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A STACKELBERG GAME-THEORETIC RETAILER-MANUFACTURER CREDIT PERIOD RATIO MODEL IN A SUPPLY CHANNEL

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ABSTRACT
It is a known fact that a number of market factors determine the provision of trade credit to a financially constrained channel member. It is only recently that credit function was developed to incorporate some of these factors. This paper considers a modification of the credit function in which the retailer-manufacturer credit period ratio determines the amount of credit the manufacturer can give to the retailer. This study considers a Stackelberg game in which the manufacturer who is the channel leader provides trade credit to the retailer through his credit period while the retailer engages in product promotion to sell the product. The work uses backward induction to determine a closed-form solution of the promotion effort, the credit period and the payoffs. The result shows that the promotion effort increases with the manufacturer's credit period, but reduces with that of the retailer. It also shows that while both players payoffs increase with the manufacturer's credit period, the manufacturer's performance is better-off. On the other hand, while the retailer's payoff reduces with his credit period, the manufacturer's payoff increases continuously. Thus, it is rational for the retailer to opt for the optimal credit period instead of over elongating the credit period.

Keywords: credit function; credit period; Stackelberg game; supply channel; trade credit

INTRODUCTION

Trade credit is a short term business strategy in which a supplier provides goods or services on credit to a retailer delaying the payment to a future date. Basically, there are two types of trade credit. The most common type is a situation where a firm transfers goods to another firm or buyer without immediate payment (Emery, 1984; Ng et al.,1999; Carvalho and Schiozer, 2015). The other form is a situation where a buyer or firm pays for the supplier's goods before the delivery date. In this case the buyer is extending credit to the supplier (Schwartz, 1974; Ng et al., 1999). This is sometimes referred to as reverse trade credit (Mateut, 2014). This work will focus on the common type of trade credit.

The much adoption of trade credit as a business strategy by firms in developing and developed economies around the world speak volumes of the fact that its importance cannot be overemphasized as was affirmed by Dary and Harvey (2020). For instance, Klapper et al. (2012) observed that about 90% of trade around the world was financed through trade credit in 2007. Further, according to Carvallno and Schiozer (2015), 67.74% of all purchases consummated among firms in Brazil was related to trade credit. According to Dary and James (2018), 55% of agro food business firms in the African continent receive trade credit while 60% supply their fellow firms with credit.

Trade credit literature is quite rich covering a lot of business transactions. Apart from empirical data-based trade credit models, a lot of mathematical trade credit models have been developed over the years. For instance, Teng et al. (2007) developed an EOQ trade credit model with permissible delay. They assumed that the retail price is higher than the cost of purchase, and that the interest charged by the supplier or bank is not higher than the retailer's return. They established an easily usable closed-form solution of trade credit problem. Considering a situation where firms know more about their business partners over time, a situation where firms charge mark-ups above the cost of producing the goods, and a situation where financing is costly, Garicia-Marin et al. (2020) examined a model which rationalizes the fact that firms that charge higher mark-ups also provide more trade credit, and the adoption and use of trade credit as a business strategy increases as relationship between partners lengthens. Recently, in an examination of a manufacturer's choice between adopting trade credit strategy and vertical merger for a retailer who is financially constrained competing with a financially abundant retailer, Zhan et al. (2021) observed that the possibility of trade credit out-performing vertical merger for a manufacturer and a capital constrained retailer depends on the intensity of the horizontal competition between the retailers, the profit sharing contract and the cost of managing the vertical merger.

Game-theoretic models have been widely employed in supply chain analysis. It is known to be an integral part of cooperative advertising models (He et al., 2009; He et al., 2014; Martin-Herran and Sigue, 2023; Ezimadu, 2022) and by extension useful in product promotion because of the possibility of substituting one for the other. There exists a number of game-theoretic trade credit models. Assuming that either a manufacturer or retailer is capital-constrained, Gao et al. (2018) examined a supply chain finance in which the manufacturer sells to a retailer whose product demand is uncertain. They obtained the players' optimal Stackelberg strategies, and observed that the players should put an online peer-to-peer cognisance into consideration when making operational decisions. Wu et al. (2021) investigated a supplier-retailer trade credit channel model using a supplier-Stackelberg game. They analysed and compared their model to that of a newsvendor. Observing that tolerating risk affects the incorporated a risk-averse parameter, and loss-sharing strategy in the case where the supplier is considered to be the Stackelberg game leader, and trade credit for a retailer who is averse to loss. Considering the possibility of demand being affected by the availability of credit Zhang et al. (2021) examined the performance of a supply chain based on credit-linked product demand. They considered a supplier-Stackelberg structure, a retailer-Stackelberg structure, and a centralized supply structure. They observed that the supplier-

Stackelberg structure out-performs the others provided credit is given, otherwise the reverse is the case. Xu et al. (2022) deliberated on the interaction between adoption of trade credit as a financing strategy and the channel encroachment in a supplier-retailer supply chain. They observed that in a Stackelberg setting, the interaction is a function of the product substitute, online market and the cost involved in producing the good. The supplier will prefer trade credit so long as cost of production is lower than a particular threshold. Considering trade credit contracts, Silaghi and Moraux (2022) provided a theoretical representation as a means of analysing trade credit, and observed that trade credit can be a coordination mechanism. They also obtained Nash and Stackelberg solutions and noted that the imposition of limit on the maturity date of trade credit can affect a number of factors which include wholesale price, credit provision and internal procurement. Zhou et al. (2022) examined trade credit and a situation with early payment consideration involving a three-party channel which includes a manufacturer, a distributor who is constrained by business capital, and a retail platform. Using a situation where either the manufacturer or the platform finances the distributor, they considered a manufacturer or the platform Stackelberg game. In an investigation of the effect of business working capital on a retailer's borrowing decision, Hovelaque et al. (2022) developed a model involving a supplier, a retailer and a bank in a non-cooperative game where demand is sensitive to change in price. They employed a Stackelberg game-theoretic strategy in a situation where either the bank or the supplier is the channel leader with the retailer as the follower.

We consider a manufacturer-retailer supply channel in which the manufacturer is the Stackelberg channel leader. We adopt an improved form of Ezimadu-Ezimadu credit function by incorporating the retailer's credit period into the manufacturer's credit function (Ezimadu and Ezimadu, 2022). This is a more robust credit function model. The work will determine the retailer's optimal promotion effort, the manufacturer's credit period, and the player's payoffs both in the short term which is usual with trade credit, in the long-run. It will also consider the effect of the credit periods on the promotion effort and the players' payoffs

MATERIALS AND METHODS

The Decision Variables

In this work we examine trade credit situation involving a manufacturer and a retailer in a bilateral monopoly. The manufacturer transfers the goods to the retailer without immediate payment. That is, he releases the goods on credit to the retailer, and allows a delayed credit payment period t_M. To appeal for patronage, and sell the goods, the retailer engages in promotion of the product using the promotion effort P_R, and also gives the goods on credit to the end-user by allowing a credit repayment period t_R.

Promotion Cost Function

Considering the substitutability of advertising and product promotion for each other in the short term, we adopt the advertising-demand function

$$f(P_R) = \lambda\sqrt{P_R} \quad (1)$$

as a short-term promotion-demand function, where λ is the promotion effectiveness parameter. Equation (1) is in accordance with commonly observed nature of advertising cost function. It exhibits saturation effect which leads to diminishing marginal return with increasing promotion spending (Ezimadu, 2019; Huang et al., 2002).

Trade Credit Function

We adopt Ezimadu-Ezimadu trade credit function with some innovation. In trade credit settings the manufacturer usually allows delayed payments. Thus, if the retailer is also providing credit to the end-user, he is usually allowed some time to obtain his credit repayment from the end-users to repay the manufacturer.

It is natural to note that early repayment from the retailer provides early revenue and hence fund for the manufacturer's re-investment. The manufacturer will expect early repayment if a large credit is to be given, and would reduce it as the retailer's repayment date t_R gets close to his allowable date t_M. That is, credit

$$C_T \propto t_M - t_R. \quad (2)$$

Further, the manufacturer would only give very small amount of credit or virtually none if the repayment date the retailer wants from the manufacturer is "too far" into the future. Thus, we have that credit

$$C_T \propto \frac{1}{t_M}. \quad (3)$$

Based on Ezimadu-Ezimadu's credit function, credit is proportional to the manufacturer's price margin M_M and the retailer's promotion effort P_R which exhibits diminishing returns over time. That is

$$C_T \propto M_M \text{ and } P_R \quad (4)$$

Thus, from (1), (2), (3) and (4) we have that the credit function can be expressed as

$$C_T(t_M, P_R, M_M) = \frac{CM_M\lambda\sqrt{P_R}(t_M - t_R)}{t_M}, \quad (5)$$

where C is the constant of proportionality.

We note that as $t_R \longrightarrow t_M$, the quantity in (5) approaches 0. That is, an excessive delay or elongation of credit period by the retailer will attract no credit. Further, we note that $\frac{t_M - t_R}{t_M} = 1 - \frac{t_R}{t_M} \longrightarrow 0$ as $t_R \longrightarrow t_M$ since the ratio $t_R : t_M$ approaches 1. That is, the retailer must not delay repayment till t_M, however if he does, then he will not get any credit. In the nutshell, credit is a function of the distance in time between t_R and t_M.

The Decision Sequence

The work studies a Stackelberg game involving a manufacturer and a retailer. The manufacturer first informs the retailer of his allowable credit period t_M and his wholesale price margin M_M for which the goods can be transferred to the retailer. The retailer in-turn decides on his promotion effort P_R and retailer margin M_R. We determine the equilibrium by backward induction. This approach was employed by Xie and Wei (2009), Ezimadu (2016), and Ezimadu and Nwozor (2018). Thus we first consider the retailer's optimal problem

$$\max_{P_R>0} \Psi_R = M_R\lambda\sqrt{P_R} - P_R + \frac{CM_M\lambda\sqrt{P_R}(t_M - t_R)}{t_M} \quad (6)$$

and then the manufacturer's optimal problem

$$\max_{t_M \geq t_R > b} \Psi_{\mathrm{M}} = M_M\lambda\sqrt{P_R} - \frac{CM_M\lambda\sqrt{P_R}(t_M - t_R)}{t_M}, \qquad (7)$$

where b is a permissible time (period) where it is not binding to make repayment. That is, repayment takes place only after this period.

We will examine two settings: an optimal credit provision setting and a long-run credit provision scenario.

RESULTS

Optimal Credit Provision Setting

Maximizing (6) with respect to P_R we have that

$$\frac{\partial \Psi_{\mathrm{R}}}{\partial P_R} = \frac{M_R\lambda}{2\sqrt{P_R}} - 1 + \frac{CM_M\lambda(t_M - t_R)}{2\sqrt{P_R}t_M} = 0,$$

$$\Longrightarrow \quad P_R = \left\{\frac{1}{2}\left[M_R\lambda + \frac{CM_M\lambda(t_M - t_R)}{t_M}\right]\right\}^2. \qquad (8)$$

Rearranging (7) we have

$$\max_{P_R > 0} \Psi_{\mathrm{M}} = \left[M_M\lambda - \frac{CM_M\lambda(t_M - t_R)}{t_M}\right]\sqrt{P_R}. \qquad (9)$$

Using (8) in (9) we have that

$$\max_{t_M \geq t_R > b} \Psi_{\mathrm{M}} = \left[M_M\lambda - \frac{CM_M\lambda(t_M - t_R)}{t_M}\right]\left\{\frac{1}{2}\left[M_R\lambda + \frac{CM_M\lambda(t_M - t_R)}{t_M}\right]\right\}. \qquad (10)$$

Maximizing (10) with respect to t_M we have that

$$\frac{\partial \Psi_{\mathrm{M}}}{\partial t_M} = \frac{1}{2}\left\{CM_M^2\lambda^2\frac{t_R}{t_M} - CM_RM_M\lambda^2\frac{t_R}{t_M^2} - \frac{2CM_M\lambda(t_M - t_R)}{t_M}\left(CM_M\frac{t_R}{t_M^2}\right)\right\} = 0$$

$$\Longrightarrow \quad t_M = \frac{2CM_Mt_R}{2CM_M + M_R - M_M}. \qquad (11)$$

Now, from (11) we observe that

$$t_R = \frac{(2CM_M + M_R - M_M)t_M}{2CM_M}. \qquad (12)$$

Using (11) in (8) we have

$$P_R = \left\{\frac{1}{2}\left[M_R\lambda + \frac{CM_M\lambda\left(\frac{2CM_Mt_R}{2CM_M+M_R-M_M} - t_R\right)}{\frac{2CM_Mt_R}{2CM_M+M_R-M_M}}\right]\right\}^2 = \left\{\frac{\lambda}{2}\left[\frac{M_R + M_M}{2}\right]\right\}^2. \qquad (13)$$

Using (11) and (13) in (6) we have

$$\Psi_{\mathrm{R}} = M_R\lambda\left\{\frac{\lambda}{2}\left[\frac{M_R + M_M}{2}\right]\right\} - \left\{\frac{\lambda}{2}\left[\frac{M_R + M_M}{2}\right]\right\}^2 + \frac{CM_M\lambda\left\{\frac{\lambda}{2}\left[\frac{M_R+M_M}{2}\right]\right\}\left(\frac{2CM_Mt_R}{2CM_M+M_R-M_M} - t_R\right)}{\frac{2CM_Mt_R}{2CM_M+M_R-M_M}}$$

$$= -\left(\frac{\lambda M_R + \lambda M_M}{4}\right)^2 + \frac{\lambda^2M_R^2}{8} + \frac{\lambda^2M_M^2}{8} + \frac{\lambda^2M_RM_M}{4} \qquad (14)$$

Using (11) and (13) in (9) we

$$\Psi_{\mathrm{M}} = \left[M_M\lambda - \frac{CM_M\lambda\left(\frac{2CM_Mt_R}{2CM_M+M_R-M_M} - t_R\right)}{\frac{2CM_Mt_R}{2CM_M+M_R-M_M}}\right]\left\{\frac{\lambda}{2}\left[\frac{M_R + M_M}{2}\right]\right\}$$

$$= \frac{\lambda^2M_M^2}{8} + \frac{\lambda^2M_R^2}{8} + \frac{\lambda^2M_RM_M}{4} \qquad (15)$$

Proposition

Given the control problems (6) and (7) in which the players are engaged in a Stackelberg game, the retailer's optimal promotion effort is given by (9) and the manufacturer's optimal credit period is given by (6), and their payoffs are given by (10) and (11) respectively.

Long-run Equilibrium

From (8) we observe that

$$P_R = \left\{\frac{1}{2}\left[M_R\lambda + CM_M\lambda\left(1 - \frac{t_R}{t_M}\right)\right]\right\}^2$$

so that as $t_M \longrightarrow \infty$, that is, as the ratio $t_R\!:t_M$ gets smaller, the quantity $CM_M\lambda\left(1 - \frac{t_R}{t_M}\right) \longrightarrow CM_M\lambda$ which leads to

$$P_R = \left\{\frac{1}{2}[M_R\lambda + CM_M\lambda]\right\}^2. \qquad (16)$$

Also from (6) we have that

$$\Psi_{\mathrm{R}} = M_R\lambda\left\{\frac{1}{2}\left[M_R\lambda + CM_M\lambda\left(1 - \frac{t_R}{t_M}\right)\right]\right\} - \left\{\frac{1}{2}\left[M_R\lambda + CM_M\lambda\left(1 - \frac{t_R}{t_M}\right)\right]\right\}^2 + CM_M\lambda\left(1 - \frac{t_R}{t_M}\right)\left\{\frac{1}{2}\left[M_R\lambda + CM_M\lambda\left(1 - \frac{t_R}{t_M}\right)\right]\right\}$$

so that as $t_M \longrightarrow \infty$ which is the same as saying that as the ratio $t_R\!:t_M$ gets smaller, we have that

$$\Psi_{\mathrm{R}} = M_R\lambda\left\{\frac{1}{2}[M_R\lambda + CM_M\lambda]\right\} - \left\{\frac{1}{2}[M_R\lambda + CM_M\lambda]\right\}^2 + CM_M\lambda\left\{\frac{1}{2}[M_R\lambda + CM_M\lambda]\right\}$$

$$= \frac{\lambda^2C^2M_M}{4} + \frac{\lambda^2CM_MM_R}{2} + \frac{\lambda^2M_R}{4}. \qquad (17)$$

Similarly, from (10) we have that as $t_M \longrightarrow \infty$, that is, as the ratio

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$t_R : t_M$ gets smaller

$$\Psi_M = [M_M\lambda - CM_M\lambda]\left\{\frac{1}{2}[M_R\lambda + CM_M\lambda]\right\}$$

$$= \frac{\lambda^2 CM_M^2 + \lambda^2 M_M M_R - \lambda^2 C^2 M_M^2 - \lambda^2 CM_M M_R}{2} \qquad (18)$$

Proposition
Given the control problems (6) and (7) in which the players are engaged in a Stackelberg game, the retailer's long-run promotion effort is given by (16), and the retailer and manufacturer payoffs are given by (17) and (18) respectively.

DISCUSSION
Since we are dealing with a Stackelberg game setting, the manufacturer enjoys first mover's advantage. As such we have that $M_M \geq M_R$. Thus we let $M_M = 5.0$, $M_R = 4.5$. Since λ is effectiveness parameter, we have that $\lambda \in (0,1)$. Thus we let $\lambda = 0.6$. Further we let $C = 0.1$ and $t_R = 25$. Since b is a permissible time when repayment is not binding, we let $b = 3$.

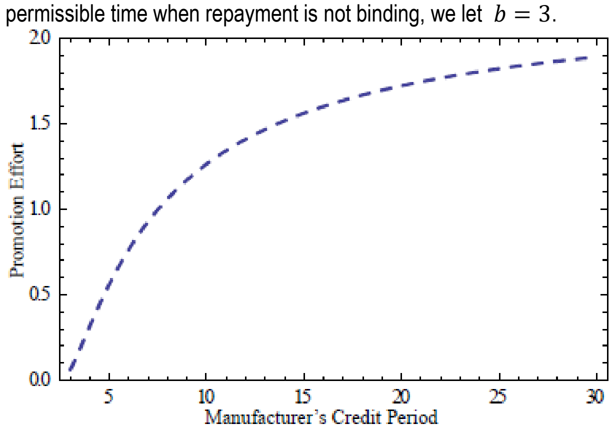

Figure 1: Effect of the Manufacturer's Credit Period on Promotion Effort

It is natural to assume that with the manufacturer's prolongation of his allowable credit period, the retailer need not border about increasing spending more on promoting the product. On the contrary, Figure 4.1 shows that the long stretch of time plays out to incentivise the retailer to engage more in promotion which will eventually lead to larger payoff.

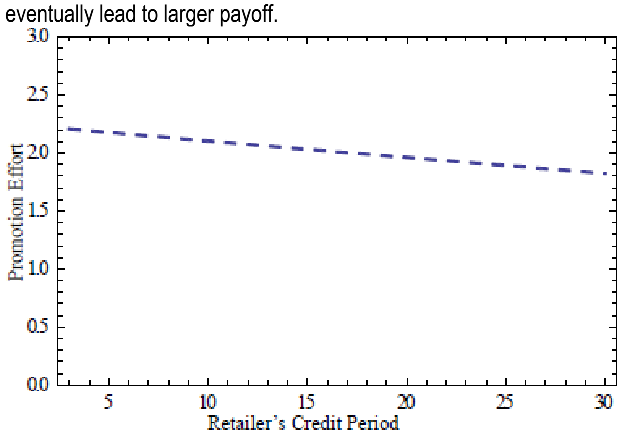

Figure 2: Effect of the Retailer's Credit Period on Promotion Effort

Clearly, Figure 4.2 shows that as the retailer gets more liberal with credit period, the promotion effort reduces. This is in consonance with common sense intuition, because the elongation of the repayment period serves as an incentive for more patronage of the product. Thus the increase in the repayment window period serves as a substitute for promotion effort since it can lead to more patronage despite the fact that it leads to reduction in promotion effort. In essence the retailer has the leverage of switching between promotion and credit period.

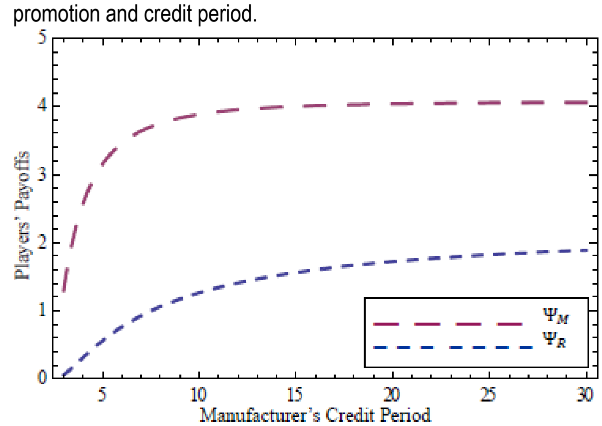

Figure 3: Effect of the Manufacturer's Credit Period on the Player's Payoffs

We observe that Figure 4.3 is a reflection of Figure 4.1. That is, the payoffs increase with the manufacturer's credit period. While both players benefit from the promotion and elongation of the credit period, it is clear that the manufacturer benefits more than the retailer. Thus his liberality to the retailer is in essence liberality to himself. As such, the manufacturer should provide trade credit and allow reasonable credit period.

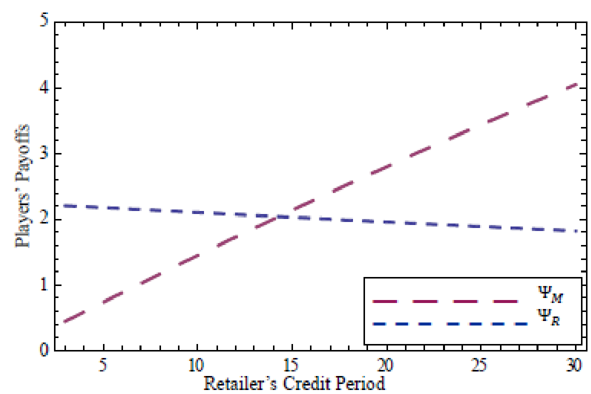

Figure 4: Effect of the Retailer's Credit Period on the Player's Payoffs

Contrary to the scenario in Figure 4.3 where both players' payoffs increase with the manufacturer's credit period, we observe from Figure 4.4 that while the manufacturer's payoff increases with the retailer's credit period, the reverse is the case with retailer. This means that increasing the retailer's credit period over time does not appear very beneficial to him. Thus, it is necessary that the retailer opts for optimal payoff. Further, since he is in control of his credit period to the end-user, he may be interested in using it to ensure

that his payoff is larger than that of the manufacturer especially if there is a strong or unhealthy rivalry between them. In such a situation he may only provide credit to only a time where his payoff is larger than that of the manufacturer.
That is,

$$\Pi_M \leq \Pi_R. \tag{19}$$

which implies

$$\left\{M_R\lambda + \frac{CM_M\lambda(t_M - t_R)}{t_M}\right\}\left\{\frac{1}{2}\left[M_R\lambda + \frac{CM_M\lambda(t_M - t_R)}{t_M}\right]\right\} - \left\{\frac{1}{2}\left[M_R\lambda + \frac{CM_M\lambda(t_M - t_R)}{t_M}\right]\right\}^2 \leq \left\{M_M\lambda - \frac{CM_M\lambda(t_M - t_R)}{t_M}\right\}\left\{\frac{1}{2}\left[M_R\lambda + \frac{CM_M\lambda(t_M - t_R)}{t_M}\right]\right\}$$

so that

$$t_R \leq \frac{(M_R - 2M_M + 3CM_M)t_M}{3CM_M} \tag{20}$$

This implies that to achieve $\Pi_M \leq \Pi_R$ for any given manufacturer's credit period t_M, the retailer's credit period must not exceed (20).
We note that for (20) to hold we need to have that

$$\frac{(M_R - 2M_M + 3CM_M)t_M}{3CM_M} \geq 1$$
$$\Rightarrow \quad M_R \geq 2M_M$$

That is, to achieve (20) and subsequently (19), the retailer's price margin must be larger than twice the manufacturer's price margin.

Table 1. A Comparison of the Optimal and Long-run Values of the Payoffs

	Optimal Value	Long-run Value
Retailer's Payoff	2.0306	2.2500
Manufacturer's Payoff	4.0613	4.0500
Channel Payoff	6.0919	6.3000

We note that while the retailer performs better in the long-run, the manufacturer is better-off without credit period elongation. The implication of Table 1 is that the manufacturer's elongation of the credit period beyond a certain threshold amounts to increasing the retailer's payoff to his (manufacturer's) detriment. The elongation of the credit period provides the retailer with enough business time, leading to higher revenue and turnover. On the other hand, the extension of the repayment period places a strain on the manufacturer's fixed assets and revenue due to delayed return on investment leading to reduction in the time value of money. Further, a look at the channel payoff shows that the channel is better-off at the long-run. Thus the players can adopt channel integration, and decide on a profit sharing which will ensure that the manufacturer being the credit provider is not short-changed.

CONCLUSION
This work considered a trade credit supply channel in which the manufacturer who is the Stackelberg game leader provides credit goods to the retailer. It considers the user credit function in which the amount of credit is considered to be a function of the credit period. The manufacturer's provided credit good is repaid in the future. The retailer in turn allows the end-user a credit repayment period and engages in product promotion.
The work determined the retailer's promotion effort, the manufacturer's credit period and the players' payoffs in the short-term and long-run. It shows that elongation of the manufacturer's credit period leads to larger payoff by incentivising the retailer into more promotion spending leading to better retailer's payoff. Although, promotion campaign reduces with the retailer's credit period, the retailer should opt for his optimal credit period rather than elongation. Both players' payoffs increase with the manufacturer's credit, and credit liberality is more beneficial to the manufacturer than to the retailer.
This work can be extended by considering a model involving multiple manufacturers and retailers. The possibility of a competition in which the players independently decide on their line of action, leading to a Nash game can provide more insight on the concept of trade credit. Further, there could be a situation where a retailer is more powerful than the manufacturer or supplier. Such a channel setting can be studied using a Stackelberg model with the retailer as the channel leader (Huang and Li, 2001; Huang et al., 2002).

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