \Omega)(1 + r_f) = E[minpminq_B, x, (w_Bq_B - \Omega)(1 + r_B)]$, $p\bar{F}(k_{B1})\frac{\partial \bar{F}(k_{B1})}{\partial w_B} = w_B(1+r_f)\frac{\partial q_B}{\partial w_B} + q_B(1+r_f)$. Therefore, we have $-pf(q_B)\frac{\partial q_B}{\partial w_B} - (\lambda_R - 1)\frac{w_B(1+r_f)^2\bar{F}(k_{B2})}{\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1}))(w_B\frac{\partial q_B}{\partial w_B} + q_B) - \frac{(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) + (1 - \lambda_R)\bar{F}(k_{B2})) = 0$. The above equation can be rewritten as $\frac{\partial q_B}{\partial w_B} = -\frac{(\lambda_R - 1)\frac{w_Bq_B(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1})) + \frac{(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) + (1 - \lambda_R)\bar{F}(k_{B2}))}{pf(q_B) + (\lambda_R - 1)\frac{w_B^2(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1}))}$. Therefore, q_B is decreasing in w_B.

Taking the first-order condition of q_B with respect to λ yields $-pf(q_B)\frac{\partial q_B}{\partial \lambda_R} - (\lambda_R - 1)\frac{w_B(1+r_f)\bar{F}(k_{B2})}{\bar{F}(k_{B1})}(z(k_{B2}) - z(k_{B1}))\frac{\partial k_{B1}}{\partial \lambda_R} - w_B(1 + r_f)\bar{F}(k_{B2}) = 0$. Since $(w_Bq_B - \Omega)(1+r_f) = E\,[min\{pmin\{q_B, x\}, (w_Bq_B - \Omega)(1 + r_B)\}]$, $p\bar{F}(k_{B1})\frac{\partial \bar{F}(k_{B1})}{\partial \lambda_R} = w_B(1+r_f)\frac{\partial q_B}{\partial \lambda_R}$. Therefore, we have $-pf(q_B)\frac{\partial q_B}{\partial \lambda_R} - (\lambda_R - 1)\frac{w_B^2(1+r_f)^2\bar{F}(k_{B2})}{\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1}))\frac{\partial q_B}{\partial \lambda_R} - w_B(1 + r_f)\bar{F}(k_{B2}) = 0$. The above equation can be rewritten as

$\frac{\partial q_B}{\partial \lambda_R} = -\frac{w_B q_B (1+r_f)\bar{F}(k_{B2})}{pf(q_B)+(\lambda_R-1)\frac{w_B^2(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2})-z(k_{B1}))}$. Further, $\frac{\partial q_B}{\partial \lambda_R} < 0$. Therefore, q_B is decreasing in λ_R.

Taking the first-order condition of q_B with respect to Ω yields $-pf(q_B)\frac{\partial q_B}{\partial \Omega} + (\lambda_R - 1)\frac{w_B(1+r_f)\bar{F}(k_{B2})}{\bar{F}(k_{B1})^2}[(z(k_{B2}) - z(k_{B1}))\bar{F}(k_{B1})\bar{F}(k_{B2})\frac{\partial k_{B1}}{\partial \Omega} + \frac{f(k_{B1})\bar{F}(k_{B2})}{p}] = 0$. Since $(w_B q_B - \Omega)(1 + r_f) = E[min\{pmin\{q_B, x\}, (w_B q_B - \Omega)(1 + r_B)\}]$, $p\bar{F}(k_{B1})\frac{\partial \bar{F}(k_{B1})}{\partial \Omega} = w_B(1 + r_f)\frac{\partial q_B}{\partial \Omega} - (1 + r_f)$. Therefore, we have $-pf(q_B)\frac{\partial q_B}{\partial \Omega} + (\lambda_R - 1)\frac{w_B(1+r_f)\bar{F}(k_{B2})}{\bar{F}(k_{B1})^2}[(z(k_{B2}) - z(k_{B1}))\bar{F}(k_{B2})\frac{\frac{w_B(1+r_f)^2\partial q_B}{\partial \Omega}}{p} + \frac{f(k_{B1})\bar{F}(k_{B2})}{p}] = 0$. The above equation can be rewritten as $+\frac{\partial q_B}{\partial \Omega} = -\frac{\frac{w_B(1+r_f)(\lambda_R-1)\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}((z(k_{B2})-z(k_{B1}))(1+r_f)+\frac{w_B(1+r_f)f(k_{B1})}{p})}{pf(q_B)+(\lambda_R-1)\frac{w_B^2(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2})-z(k_{B1}))}$. Further, $\frac{\partial q_B}{\partial \Omega} < 0$. Therefore, q_B is decreasing in Ω.

Appendix B (Proof of proposition 2). Taking the first-order condition of π_{SB} with respect to w_B yields $\frac{\partial EU(\pi_{SB})}{\partial w_B} = (1 + r_f)(q_B + (w_B - c)\frac{\partial q_B}{\partial w_B})$. Further, $\frac{\partial^2 EU(\pi_{SB})}{\partial w_B^2} = (1 + r_f)(2\frac{\partial q_B}{\partial w_B} + (w_B - c)\frac{\partial^2 q_B}{\partial w_B^2})$. Similar to Zhang et al. (2016), we have $\frac{\partial^2 EU(\pi_{SB})}{\partial w_B^2} < 0$. Therefore, $EU(\pi_{SB})$ is concave. Substituting $\frac{\partial q_B}{\partial w_B}$ in $\frac{\partial EU(\pi_{SB})}{\partial w_B}$, we can obtain

$$\frac{\partial EU(\pi_{SB})}{\partial w_B} = \frac{\left\{\begin{array}{r} pq_B f(q_B) - (\lambda_R - 1)\frac{w_B^2 q_B(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1})) \\ +(w_B - c)(\lambda_R - 1)\frac{w_B^2 q_B(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1})) \\ +(w_B - c)\frac{(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) + (1 - \lambda_R)\bar{F}(k_{B2})) \end{array}\right\}}{pf(q_B) + (\lambda_R - 1)\frac{w_B^2(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1}))}.$$

From Proposition 1, we have $p\bar{F}(q_B) - \frac{w_B(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) + (1-\lambda_R)\bar{F}(k_{B2})) = 0$. Substituting into $\frac{\partial EP_{ST}}{\partial w_T}$ yields

$$\frac{\partial EU(\pi_{SB})}{\partial w_B} = \frac{\left\{\begin{array}{r} p\bar{F}(q_B)(q_B z(q_B) - 1) - c[(\lambda_R - 1)\frac{w_B q_B(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1}))] \\ +\frac{(1+r_f)}{\bar{F}(k_{B1})}(\lambda_R\bar{F}(k_{B1}) + (1 - \lambda_R)\bar{F}(k_{B2})) \end{array}\right\}}{pf(q_B) + (\lambda_R - 1)\frac{w_B^2(1+r_f)^2\bar{F}(k_{B2})}{p\bar{F}(k_{B1})^2}(z(k_{B2}) - z(k_{B1}))}.$$

Let $\frac{\partial EP_{ST}}{\partial w_T} = 0$, we obtain $\bar{F}(q_B)(q_B z(q_B) - 1) - c\frac{(1+r_f)}{\bar{F}(k_{B1})}[(\lambda_R - 1)\frac{w_B q_B(1+r_f)\bar{F}(k_{B2})}{p\bar{F}(k_{B1})}(z(k_{B2}) - z(k_{B1})) + \lambda_R\bar{F}(k_{B1}) + (1 - \lambda_R)\bar{F}(k_{B2})] = 0$.

Appendix C (Proof of Lemma 1). (i) At the end of the sales season, the retailer accumulates sales income $pmin\{q_T, x\}$ and pays $(w_T q_T - \Omega)(1 + r_T)$ to the supplier. If $pmin\{q_T, x\} = (w_T q_T - \Omega)(1 + r_T)$, then the retailer can just pay his loans. Therefore, we obtain the retailer's bankruptcy critical market demand $k_{RT1} = \frac{(w_T q_T - \Omega)(1+r_T)}{p}$.

(ii) If $\Omega < cq_T$, whether the supplier goes bankrupt depends on the retailer's sales income. If the retailer goes bankrupt, he has to pay full sales income px to the supplier. Therefore, the supplier's profit at the end of the sales season is $px - (cq_T - \Omega(1 + r_f)$. Further, we obtain the supplier's bankruptcy critical market demand $k_{ST} = \frac{(cq_T - \Omega)(1+r_f)}{p}$. If $\Omega \geq cq_T$, the supplier's profit is $px - (cq_T - \Omega)(1 + r_f) \geq 0$

when the retailer goes bankrupt and pays all sales income. Therefore, the supplier will not go bankrupt.

Appendix D (Proof of proposition 3). The proofs of Proposition 3(i) are similar to those of Proposition 1(i) and hence are omitted. Taking the first-order condition of q_T with respect to λ_R yields $-pf(q_T)\frac{\partial q_T}{\partial \lambda_R} - w_T(1+r_T)(\bar{F}(k_{RT1}) - \bar{F}(k_{RT2}) - \frac{w_T(1+r_T)}{p}(\lambda_R f(k_{RT1}) + (1-\lambda_R)f(k_{RT2}))\frac{\partial q_T}{\partial \lambda_R} = 0$. The above equation can be rewritten as $\frac{\partial q_T}{\partial \lambda_R} = \frac{\frac{w_T(1+r_T)}{p}(\bar{F}(k_{RT2})-\bar{F}(k_{RT1}))}{f(q_T)-\frac{w_T^2(1+r_T)^2}{p^2}(\lambda_R f(k_{RT1})+(1-\lambda_R)f(k_{RT2}))}$. Similar to the proofs of Proposition 1(i), we have $f(q_T) - \frac{w_T^2(1+r_T)^2}{p^2}(\lambda_R f(k_{RT1}) + (1-\lambda_R)f(k_{RT2})) < 0$. Obviously, $\frac{\partial q_T}{\partial \lambda_R} < 0$. Therefore, q_T is decreasing in λ_R.

Taking the first-order condition of q_T with respect to Ω yields $-pf(q_T)\frac{\partial q_T}{\partial \Omega} + \frac{w_T(1+r_T)}{p}(\lambda_R(1+r_T)f(k_{RT1})(1 - w_T\frac{\partial q_T}{\partial \Omega}) + (1-\lambda_R)r_T f(k_{RT2})(r_T - w_T(1+r_T)\frac{\partial q_T}{\partial \Omega})) = 0$. The above equation can be rewritten as $\frac{\partial q_T}{\partial \Omega} = \frac{\frac{w_T(1+r_T)}{p}(\lambda_R(1+r_T)f(k_{RT1})+(1-\lambda_R)r_T f(k_{RT2}))}{f(q_T)-\frac{w_T^2(1+r_T)^2}{p^2}(\lambda_R f(k_{RT1})+(1-\lambda_R)f(k_{RT2}))}$. Obviously, $\frac{\partial q_T}{\partial \Omega} < 0$. Therefore, q_T is decreasing in Ω.

Appendix E (Proof of proposition 4). (i) From Proposition 3(i), the retailer's order quantity is uniquely given by$p\bar{F}(q_T) - w_T(1+r_T)(\lambda_R\bar{F}(k_{RT1}) + (1-\lambda_R)$ $\bar{F}(k_{RT2})) = 0$. The supplier's wholesale price w_T is a one-to-one mapping with the retailer's order quantity q_T. Therefore, the problem of setting w_T is equivalent to setting q_T.

(a)When $\Omega \geq cq_T$, the first-order condition of $EU(\pi_{ST})$ with respect to q_T yields $\frac{\partial EU(\pi_{ST})}{\partial q_T} = (1+r_T)\bar{F}(k_{RT1})\frac{\partial w_T q_T}{\partial q_T} - c(1+r_f)$. Further, $\frac{\partial^2 EU(\pi_{ST})}{\partial q_T^2} = \frac{(1+r_T)^2}{p}f(k_{RT1})(\frac{\partial w_T q_T}{\partial q_T})^2 + (1+r_T)\bar{F}(k_{RT1})\frac{\partial^2 w_T q_T}{\partial q_T^2}$. From Proposition 3(i), we have $p\bar{F}(q_T) - w_T(1+r_T)(\lambda_R\bar{F}(k_{RT1}) + (1-\lambda_R)\bar{F}(k_{RT2})) = 0$. Taking the first-order condition of q_T on both sides yields $-pf(q_T) - (1+r_T)(\lambda_R\bar{F}(k_{RT1}) + (1-\lambda_R)\bar{F}(k_{RT2}))\frac{\partial w_T}{\partial q_T} + \frac{(1+r_T)^2}{p}(\lambda_R f(k_{RT1}) + (1-\lambda_R)f(k_{RT2}))\frac{\partial w_T q_T}{\partial q_T} = 0$. The above equation can be rewritten as

$$\frac{\partial w_T}{\partial q_T} = \frac{-pf(q_T)+\frac{w_T(1+r_T)^2}{p}(\lambda_R f(k_{RT1})+(1-\lambda_R)f(k_{RT2}))}{(1+r_T)(\lambda_R\bar{F}(k_{RT1})+(1-\lambda_R)\bar{F}(k_{RT2})-\frac{w_T q_T(1+r_T)}{p}(\lambda_R f(k_{RT1})+(1-\lambda_R)f(k_{RT2})))}.$$

Further, we obtain

$$\frac{\partial w_T q_T}{\partial q_T} = \frac{-pf(q_T)+w_T(1+r_T)(\lambda_R\bar{F}(k_{RT1})+(1-\lambda_R)\bar{F}(k_{RT2}))}{(1+r_T)(\lambda_R\bar{F}(k_{RT1})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT1}))+(1-\lambda_R)\bar{F}(k_{RT2})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT2})))}.$$

From Proposition 3, we have $p\bar{F}(q_T) - w_T(1+r_T)(\lambda_R\bar{F}(k_{RT1}) + (1-\lambda_R)\bar{F}(k_{RT2})) = 0$. Therefore,

$$\frac{\partial w_T q_T}{\partial q_T} = \frac{p\bar{F}(q_T)(1-q_T z(q_T))}{(1+r_T)(\lambda_R\bar{F}(k_{RT1})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT1}))+(1-\lambda_R)\bar{F}(k_{RT2})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT2})))}.$$

Assume $z(q)$ is the increasing failure rate; then, $qz(q)$ is increasing in q. Let$\tilde{q}$ solve $\tilde{q}z(\tilde{q}) = 1$. When $q \leq \tilde{q}$, $\frac{\partial w_T q_T}{\partial q_T} \leq 0$. When $q > \tilde{q}$, $\frac{\partial w_T q_T}{\partial q_T} < 0$. Therefore, $w_T q_T$ is a concave function of q_T. Further,$\frac{\partial^2 w_T q_T}{\partial {q_T}^2} < 0$. Therefore, $\frac{\partial^2 EU(\pi_{ST})}{\partial {q_T}^2} < 0$. $EU(\pi_{ST})$ is a concave function of q_T. Substituting $\frac{\partial w_T q_T}{\partial q_T}$ into$\frac{\partial EU(\pi_{ST})}{\partial q_T} < 0$, we have $\frac{\partial EU(\pi_{ST})}{\partial q_T} = \frac{\bar{F}(k_{RT1})p\bar{F}(q_T)(1-q_T z(q_T))}{\lambda_R\bar{F}(k_{RT1})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT1}))+(1-\lambda_R)\bar{F}(k_{RT2})(1-\frac{w_T q_T(1+r_T)}{p}z(k_{RT2}))}$ $- c(1+r_f)$.

Let $\frac{\partial EU(\pi_{ST})}{\partial q_T} = 0$. We obtain $\bar{F}(k_{RT1})p\bar{F}(q_T)(1-q_Tz(q_T))-c(1+r_f)[\lambda_R\bar{F}(k_{RT1})(1-\frac{w_Tq_T(1+r_T)}{p}z(k_{RT1}))+(1-\lambda_R)\bar{F}(k_{RT2})(1-\frac{w_Tq_T(1+r_T)}{p}z(k_{RT2}))]$.

(b) When $\Omega < cq_T$, taking the first-order condition of $EU(\pi_{ST})$ with respect to q_T yields $\frac{\partial EU(\pi_{ST})}{\partial q_T} = (1+r_T)\bar{F}(k_{RT1})\frac{\partial w_Tq_T}{\partial q_T} - c(1+r_f)[1+(\lambda_S-1)F(\frac{(c-\Omega)(1+r_f)}{P})]$. Further, $\frac{\partial^2 EU(\pi_{ST})}{\partial {q_T}^2} = \frac{(1+r_T)^2}{p}f(k_{RT1})(\frac{\partial w_Tq_T}{\partial q_T})^2 + (1+r_T)\bar{F}(k_{RT1})\frac{\partial^2 w_Tq_T}{\partial {q_T}^2} - (\lambda_S - 1)\frac{c(1+r_T)^2}{p}f(\frac{(c-\Omega)(1+r_f)}{P})$. Since $\frac{\partial^2 w_Tq_T}{\partial {q_T}^2} < 0$, then $\frac{\partial^2 EU(\pi_{ST})}{\partial {q_T}^2} < 0$. Therefore, $EU(\pi_{ST})$ is a concave function of q_T. Substituting $\frac{\partial w_Tq_T}{\partial q_T}$ into $\frac{\partial EU(\pi_{ST})}{\partial q_T} = 0$ yields

$\bar{F}(k_{RT1})p\bar{F}(q_T)(1-q_Tz(q_T))-c(1+r_f)(1+(\lambda_S-1)F(\frac{(c-\Omega)(1+r_f)}{P})(\lambda_R\bar{F}(k_{RT1})(1-\frac{w_Tq_T(1+r_T)}{p}z(k_{RT1}))+(1-\lambda_R)\bar{F}(k_{RT2})(1-\frac{w_Tq_T(1+r_T)}{p}z(k_{RT2})))$. Further, the optimal wholesale price satisfies $p\bar{F}(q_T)-w_T(1+r_T)(\lambda_R\bar{F}(k_{RT1})+(1-\lambda_R)\bar{F}(k_{RT2}))=0$.

(ii) The first-order condition of $EU(\pi_{ST})$ with respect to r_T yields $\frac{\partial EU(\pi_{ST})}{\partial r_T} = p\bar{F}(q_T)\frac{k_{RT1}}{\partial r_T} - c(1+r_f)\frac{q_T}{\partial r_T} = p\bar{F}(q_T)(\frac{(w_Tq_T-\Omega)}{P} + \frac{1+r_T}{P}(w_T\frac{q_T}{\partial r_T} + q_T\frac{w_T}{\partial r_T})) - c(1+r_f)\frac{q_T}{\partial r_T}$.

(a) When $\Omega \geq cq_T$, the supplier's optimal wholesale price satisfies $\bar{F}(k_{RT1})p\bar{F}(q_T)(1-q_Tz(q_T))$
$-c(1+r_f)[\lambda_R\bar{F}(k_{RT1})(1-\frac{w_Tq_T(1+r_T)}{p}z(k_{RT1}))+(1-\lambda_R)\bar{F}(k_{RT2})(1-\frac{w_Tq_T(1+r_T)}{p}z(k_{RT2}))]$.
Let $\rho = \frac{w_T(1+r_T)}{p}$, $\varphi = \frac{q_T(1+r_T)}{p}$, $V_1 = \bar{F}(k_{RT1})p\bar{F}(q_T(1-q_Tz(q_T)) - c(1+r_f)[\lambda_R\bar{F}(k_{RT1})(1-\rho q_Tz(k_{RT1}))(1-\lambda_R)\bar{F}(k_{RT2})(1-\rho q_Tz(k_{RT2}))] = 0$, $V_2 = p\bar{F}(q_T) - w_T(1+r_T)(\lambda_R\bar{F}(k_{RT1})+(1-\lambda_R)\bar{F}(k_{RT2})) = 0$. Then, from the system of the two equations and from the implicit function theorem, we have

$$\begin{cases} V_{1q_T}d_{q_T} + V_{1w_T}d_{w_T}V_{1r_T}d_{r_T} = 0 \\ V_{2q_T}d_{q_T} + V_{2w_T}d_{w_T}V_{2r_T}d_{r_T} = 0. \end{cases}$$

Those partial derivatives are obtained as follows, after simplification:

$$\begin{aligned} V_{1q_T} =& -w_T(1+r_T)f(k_{RT1})\bar{F}(q_T)(1-q_Tz(q_T)) - p\bar{F}(k_{RT1})f(q_T)(1-q_Tz(q_T)) - \\ & p\bar{F}(k_{RT1})\bar{F}(q_T)(z(q_T)+z^{'}(q_T)) + \rho c(1+r_f)[\lambda_R\bar{F}(k_{RT1})(z(k_{RT1}) \\ & + \rho q_Tz^{'}(k_{RT1})) + \lambda_Rf(k_{RT1})(1-\rho q_Tz(k_{RT1})) + (1-\lambda_R)\bar{F}(k_{RT2})(z(k_{RT2}) \\ & + \rho q_Tz^{'}(k_{RT2})) + (1-\lambda_R)f(k_{RT2})(1-\rho q_Tz(k_{RT2})), \end{aligned}$$

$$\begin{aligned} V_{1w_T} =& -q_T(1+r_T)f(k_{RT1})\bar{F}(q_T)(1-q_Tz(q_T)) + \varphi c(1+r_f)[\lambda_R\bar{F}(k_{RT1})(z(k_{RT1}) \\ & + \rho q_Tz^{'}(k_{RT1})) + \lambda_Rf(k_{RT1})(1-\rho q_Tz(k_{RT1})) + (1-\lambda_R)\bar{F}(k_{RT2})(z(k_{RT2}) \\ & + \rho q_Tz^{'}(k_{RT2})) + (1-\lambda_R)f(k_{RT2})(1-\rho q_Tz(k_{RT1})), \end{aligned}$$

$$\begin{aligned} V_{1r_T} =&(w_Tq_T-\Omega)f(k_{RT1})\bar{F}(q_T)(1-q_Tz(q_T)) + c(1+r_f)[\lambda_R\bar{F}(k_{RT1}) \\ & \times(\frac{w_Tq_T}{p}z(k_{RT1}) + \rho q_Tz^{'}(k_{RT1})\frac{w_Tq_T-\Omega}{p}) + \lambda_R\frac{w_Tq_T-\Omega}{p}f(k_{RT1}) \\ & \times(1-\rho q_Tz(k_{RT1})) + (1-\lambda_R)\bar{F}(k_{RT2})(\frac{w_Tq_T}{p}z(k_{RT2}) \\ & + z^{'}(k_{RT2})\frac{w_Tq_T-\Omega}{p}) + (1-\lambda_R)\frac{w_Tq_T-\Omega}{p}f(k_{RT2})(1-\rho q_Tz(k_{RT1}))], \end{aligned}$$

$$V_{2q_T} = -pf(q_T) + \rho w_T(1+r_T)(\lambda_Rf(k_{RT1}) + (1-\lambda_R)f(k_{RT2})),$$

$$V_{2w_T} = -(1+r_T)(\lambda_R \bar{F}(k_{RT1} + (1-\lambda_R)\bar{F}(k_{RT2})) + \varphi w_T(1+r_T)(\lambda_R f(k_{RT1}) + (1-\lambda_R) f(k_{RT2})),$$

$$V_{2r_T} = -w_T(\lambda_R \bar{F}(k_{RT1} + (1-\lambda_R)\bar{F}(k_{RT2})) + \frac{w_T q_T - \Omega}{p}(\lambda_R f(k_{RT1}) + (1-\lambda_R) f(k_{RT2})).$$

By solving the equations, we obtain $\frac{q_T}{\partial r_T} = \frac{\partial V_{1w_T} V_{2r_T} - V_{1r_T} V_{2w_T}}{V_{1q_T} V_{2w_T} - V_{1w_T} V_{2q_T}}$ and $\frac{w_T}{\partial r_T} = \frac{\partial V_{1r_T} V_{2q_T} - V_{1q_T} V_{2r_T}}{V_{1q_T} V_{2w_T} - V_{1w_T} V_{2q_T}}$.

Substituting $\frac{q_T}{\partial r_T}$ and $\frac{w_T}{\partial r_T}$ into $\frac{EU(\pi_T)}{\partial r_T}$, similar to the proofs of Proposition 3 in [21], we obtain $\frac{EU(\pi_T)}{\partial r_T} < 0$. Since $r_T \geq r_f$, $r_T = r_f$.

(b) When $\Omega < cq_T$, the supplier's optimal wholesale price satisfies $\bar{F}(k_{RT1})\bar{F}(q_T)(1 - q_T z(q_T)) - c(1+r_f)[1 + (\lambda_S - 1)F(\frac{(cq_T - \Omega)(1+r_f)}{p})](\lambda_R \bar{F}(k_{RT1})(1 - \frac{w_T q_T(1+r_T)}{p} z(k_{RT1})) + (1-\lambda_R)\bar{F}(k_{RT2})(1 - \frac{w_T q_T (1+r_T)}{p} z(k_{RT2}))) = 0$. Similar to the proofs of (a), we obtain $\frac{EU(\pi_T)}{\partial r_T} < 0$. Since $r_T \geq r_f$, $r_T = r_f$.

To summarize the proofs of (a) and (b), we have $r_T = r_f$.

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