OPTIMAL CREDIT PERIODS UNDER TWO-LEVEL TRADE CREDIT

HONGLIN YANG* AND HEPING DAI
School of Business Administration, Hunan University
Changsha, Hunan Province 410082, China

HONG WAN
School of Business, State University of New York at Oswego
Oswego, NY 13126, USA

LINGLING CHU
School of Business Administration, Hunan University
Changsha, Hunan Province 410082, China

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ABSTRACT. In a two-echelon single-supplier and single-retailer supply chain with permissible delay in payment, we investigate the two-level trade credit policy in which the supplier offers the retailer with limited capital a credit period and in turn the retailer also provides a credit period to customers. The demand rate is sensitive to both retail price and the customers credit period. By using the backward induction method, we analytically derive the unique equilibrium of both credit periods in the Stackelberg game to determine the retailers pricing strategy. We find that the optimal retail price is not always decreasing in the credit period offered by the supplier to the retailer. In addition, we characterize the conditions under which the retailer is willing to voluntarily provide customers a credit period. Numerical examples and sensitivity analysis of key parameters are presented to illustrate the theoretical results and managerial insights.

1. Introduction. In today’s supply chain operation, trade credit is increasingly becoming one of the most popular short-term financing vehicles. The dominant supplier endowed with sufficient capital often offers the financially constrained retailer a permissible delay period to fund the retailers business. To boost sales, the retailer tends to provide customers a delayed payment period as well. For example, over 80% of manufactures or suppliers in the U.S. allow their buyers to delay in payment [28]. In China, on average, 27% of the business sales are based on trade credit [7]. JD and Alibaba, two giants of the e-business companies, offer online sales credit to motivate customers to buy more merchandise.

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* Corresponding author: ottoyang@126.com (Honglin Yang).
To investigate the trade credit policy, many studies proposed various inventory models [9, 21, 22, 25, 26]. To be more specific, [9] first investigated EOQ in a two-echelon supply chain with permissible delay in payment under the condition of deterministic demand and concluded that the delayed payment reduced the retailers cost. Recent studies extend [9] to model more realistic situations such as allowable shortage [15], deteriorating items [2, 27, 34], partial permissible delay payments [4, 13, 39], two-part flexible trade credit [41], and commodity options [6]. Previous literature on permissible delay in payment assumed that the demand was constant and that only the supplier offered the retailer a permissible delayed payment period. By relaxing the constant demand, many researchers developed a series of models through considering the time-dependent demand [32], the pricesensitive demand [1], and the time-and-price-linked demand [16]. In the same vein, some literature focused on the supply chain decisions with the two-level trade credit policy in which the retailer received a delayed payment period from the supplier, and subsequently provided a delayed payment period to customers [1, 5, 23, 33]. More specifically, [11] discussed the retailer’s ordering strategy under the two-level trade credit policy. Later, various inventory models with the two-level trade credit policy were developed by [3, 12, 17, 18, 19, 20, 24, 25, 27, 30]. It is worthy to note that early literature mainly focused on the inventory strategy with price-and-time dependent demand under two-level trade credit. Comparatively, the impact of a permissible delayed period on inventory decisions has been under-researched. In practice, however, by providing a delayed payment period, the retailer would motivate customers to order more items. It implies that there exists a positive correlation between customers demand and the delayed period provided by the retailer to customers. By appropriately setting a delayed payment period, the retailer would efficiently adjust customers demand. Currently, an increasing number of studies began to consider incorporating the delayed payment period into the demand function [8, 10, 14, 31, 35, 36, 37]. However, the literature mentioned above neglected the delayed payment period as a crucial factor in their integrated inventory models. To fill these gaps, we present a generalized supplier-retailer inventory model in which the delayed period served as a decision variable to determine the two-level trade credit policy and the retailers pricing strategy.

Through discussing an SMF firm in China, we observe a typical two-level trade credit policy. Turner is a company that sells art material, and Arjowiggins is its biggest supplier. To motivate Turner to order more items, Arjowiggins offered a 60-day delayed payment period and RMB 30,000-500,000 credit. At the same time, Turner provided a 30-day delayed payment period and RMB 10,000-20,000 credit
to its core customers, such as ZYxu and BiBG, to boost sales. Turner often adjusts its trade credit policy according to its customers' sales, market competition, and financial status. Thanks to proactive market exploration, the profit of Turner grew up to RMB 4.2m in 2016 from about RMB 1.1m in 2009. As market competition rises, both Arjowiggins and Turner are facing a big challenge of how to set a feasible and efficient trade credit policy. Fig. 1 illustrates a practical two-period trade credit case.

Our supplier-retailer inventory model is distinct from the previous literature in which both credit periods offered by the supplier and retailer are considered as crucial decision variables. By using the backward induction method, we analytically derive the unique equilibrium of both credit periods to determine the impact of the credit periods on the retailer’s pricing strategy. We propose an inventory model that considers both delayed periods as crucial decision variables. Our model is along the same line to [38] and [29]. Table 1 summarizes the differences of the three models with permissible delay in payment. The contribution of our paper is twofold. Firstly, our paper contributes to the trade credit literature by investigating the implication of both credit periods offered by the supplier and retailer for the two-level trade credit policy. Further, we develop insights into how the credit period affects the retailer’s pricing strategy. Secondly, this paper also contributes to the growing literature on the conditions under which the retailer is willing to voluntarily provide customers credit period when the retailer enjoys the permissible delayed period offered by the supplier. It is noteworthy that the optimal retail price is not always decreasing in the credit period offered by the supplier to the retailer. This finding is novel to the existing literature on a traditional one-level trade credit policy with the price-and-credit linked demand that documents the retail price is monotonically decreasing in the credit period offered by the supplier to the retailer.

The remainder of the paper is organized as follows. Section 2 introduces the notations and assumptions. Section 3 develops the inventory model considering the two-level trade credit policy with price-and-credit dependent demand and derives the equilibrium in the Stackelberg game. In Section 4, numerical examples and sensitivity analysis are provided to illustrate the theoretical results. Section 5 concludes and presents the management insights.

2. Notations and assumptions. We consider a two-echelon single-supplier and single-retailer supply chain with permissible delay in payment. Under the two-level trade credit policy, the supplier offers the retailer with limited capital a credit period and in turn the retailer also provides a credit period to customers. For convenience, we refer to the supplier as she and the retailer as he. The notations and assumptions throughout this paper are as follows.

| Trade credit policy | Demand | Decision variable | Optimal delay period |
|---------------------|--------|-------------------|----------------------|
| one-level (Yangs et al., 2017) | price-and-time dependent | $M$ | obtain the analytic solution of optimal $M$ |
| two-level (Shahs et al., 2015) | price-and-credit dependent | constant | give a solution algorithm of optimal |
| two-level (our paper) | price-and-credit dependent | $M, N$ | obtain the analytic solutions of optimal $M$ and $N$ |

Note: $M$ represents the credit period offered by the supplier to the retailer, and $N$ represents the credit period provided by the retailer to customers.
Table 2. Notations and explanations

| Notation | Definition |
|----------|------------|
| w        | wholesale price per unit. |
| p        | retail price per unit (decision variable). |
| M        | credit period offered by the supplier (decision variable). |
| N        | credit period provided by the retailer (decision variable). |
| T        | ordering cycle. |
| D(p, N)  | customers’ annual demand rate depending on p and N. |
| I_e      | retailer’s interest charged per dollar per year. |
| I_e      | retailer’s interest earned per dollar per year. |
| c        | supplier’s procurement cost per unit. |
| h        | retailer’s holding cost per unit. |
| A        | ordering cost per order. |
| TPS      | supplier’s annual total profit. |
| TPR      | retailer’s annual total profit. |

2.1. Notations.

2.2. Assumptions. (i) In practice, the demand usually falls as retail price rises. Providing a long credit period to customers can encourage them to order more items. Therefore, the demand rate $D(p, N)$ is sensitive to both retail price and customers’ credit period, i.e., $D = a - bp + \gamma N$, where $a > 0$ is scale demand, $b > 0$ is price elasticity and $\gamma > 0$ is credit elasticity \[10, 30, 40\]. For simplicity, $D(p, N)$ and $D$ are used interchangeably throughout this paper. (ii) To avoid triviality, the fixed production cost is omitted and the shortages are not allowed. (iii) The player’s loans must be paid off at the end of the credit period. Otherwise, the player goes bankrupt \[1\]. (iv) To control the risk of cash flow, the length of the credit period $N$ provided by the financially constrained retailer is shorter than the length of the credit period $M$ offered by the supplier, i.e., $N < M$\[11, 20\]. (v) The retailer accumulates the sales revenue to earn interest at a rate of $I_e$ before his payment is due. In case that the retailer’s profit is not enough to pay off the supplier at the end of $M$, the retailer may borrow from a bank at a rate of $I_c$. $I_c > I_e$ avoids the potential arbitrage \[9, 29, 38\].

3. Mathematic models. We consider a two echelon single-supplier and single-retailer supply chain with the two-level trade credit policy. With a wholesale price contract the supplier as a Stackelberg leader first decides the credit period $M$ to maximize her profit. Then the retailer as a follower decides the credit period $N$ and retail price $p$ to maximize his profit. By using the backward induction method, we solve the non-cooperative equilibrium in the Stackelberg game.

3.1. The retailer’s problem. We first solve the retailer’s optimal decisions. The retailer sets $p$ and $N$ for maximizing his profit. The annual total profit of the retailer include the following elements: (i) sales revenue per year = $pD$; (ii) purchase cost per year = $wD$; (iii) holding cost per year = $\frac{hDT}{2}$; (iv) ordering cost per year = $\frac{AT}{T}$; and (v) interest earned and interest charged per ordering cycle, depending on $T$, $M$ and $N$.

Based on the values of $T$, $M$ and $N$, two cases need to be considered: $T + N \leq M$ (as seen in Fig. 2), and $M < T + N$ (as seen in Fig. 3). For $T + N \leq M$, the retailer’s interest earned is $wI_e\left(\frac{DT^2}{2}\right) + \frac{DT(M-T-N)}{T}$ and the interest charged is zero.
For $M < T + N$, the retailer's interest earned is $\frac{wL(T - M + N)^2}{2T}$ and the interest charged is $\frac{wL(D(T - M + N)^2)}{2T}$. Therefore, the retailer's annual total profit is given by

$$TPR(p, N) = \begin{cases} 
TPR_1(p, N), & \text{if } T + N \leq M, \\
TPR_2(p, N), & \text{if } M < T + N,
\end{cases}$$

where

$$TPR_1(p, N) = (p - w)D - \frac{hDT}{2} - \frac{A}{T} + wI_e \left[ \frac{DT}{2} + D(M - T - N) \right],$$

$$TPR_2(p, N) = (p - w)D - \frac{hDT}{2} - \frac{A}{T} + wI_e \frac{D(M - N)^2}{2T} - \frac{wL(D(T - M + N)^2)}{2T}.$$ 

**Proposition 1.** Given $N$, there exists a unique $p^*$ to maximize the retailer's annual total profit:

(i) when $T + N \leq M$, where $p_1^* = \frac{2a + 2\gamma N + bhT}{46} + \frac{2 + I_e T - 2I_e (M - N)w}{4}$;

(ii) when $M < T + N$, then $p_2^* = \frac{2a + 2\gamma N + bhT}{46} + \frac{2I_e (M - N)^2 + I_e (T - M - N)^2 w}{4T}.$

From Proposition 1, it is noticeable that $\frac{dp^*_1}{dN} > 0$ and $\frac{dp^*_2}{dN} > 0$. In providing a credit period to customers, the retailer bears a capital opportunity cost at a rate of $I_e$. When an extended credit period is provided to customers, the retailer suffers more interest loss. To compensate the potential loss, the retailer correspondingly increases the retail price.

**Proposition 2.**

(i) when $\gamma \leq bwI_e$, then $\frac{dD}{dN} \leq 0$ and $N^* = 0$;

(ii) when $bwI_e < \gamma < bwI_c$, if $M \leq \Delta_1$ then $\frac{dD}{dN} \leq 0$ and $N^* = 0$ in $N \in [0, M]$; if $M > \Delta_1$ then $\frac{dD}{dN} \geq 0$ in $N \in [0, M - \Delta_1]$, $\frac{dD}{dN} < 0$ in $N \in (M - \Delta_1, M]$; and $N^* = M - \Delta_1$, where $\Delta_1 = \frac{bwI_e - \gamma I_e}{bwI_e - I_e} T$;

(iii) where $\gamma > bwI_c$, then $\frac{dD}{dN} > 0$ and $N^* = M$.

Proposition 2 gives the optimal $N$. The demand is linked to both $p$ and $N$ in which $p$ has a negative and $N$ has a positive impact on demand. Based on Proposition 1, when the retailer provides a longer $N$ to customers, the retail price will increase to make up the potential loss. Due to higher credit elasticity $\gamma$, the
demand will be increased more when providing an identical $N$. Hence, the optimal $N$ depends on $p$ and its elasticity $\gamma$.

When $\gamma \leq bwI_e$, the increased demand from a longer $N$ does not make up the reduced demand from a higher $p$. The demand is not increasing in $N$ (Proposition 2(i)). Therefore, at $N = 0$, the maximum demand is reached and the retailer realizes his maximum profit. When $\gamma > bwI_e$, the increased demand from a longer $N$ exceeds the reduced demand from a higher $p$. The demand therefore is increasing in $N$ (Proposition 2(iii)). Therefore, at $N = M$, the maximum demand is achieved and the retailer obtains his maximum profit. When $bwI_e < \gamma < bwI_c$, the maximum demand is received in the interval of $(0, M)$. Therefore, at a certain $N \in (0, M)$, the retailer obtains his maximum profit.

Proposition 3.

(i) when $\gamma \leq bwI_e$, then $dD/dM = 0$ and $dp^*/dM < 0$;
(ii) when $bwI_e < \gamma < bwI_c$, if $M \leq \Delta_1$ then $dN^*/dM = 0$ and $dp^*/dM < 0$; and if $M > \Delta_1$ then $dN^*/dM > 0$ and $dp^*/dM > 0$;
(iii) where $\gamma > bwI_e$, then $dN^*/dM > 0$ and $dp^*/dM > 0$.

Proposition 3 shows the relationship between $N$ and $M$. When $\gamma \leq bwI_e$, $N^* = 0$ independent of $M$. The two-level trade credit is equivalent to one-level trade credit. When the supplier offers a longer credit period, the retailer obtains more allowance. It is considered that a wholesale price discount is offered [4]. The retailer is able to decrease retail price to enlarge demand (Proposition 3(i)). When $\gamma > bwI_e$, the demand is increasing in $N$. The demand reaches maximum value at $N^* = M$. When the supplier offers a longer credit period, the retailer correspondingly gains a longer $N^*$. To compensate the opportunity cost, the retailer increases the retail price (Proposition 3(iii)). When $bwI_e < \gamma < bwI_c$ and $M \leq \Delta_1$, the demand reaches maximum value at $N^* = 0$. The trends of $N^*$ and $p^*$ in $M$ are similar to Proposition 3(i). When $bwI_e < \gamma < bwI_c$ and $M > \Delta_1$, the demand reaches maximum value at $N^* = M - \Delta_1$. The trends of $N^*$ and $p^*$ in $M$ are similar to Proposition 3(iii).

3.2. The supplier’s problem. The supplier sets $M$ for maximizing her profit. The supplier’s annual total profit consist of the following elements: (1) sales revenue per year = $wD$; (2) opportunity cost per year = $wDMI_e$; and (3) procurement cost per year = $cD$.

The supplier obtains her total profit at the end of $M$. If there is not enough profit to pay off the supplier at the end of $M$, the retailer may consider to borrow from a bank. Then the bank charges interest on the retailer’s loans. Therefore, the supplier’s total profit does not include the retailer’s interest charged in the interval $(M, T + N]$ [1]. The supplier’s annual total profit is given by

$$TPS = (w - wMI_e - c)(a - bp + \gamma N).$$

In the Stackelberg game, the supplier as a leader decides $M$ according to the retailer’s optimal $p$ and $N$. We consider three possible cases.

Case 1. $\gamma \leq bwI_e$

From Proposition 2(i), $N^* = 0$. We discuss two possible sub-cases: (1) $M \leq T$, and (2) $M > T$. 


Sub-case 1-1. $M \leq T$: From Proposition 1(ii), we have $p^* = p_2^*$. Substituting $p^*$ and $N^*$ into Equation 3, the supplier’s annual total profit is given by

$$TPS_{11}(M) = (w - wMI_c - c) \left[ \frac{2a - bhT}{4} - \frac{2T - I_e M^2 + I_e (T - M)^2}{4T} wb \right].$$

(5)

Sub-case 1-2. $M > T$: From Proposition 1(i) we have $p^* = p_1^*$. The supplier’s annual total profit is given by

$$TPS_{12}(M) = (w - wMI_c - c) \left[ \frac{2a - bhT}{4} - \frac{2T - I_e T - 2I_e M}{4} wb \right].$$

(6)

Hence, in Case 1. $\gamma \leq bwI_c$, the supplier’s annual total profit is

$$TPS_1(M) = \begin{cases} 
TPS_{11}(M), & \text{if } M \leq T; \\
TPS_{12}(M), & \text{if } M > T.
\end{cases}$$

(7)

**Case 2.** $bwI_c < \gamma \leq bwI_c$

Similarly, we discuss two possible sub-cases: (1) $M \leq \Delta_1$, and (2) $M > \Delta_1$.

Sub-case 2-1. $M \leq \Delta_1$: From Proposition 2(ii) and Proposition 1, we have $N^* = 0$ and $p^* = p_2^*$. Then the supplier’s annual total profit is given by

$$TPS_{21}(M) = (w - wMI_c - c) \left[ \frac{2a + 2\gamma (M - \Delta_1) - bhT}{4} - \frac{2T - I_e \Delta_1^2 + I_e (T - \Delta_1)^2}{4T} wb \right].$$

(8)

Sub-case 2-2. $M > \Delta_1$: From Proposition 2(ii) and Proposition 1(iii), we have $N^* = M - \Delta_1$ and $p^* = p_2^*$. Then the supplier’s annual total profit is given by

$$TPS_{22}(M) = \begin{cases} 
TPS_{21}(M), & \text{if } M \leq \Delta_1; \\
TPS_{22}(M), & \text{if } M > \Delta_1.
\end{cases}$$

(9)

Therefore, in Case 2, $bwI_c < \gamma \leq bwI_c$, the supplier’s annual total profit is

$$TPS_2(M) = \begin{cases} 
TPS_{21}(M), & \text{if } M \leq \Delta_1; \\
TPS_{22}(M), & \text{if } M > \Delta_1.
\end{cases}$$

(10)

**Case 3.** $\gamma > bwI_c$

From Proposition 2(iii) and Proposition 1, we have $N^* = M$ and $p^* = p_2^*$. The supplier’s annual total profit is given by

$$TPR_3(M) = (w - wMI_c - c) \left[ \frac{2a + 2\gamma M - bhT}{4} - \frac{2T + I_e T^2}{4T} wb \right].$$

(11)

Considering (7), (10) and (11), the supplier annual total profit is

$$TPR_2(M) = \begin{cases} 
TPS_1(M), & \text{if } \gamma \leq bwI_c; \\
TPS_2(M), & \text{if } bwI_c < \gamma \leq bwI_c; \\
TPS_3(M), & \text{if } \gamma > bwI_c.
\end{cases}$$

(12)

**Proposition 4.** The supplier’s annual total profit $TPS(M)$ is concave in $M$. There exists a unique $M^*$ to maximize the supplier’s annual total profit:

(i) when $\gamma \leq bwI_c$, if $\Delta_2 < \Delta_3 \leq 0$, then $M_1^* = 0$; if $\Delta_2 < 0 < \Delta_3$, then $M_1^* = \frac{\gamma - \sqrt{\gamma^2 - \Delta_3^2}}{2X}$; and if $0 \leq \Delta_2 < \Delta_3$, then $M_1^* = T + \frac{\Delta_2}{2bwI_c}$;

(ii) when $bwI_c < \gamma \leq bwI_c$, if $\Delta_4 \leq \Delta_3 \leq 0$, then $M_2^* = 0$; if $\Delta_4 \leq 0 < \Delta_3$, then $M_2^* = \frac{\gamma - \sqrt{\gamma^2 - \Delta_3^2}}{2X}$; and if $0 < \Delta_4 \leq \Delta_3$, $M_2^* = \Delta_1 + \frac{\Delta_3}{4\gamma I_c}$;

(iii) where $\gamma > bwI_c$, if $\Delta_5 \leq 0$, then $M_3^* = 0$; and if $\Delta_5 > 0$, then $M_3^* = \frac{\Delta_5}{4\gamma I_e}$;
where \( \Delta_2 = 2bI_e(w - wT_e - c) - I_e[2a - bhT - (2 - I_e)wb], \Delta_3 = 2bI_e(w - c) - I_e[2a - bhT - (2 + I_e)wb], \Delta_4 = \frac{3}{w}(w - w\Delta_1I_e - c) - I_e\left\{2a - bhT - \frac{(2T_e - L_e)^2 + L_e(T_e - \Delta_1)^2}{2}wb\right\}, \Delta_5 = \frac{2}{b(w - c)}(w - c) - I_e[2a - bhT - (2 + I_e)wb], \) and \( X = \frac{3bwI_e(I_e - I_s)}{4T_e} \) and \( Y = bwI_eI_e + \frac{b(w - c)(I_e - I_s)}{2T_e}. \)

Proposition 4 shows that there exists the optimal \( M \) in the two-level trade credit. By using the backward induction method, we obtain the optimal \( M \) offered by the supplier as a Stackelberg leader in three possible cases. In practice, once the supplier decides on \( M \), the retailer subsequently decides on \( N^* \) and \( p^* \) (Proposition 1 and 2). Note that the condition of \( M^* > 0 \) is a necessary condition that the retailer provides a credit period to customers. When the supplier offers \( M^* > 0 \), the retailer provides \( N^* = 0 \). When the supplier offers \( M^* > 0 \), the retailer may also not provide a credit period to customers.

4. Numerical examples and sensitivity analysis.

4.1. Numerical examples. This section presents numerical examples and sensitivity analysis to illustrate the proposed theoretical results. The parameters are set as follows: \( a = 120,000, b = 50, I_e = 0.06, I_s = 0.08, h = 50, c = 1,500, A = 1,000, T = 0.5 \) and \( w = 2,000 \) [38]. The numerical results are given as follows.

Example 1. Given \( \gamma = 5,500 \), where \( \gamma < bwI_e = 6,000 \) and \( 0 < \Delta_2 = 135 < \Delta_3 = 1,915 \). From Proposition 3(i), \( p \) is decreasing in \( M \) while \( N \) is zero and is independent of \( M \) (Figure 4). From Proposition 4(i), we have \( M^* = T + \frac{\Delta_2}{3bwI_e} = 0.5938 \). Figure 5 shows that the demand and the retailer’s profit are decreasing on \( N \) given \( M = 0.5938 \). This numerical finding verifies Proposition 2(i) and \( N^* = 0 \). Further, based on Proposition 1(i), we have \( p^* = 2,185.6 \) (Figure 4). Hence, the retailers maximum annual total profit are \( TPR^* = 2.2958 \times 10^6 \) and the supplier’s is \( TPS^* = 4.5957 \times 10^6 \) (Figure 6).

Example 2. Given \( \gamma = 7,000 \), then \( bwI_e = 6,000 < \gamma < bwI_e = 8,000 \) and \( 0 \leq \Delta_4 < \Delta_4 \). From Proposition 3(ii), \( p \) is decreasing in \( M \) and \( N \) is zero when \( M \leq \Delta_4 \), while \( p \) and \( N \) are increasing in \( M \) when \( M > \Delta_4 \) (Figure 7). Figure 8 shows that the demand and the retailer’s profit are both increasing on \( N \in [0, 0.5833] \) and are both decreasing on \( N \in (0.5833, M] \) given \( M = 0.5938 \). This numerical finding verifies Proposition 2(ii) and \( N^* = 0.5833 \). From Proposition 4(ii), \( M^* = M_2^* = \Delta_1 + \frac{\Delta_4}{I_s} = 0.8333 \). Similarly, we have \( N^* = \Delta_1 = 0.5833 \) and \( p^* = 2248.3 \) (Figure 7). Hence, the retailer’s maximum annual total profit is \( TPR^* = 2.7202 \times 10^6 \) and the supplier’s is \( TPS^* = 4.6667 \times 10^6 \) (Figure 9).

In Example 3, given \( \gamma = 8,500 \), then \( \gamma > bwI_e = 8,000 \) and \( \Delta_5 > 0 \). From Proposition 3(iii), \( p \) and \( N \) are increasing in \( M \) (Figure 10). From Proposition 4(iii), \( M^* = M_3^* = \frac{\Delta_5}{I_e} = 1.0613 \). Figure 11 shows that the demand and the retailers profit are both increasing on \( N \in [0, M] \) and \( N^* = 1.0613 \). Further, we obtain \( p^* = 23165.5 \) (Figure 10). Hence, the retailer’s maximum annual total profit is \( TPR^* = 3.4817 \times 10^6 \) and the supplier’s is \( TPS^* = 3.4817 \times 10^6 \) (Figure 12).

4.2. Sensitivity analysis. To interpret our theoretical results more explicitly, the sensitivity analysis is performed to investigate the effects of changes in the parameter values of \( i_e, I_e, \) and \( \gamma \) on the optimal solutions. All the settings are identical to those in Example 2. The results are shown in Tables 3 and 4.
According to Table 3, we find that higher values of $\gamma$ leads to corresponding $M^*, N^*, p^*, \pi_r^*$ and $\pi_s^*$ higher. Hence, in an active market (due to higher credit elasticity), to increase the player’s total profit, the supplier and retailer should work together to offer extended credit periods to their downstream players. In the same vein, when the retailer provides an identical $N$ to customers, it brings a higher demand and further produces greater total profits of the supplier and retailer. Moreover, in enjoying a longer $M$, the retailer may provide customers a longer $N$ to increase demand and thus brings greater total profits to the supplier and retailer.
Table 3. Sensitivity analysis with respect to $\gamma$

| Parameter | Value | $M^*$ | $N^*$ | $p^*$ | $\pi^*_s$ | $\pi^*_c$ |
|-----------|-------|-------|-------|-------|-----------|-----------|
| $\gamma$  | 4500  | 0.5938| 0.0000| 2185.6| 2295832   | 4595664   |
|           | 5000  | 0.5938| 0.0000| 2185.6| 2295832   | 4595664   |
|           | 5500  | 0.5938| 0.0000| 2185.6| 2295832   | 4595664   |
|           | 6000  | 0.5938| 0.0000| 2185.6| 2295832   | 4595664   |
|           | 6500  | 0.7252| 0.3502| 2221.8| 2500038   | 4619147   |
|           | 7000  | 0.8333| 0.5833| 2248.3| 2720222   | 4666667   |
|           | 7500  | 0.9229| 0.7979| 2276.4| 2957288   | 4734861   |
|           | 8000  | 0.9974| 0.9974| 2306.0| 3212169   | 4821253   |
|           | 8500  | 1.0613| 1.0613| 2316.5| 3481700   | 4918165   |
|           | 9000  | 1.1181| 1.1181| 2326.9| 3762082   | 5018776   |

Table 4 shows that as $I_e$ increases, $M^*$, $N^*$ and $p^*$ are decreasing and that as $I_c$ increases, $N^*$ and $p^*$ are decreasing while $M^*$ is increasing. At the same time, as $I_e$ and $I_c$ increases, $\pi^*_s$ and $\pi^*_c$ are decreasing. This numerical finding is in contrast with the results in [10] in which higher values of $I_e$ lead to a corresponding greater $\pi^*_c$. Hence, both the supplier and retailer should attach more importance to the interest cost. By efficiently reducing interest cost, either $I_e$ and $I_c$, increases the total profits of the supplier and retailer. The higher $I_e$ induces greater opportunity costs of both the supplier and retailer. Furthermore, both players reduce $M$ and $N$, leading to lower demand and less total profits. Similarly, the higher $I_c$ raises the retailer’s interest cost. The retailer correspondingly shortens $N$ and further reduces total profits.
Appendix A (Proof of proposition 1)

Besides, we could also consider incorporating the asymmetric information of the demand to make our model more realistic in production and inventory management. We could potentially consider the uncertain demand instead of the current deterministic period, and further increases demand and total profits. In future research, we reduce the interest cost. This action encourages the player to lengthen its credit period. We also analytically derive the unique equilibrium of both credit periods in the Stackelberg game with the supplier as the leader. Our study finds that the retailer does not always voluntarily provide customers a credit period even though he enjoys a credit period offered by his supplier. The optimal retail price is not always decreasing in the credit period offered by the supplier to the retailer. This finding distinguishes our study from the majority of the existing literature on a traditional one-level trade credit policy with the price-and-credit linked demand in which the retail price is monotonically decreasing in the credit period offered by the supplier. Whether the retailer is willing to voluntarily provide a credit period to customers depends on the conditions of the credit elasticity and the credit period offered by the supplier.

Our article presents two important managerial insights. Firstly, in an active market (with higher credit elasticity), the supplier and retailer should work together to offer extended credit periods to their downstream players so that they can obtain greater total profits. Secondly, both the supplier and retailer should efficiently reduce the interest cost. This action encourages the player to lengthen its credit period, and further increases demand and total profits. In future research, we could potentially consider the uncertain demand instead of the current deterministic demand to make our model more realistic in production and inventory management. Besides, we could also consider incorporating the asymmetric information of the credit period into the model.

5. Conclusion and management insights. We investigate the two-level trade credit policy in a two-echelon supply chain in which the demand rate depends on both retail price and the customers’ credit period. We also analytically derive the unique equilibrium of both credit periods in the Stackelberg game with the supplier as the leader. Our study finds that the retailer does not always voluntarily provide customers a credit period even though he enjoys a credit period offered by his supplier. The optimal retail price is not always decreasing in the credit period offered by the supplier to the retailer. This finding distinguishes our study from the majority of the existing literature on a traditional one-level trade credit policy with the price-and-credit linked demand in which the retail price is monotonically decreasing in the credit period offered by the supplier. Whether the retailer is willing to voluntarily provide a credit period to customers depends on the conditions of the credit elasticity and the credit period offered by the supplier.

Our article presents two important managerial insights. Firstly, in an active market (with higher credit elasticity), the supplier and retailer should work together to offer extended credit periods to their downstream players so that they can obtain greater total profits. Secondly, both the supplier and retailer should efficiently reduce the interest cost. This action encourages the player to lengthen its credit period, and further increases demand and total profits. In future research, we could potentially consider the uncertain demand instead of the current deterministic demand to make our model more realistic in production and inventory management.

Besides, we could also consider incorporating the asymmetric information of the credit period into the model.

Appendixes

Appendix A (Proof of proposition 1)

(i) When \( T + N \leq N \), then \( \frac{\partial TPR_s}{\partial p} = (a - bp + \gamma N) - b(p - w) - \frac{bTw_t}{2} + \frac{hbT}{2} \) and \( \frac{\partial^2 \pi_c^1}{\partial p^2} = -2b < 0 \). Utilizing \( \frac{\partial TPR_s}{\partial p} = 0 \) yields \( p_1^* = \frac{2a + 2\gamma N + bhT}{4b} + \frac{2 + I_1 T - 2 I_1 (M - N)}{4} w \).

(ii) When \( M < T + N \), then \( \frac{\partial TPR_s}{\partial p} = (a - bp + \gamma N) - b(p - w) - \frac{bw I_t (M - N)^2}{2T} - \frac{bhT}{2} \) and \( \frac{\partial^2 TPR_s}{\partial p^2} = -2b < 0 \). Let \( \frac{\partial \pi_c^1}{\partial p} = 0 \). Hence, we have \( p_2^* = \frac{2a + 2\gamma N + bhT}{4b} + \frac{bw I_t (M - N)^2 + I_t (T - M + N)^2}{4T} \).

Appendix B (Proof of proposition 2)

When \( T + N \leq M \), \( p_1^* = \frac{2a + 2\gamma N + bhT}{4b} + \frac{2 + I_1 T - 2 I_1 (M - N)}{4} w \), then \( D_1 = a - bp_1^* + \gamma N = \frac{2a + 2\gamma N - bhT}{4} - \frac{2 + I_1 T - 2 I_1 (M - N)}{4} w b, \frac{dD_1}{dn} = \frac{-bw I_t}{2} \). When \( M < T + N \), \( p_2^* = \frac{2a + 2\gamma N + bhT}{4b} + \frac{bw I_t (M - N)^2}{4T} \).

Table 4. Sensitivity analysis with respect to \( I_c \) and \( I_e \)

| Parameter | Value | \( M^* \) | \( N^* \) | \( p^* \) | \( \pi_c^* \) | \( \pi_e^* \) |
|-----------|-------|----------|----------|----------|-----------|-----------|
| \( I_c \) | 0.050 | 1.2530   | 1.0863   | 2289.8   | 343736   | 4914066   |
|           | 0.055 | 1.0245   | 0.8245   | 2269.0   | 3035272  | 4772856   |
|           | 0.060 | 0.8333   | 0.5833   | 2248.3   | 2720222  | 4666667   |
|           | 0.065 | 0.6701   | 0.3368   | 2224.8   | 2469392  | 4589728   |
|           | 0.070 | 0.5268   | 0.0000   | 2186.9   | 2269113  | 4542227   |
| \( I_e \) | 0.07  | 0.8244   | 0.8244   | 2281.5   | 2734825  | 4691700   |
|           | 0.075 | 0.8304   | 0.6637   | 2259.4   | 2725086  | 4675004   |
|           | 0.080 | 0.8333   | 0.5833   | 2248.3   | 2720222  | 4666667   |
|           | 0.085 | 0.8351   | 0.5351   | 2241.7   | 2717306  | 4661668   |
|           | 0.090 | 0.8363   | 0.5030   | 2237.3   | 2715366  | 4658337   |
$$\frac{2a + 2\gamma N - hhT}{4b} + \frac{2T - I_e(M - N)^2 + I_e(T - M)^2}{2T} w,$$
then $D_2 = a - bp_2^* + \gamma N - \frac{2a + 2\gamma N - hhT}{4b} + \frac{2T - I_e(M - N)^2 + I_e(T - M)^2}{2T} w$ and $\frac{dD_2}{dN} = \frac{\gamma}{2} - \frac{I_e(M - N) + f_e(T + N - M)}{2T} w$.

From the envelope theorem, $\frac{dT^*_{PR_1}}{dN} = \frac{\partial T^*_{PR_1}}{\partial N} (p = p_1^*) = (p_1^* - w) \gamma + \frac{wT}{2}.$

(i) When $\gamma \leq bw I_e$, then $\frac{dD_2}{dN} = \frac{\gamma - bw I_e}{2} \leq 0$ and $\frac{dD_2}{dN} = \frac{\gamma - I_e(M - N) + f_e(T + N - M)}{2T} w < 0$. Based on $D = D_1$, if $T + N < M$ or $D = D_2$, if $T + N > M$, we have $\frac{dD_2}{dN} \leq 0$. Further, $\frac{dT^*_{PR_1}}{dN} = 8D_1 \frac{dD_2}{dN} \leq 0$ and $\frac{dT^*_{PR_2}}{dN} = \frac{bD_d}{dN} \leq 0$. Therefore, $\frac{dT^*_{PR}}{dN} = 0$ and $\frac{dN^*}{dM} = 0$.

(ii) When $bw I_e < \gamma \leq bw I_e$, then $\frac{dD_2}{dN} = \frac{\gamma - bw I_e}{2} \geq 0$ and $\frac{dT^*_{PR_2}}{dN} = \frac{bD_d}{dN} \leq 0$. Let $\Delta_1 = \frac{\gamma - I_e(M - N) + f_e(T + N - M)}{2T} w < 0$. According to $bw I_e < \gamma \leq bw I_e$, we have $0 \leq \Delta_1 \leq T$.

When $M \leq \Delta_1$, then $M \leq \Delta_1 \leq T$, $\frac{dD_2}{dN} = \frac{dD_2}{dN} > 0$ on $[0, M - \Delta_1]$ and $\frac{dD_2}{dN} = \frac{dD_2}{dN} < 0$ on $[0, M - \Delta_1)$.

(iii) When $\gamma > bw I_e$, then $\frac{dD_2}{dN} = \frac{\gamma - bw I_e}{2} > 0$ and $\frac{dD_2}{dN} = \frac{\gamma - I_e(M - N) + f_e(T + N - M)}{2T} w < 0$. Similarly, $\frac{dD_2}{dN} > 0$. Further, $\frac{dT^*_{PR_1}}{dN} = 8D_1 \frac{dD_2}{dN}$ and $\frac{dT^*_{PR_2}}{dN} = \frac{bD_d}{dN} > 0$. Base on $\frac{dT^*_{PR}}{dN} = 0$, exists a maximum value at $N^* = M$.

Appendix C (Proof of proposition 3)

(i) When $\gamma \leq bw I_e$, then $N^* = 0$ and $\frac{dN^*}{dM} = 0$. From Proposition 1, if $T \leq M$, then $p^* = p_1^* = \frac{2a + hhT}{4b} + \frac{2T + I_e(T - M)^2}{4T} w$ and $\frac{dp^*}{dM} = \frac{-I_e T}{2} < 0$; if $M < T$, then $p^* = p_2^* = \frac{2a + hhT}{4b} + \frac{2T - I_e(M - N)^2 + I_e(T - M)^2}{2T} w$ and $\frac{dp^*}{dM} = \frac{-2I_e M^2 + I_e(T - M)^2}{4T} < 0$. Hence, we have $\frac{dp^*}{dM} < 0$.

(ii) When $bw I_e < \gamma \leq bw I_e$, then if $M \leq \Delta_1$, $N^* = 0$. Similarly, $p^* = p_2^* = \frac{2a + hhT}{4b} + \frac{2T - I_e(M - \Delta)^2 + I_e(T - M)^2}{4T} w$ and $\frac{dp^*}{dM} < 0$; if $M > \Delta_1$, then $N^* = M - \Delta_1$ and $p^* = p_2^* = \frac{2a + 2(M - \Delta)^2 + hhT}{4b} + \frac{2T - I_e(M - \Delta)^2 + I_e(T - \Delta)^2}{4T} w$. Therefore, we have $\frac{dp^*}{dM} > 0$.
(iii) When \( \gamma > bwI_c \), then \( N^* = M \) and \( p^* = p_2^* = \frac{2a+2bM+bhT}{4T} + \frac{2T+L_cT^2}{4T^2}w \).

Therefore, we have \( \frac{dN^*}{dM} > 0 \) and \( \frac{dp^*}{dM} = \frac{\Delta_2}{2} > 0 \).

**Appendix D (Proof of proposition 4)**

(i) From Equation (5), \( \frac{dT_{PS_{11}}}{dM} = -wI_c \left[ \frac{2a-bhT - 2T-I_cM^2+I_c(T-M)^2}{4T}w_1 \right] + wb(w-wMI_c-c) \left( \frac{I_cM+I_c(T-M)}{2T} \right) \) and \( \frac{dT_{PS_{11}}}{dM^2} = 2wb(-wI_c) \left[ \frac{I_cM+I_c(T-M)}{2T} \right] + wb(w-wMI_c-c) \left( \frac{I_cM+I_c(T-M)}{2T} \right) < 0 \). Similarly, we have \( \frac{dT_{PS_{12}}}{dM} = (-wI_c) \left[ \frac{2a-bhT - 2T-I_cM^2+I_c(T-M)^2}{4T}w_1 \right] + wb(w-wMI_c-c) \left( \frac{I_cM+I_c(T-M)}{2T} \right) \) and \( \frac{dT_{PS_{12}}}{dM^2} = \frac{wI_c}{2} - wI_c \left( \frac{2a-bhT-(2+I_c)T}{4T}w_1 \right) < 0 \). Hence, there exists a unique \( M_1^* \in (0, T) \). Solving \( \frac{dT_{PS_{11}}}{dM} = 0 \) yields \( M = \frac{2a-bhT-(2+I_c)T}{4T} \) and \( Y = bwI_c + \frac{b(w-c)(I_cM-I_c)}{4T} \). Since \( M_1^* = 0 \) when \( \Delta_3 = 0 \), \( M_1^* = 0 \) when \( \Delta_3 = 0 \), \( M_1^* = \frac{Y-bhT-(2+I_c)T}{2X} \). \( \frac{d^2T_{PS_{11}}}{dM^2} < 0 \) and \( \frac{d^2T_{PS_{12}}}{dM^2} < 0 \). Since \( M_1^* = 0 \) and \( \frac{d^2T_{PS_{12}}}{dM^2} < 0 \), we have \( M_1^* > T \). Let \( \frac{dT_{PS_{12}}}{dM} = 0 \). We have \( M_2^* = \frac{a+I_c^2M+I_c(T-M)^2}{4T}w_1 \).

(ii) \( \frac{dT_{PS_{12}}}{dM} \) when \( bwI_c \leq \gamma \leq bwI_c \). Then \( T_{PS_{12}} = T_{PS_{11}} \). Let \( \Delta_3 = \frac{2\gamma}{w} \left( a-bhT - \frac{I_c^2M+I_c(T-M)^2}{4T}w_1 \right) \). Note that \( \Delta_4 \leq \Delta_3 \). We have \( \frac{d^2T_{PS_{11}}}{dM^2} > 0 \).

Since \( M = \Delta_3 = \frac{a+I_c^2M+I_c(T-M)^2}{4T}w_1 \), we have that (a) if \( \Delta_4 \leq \Delta_3 \leq 0 \), then \( \frac{dT_{PS_{11}}}{dM} < \frac{d^2T_{PS_{11}}}{dM^2}M = \frac{w\Delta_4}{4T} \), and \( \frac{dT_{PS_{12}}}{dM} < \frac{d^2T_{PS_{12}}}{dM^2}M = \frac{w\Delta_4}{4T} \). Thus, \( M_3^* = 0 \); (b) if \( \Delta_4 \leq 0 \leq \Delta_3 \), similar to (i), solving \( \frac{dT_{PS_{12}}}{dM} = 0 \) yields \( M_2^* = \frac{a+I_c^2M+I_c(T-M)^2}{4T}w_1 \), and \( \frac{dT_{PS_{12}}}{dM} = \frac{w\Delta_4}{4T} \) and \( M_3^* > \Delta_1 \).

(iii) \( \frac{dT_{PS_{12}}}{dM} = 0 \). We have \( \frac{dT_{PS_{12}}}{dM} = 0 \). Therefore, we have \( \frac{dN^*}{dM} > 0 \) and \( \frac{dp^*}{dM} = \frac{\Delta_2}{2} > 0 \).

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E-mail address: ottoyang@126.com (Honglin Yang)
E-mail address: daihp19920163.com (Heping Dai)
E-mail address: hong.wan@oswego.edu (Hong Wan)
E-mail address: chull1007@163.com (Lingling Chu)