

Inventory Replenishment Policies for Two Successive Generations of Technology Products Under Permissible Delay in Payments

Gaurav Nagpal, Birla Institute of Technology and Science, Pilani, India*

 <https://orcid.org/0000-0003-1957-7865>

Udayan Chanda, Birla Institute of Technology and Science, Pilani, India

Himanshu Seth, Woxsen University, India

Namita Ruparel, Woxsen University, India

ABSTRACT

In this age of digitalization, when every industry is undergoing technological disruption, there is a big role in digital products and technology products. A key feature of these digital products is the short length of the product life cycle since the newer and more advanced generations of technologies are developed regularly to replace the earlier conventional technologies. The traditional EOQ models that assume a constant demand cannot be used here. This research paper formulates an inventory optimization model for the multi-generational products under the trade credits and the credit-linked and innovation diffusion-dependent demand. The study also performs a numerical illustration of the proposed model and establishes important dynamics among the key variables. It also performs the sensitivity analysis with the cost of credit and the trade credit period. The paper concludes with the managerial implications for the inventory practitioners and the possible areas of extension for this research in the future.

KEYWORDS

Credit-Linked Demand, Inventory Optimization, Multi-Generational Diffusion, Permissible Delay In Payments

1. INTRODUCTION

The past few decades have witnessed fast growth in the penetration of technology products such as smartphones, smart wearables, portable devices, etc. These products have a very short product life cycle amid the changing consumer preferences and competitor dynamics. As a result, these products, within their respective categories, are substitutable since they perform the same intended function as the other products in the category.

The product variety in each of these categories is also increasing at a fast rate. The firms that manufacture the technology products are not afraid of launching the newer generations for the fear of cannibalization of existing products. Rather, they believe that cannibalizing their existing products by themselves is better than that by their competitors. Therefore, they are in the constant pursuit of identifying the stated and implied needs of the consumer, and anticipating the changing consumer

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*Corresponding Author

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preferences to incorporate the suitable features and functions to the products that can bring more value to the consumer. A few examples of the technology giants that have grown immensely during the past decades by embracing self-cannibalization are Google, Apple, Amazon, and Facebook. These companies have been proactive in replacing the existing products with newer products that are worth more in terms of functionality, form, or features. Netflix is another example of such a firm since it switched its business from selling DVDs to streaming media services that can be used on all the devices (Littleton & Roettgers, 2018). Some of the firms also track the metrics that mandate a certain percentage of their revenues to come from the newer range of products. For example, 3M has a rule that thirty percent of its revenues in any year have to come from the products launched in the last four years, a metric that it monitors rigorously (Govindarajan & Srinivas, 2013).

Thus, we can say that the technologies are at the constant risk of being outflanked. And therefore, the technology firms have to work with two faces, like the Roman god “Janus”, one face looking inward for sustaining incremental innovations in the existing products, and the other face looking outward for the disruptive business innovations. Knowing when the new technology will take off is very important for the firms not to miss upon the opportunity, and not to deplete their resources even before the take-off starts.

1.1. Diffusion of Innovations

The demand for technology products follows the process of innovation diffusion process (Rogers, 1971). The theory of diffusion of innovations said that the adoption of the new products follows a bell-shaped distribution over time and that the innovativeness of a customer influences his adoption timing of a product. To further add to this complexity of a highly non-linear demand pattern, multiple products are co-existing at the same time in the market. These different generations of products have an inter-play among themselves to influence the demand pattern which creates further stress for the supply chain. This type of substitution in which the consumers switch to another product due to its technological superiority is called technological substitution. Hung and Lai (2012) highlighted the non-linear behavior of demand when the older technologies are replaced by the newer ones.

1.2. Trade Credits

Trade credits play an important role in the business transactions related to these products. The importance of the trade credits is on account of two reasons: first, these products are high-value products that need support on the working capital constraints; and second, the distribution channel can find pushing these products more lucrative if it is offered the trade credits. Trade financing among the firms is one of the most popular sources of financing globally. There are many benefits of inter-firm credit in a supply chain. Credit terms are an important tool for managing the risk in the supply chains (Vanany and Pujawan, 2007). Credit terms help incentivize the buyer to take some risk while deciding the purchasing quantities, although they create a credit default risk for the supplier also (Gupta et al. 2014). To trade off liquidity risk and profitability, a credit policy is not only desirable but also essential for an organization's success (Kehinde et al. 2017). A combination of bank financing and supplier financing gives a retailer the best of both worlds (Chod, 2017). Also, the firms receiving purchase orders from creditworthy firms can borrow money to enhance the sales (Yamanaka, 2016). The win-win credit terms between the buyer and seller can also help in overcoming the disruptions in the supply chains (Filbeck and Zhao, 2020). In a recessionary environment that is characterized by an increased liquidity crunch and the higher opportunity cost of liquidity risk, the trade credits may also influence the product price to cover up for that opportunity cost (Amberg et al. 2021).

Trade credit offered by the supplier to the buyers is a crucial tool to enhance sales. Sometimes, the suppliers with weak bargaining power with their customers, sell a larger share of goods on credit and offer a longer payment period before charging penalties (Fabbri and Klapper, 2016). Sometimes, the firms offer differential trade credits on the different products to promote cross-selling and to promote the sales of one product at the expense of another one. There is evidence that firms also tend

to use trade credits as a channel of promoting growth (Ferrando and Mulier, 2013). At times, it also happens that the firms offer higher credit periods on the higher profit margin products while acting conservative on the low margin products. The trade credits not only influence the sales volumes but also influence the overall profitability dynamics of the products. It has been observed that the businesses which find it difficult to raise credit from financial institutions find that source of credit in their suppliers (Fountaine and Zhao, 2021).

Therefore, it becomes highly imperative for the supply chain managers to consider the effect of trade credits on the optimal replenishment norms for these products. This influence needs to be considered by the supply chain practitioners involved in the procurement of these products. The cost efficiencies can be achieved if the perfect balance between the two conflicting costs- the one-time fixed cost of ordering and the recurring inventory carrying cost is achieved. This is because while the former of these costs rise with the increase in replenishment frequency, the latter falls with the same.

It is with the above-mentioned objective that this model has been formulated. The model is going to provide valuable insights on the optimal trade credit terms in the different business environments and the different stages of the life cycle of the technology products. Having said that, it is going to help inventory managers and practitioners who are dealing with the technology products.

This paper is structured as follows. Section 1 explains the motivation behind this research and the general background to the topic of study. Section 2 covers the existing literature on the inventory modeling for substitutable products under credit periods. Section 3 puts forward the assumptions of the model and the notations used. Section 4 lays down the demand model used in the paper, which is then used for inventory modeling in Section 5, along with a few theorems and generalizations. Section 6 illustrates the working of the model by using some numerical values of the parameters, while Section 7 pens down the implications for the managers. Section 8 puts forward the conclusions of the work, along with the possible extensions of research in the future.

2. LITERATURE REVIEW

The role of credit periods in modern trade cannot be ignored. Smith (1987) said that credit period information helps the sellers in identifying the prospective defaults more quickly than if the financial institutions were the sole providers of the credit. Suppliers may also act as debt collectors, and protect the customers from liquidity shocks (Cunat, 2007). Trade credits also help in achieving financial stability during turbulent times (Love et al. 2007; Edoardo and Lucio, 2021). Private firms located in particularly high social trust regions tend to use more inter-firm credit (Wu et al. 2014). Inter-firm credit terms and credit policies vary widely among the different firms and across the industries depending upon the relative bargaining power of the parties. (Smith et al. 1999, Inderst, 2007). Trade credits also help in alleviating the problem of information asymmetry that lies between firms and banks (Biais and Gollier, 1997). The increased globalization has also triggered government initiatives on trade finance (Menichini, 2011).

Panda et al. (2005) used non-linear goal programming for determining the EOQ for multi-item supply chains. Basu et al. (2006) developed the inventory models for multiple items with exponentially declining demand under three ranges of credit terms concerning the cycle time of the items. Tsao and Sheen (2007) developed the inventory models to incorporate the purchase costs that were dependent upon time and lot size for multiple items under the permissible delay of payments. Taleizadeh et al. (2008) used hybrid harmony materials. Tsao (2009) studied the impact of credit period and sales learning curve to determine the retailer's optimal promotional effort for multiple items under joint replenishment; and concluded that both the retailer and the supplier can earn a higher profit under a centralized decision model in the search algorithm to solve the EOQ model with advance payments done for multiple and high price raw contrast to that under the de-centralized decision model. Wang and Hu (2010) proposed a heuristic to solve the inventory model for the multiple substitutable components used in production in this era of modularization and customization. Tsao (2010)

extended the scope of existing research by considering multiple echelons with trade allowances under credit period. This work was later appended by Huang et al. (2012). Min et al. (2010) developed an inventory optimization model to maximize the profits of a retailer facing stock-dependent demand of multiple items under a trade credits mechanism. Dye and Ouyang (2011) showed that particle swarm optimization offers acceptable efficiency while solving the joint pricing and replenishment problem with fluctuating demand and trade credit financing. Maihami and Abadi (2012) adopted the price-dependent demand function for jointly priced and replenished, gradually deteriorating items under trade credit. Tripathi and Misra (2012) formulated an optimal inventory policy for the constant demand items under trade credit.

Tsao and Sheen (2012) considered the discounts in the freight costs in the supply chain of multiple items under credit periods. Jiangtao et al. (2014) formulated the inventory model for profit maximization in case of multiple items with stock-dependent demand under storage capacity constraints and credit terms and solved it using langrange approach and line search algorithms. This problem was carried out by first solving the single objective problems and then performing global optimization using signomial geometric programming. Tsao and Teng (2013) developed the two heuristic methods to solve the joint replenishment model for multiple items under trade credits. Das et al. (2014) allowed partial backlogging of demand and used a genetic algorithm to solve the model for multiple deteriorating items under inflation and credit period. Priyan and Uthayakumar (2014) developed a two-echelon inventory model with reverse logistics for multiple items under multiple constraints and a trade credits mechanism. Otrodi et al. (2016) suggested the optimal pricing and replenishment norms for the perishable items under trade credits when the demand was dependent upon the selling price, price of substitutes and complementary products, and on credit period for deteriorating items whose deterioration rate was dependent upon time and temperature. Rabani and Aliabadi (2018) developed the inventory model for multiple items with stochastic demands depending upon the price and marketing expenditure as multi-objective non-linear optimization, with each objective having signomial terms. Wang et al. (2020) formulated a joint replenishment model for multiple items under the penalty cost for the simultaneous transportation of heterogeneous goods. Rapolu and Kandpal (2020) linked inventory policies for items under trade credit mechanism with the dynamics of pricing, advertising, and investment in preservation technology. Taleizadeh et al. (2020) allowed full back-ordering under partial trade credit and multiple pre-payments for a product mix.

When we think of technology products, their demand is governed by diffusion of innovations theory. And it is not just these products, but the usage of newer functions on these products that follows the innovation diffusion theory (Lim et al. 2019). Technological substitution is very different from the other types of demand substitution (Nagpal et al. 2021). Even the demand for the low involvement products gets influenced by electronic word-of-mouth suggesting an imitation effect (Kim et al. 2017). The customer reviews also have a substantial influence on the products' sales (Kim and Shin, 2015). The product preferences of the consumers among the technology products change with time (Lee et al. 2016).

When it comes to the inventory modeling for the technology generations under the trade credits mechanism, the work is hard to find in the existing literature. Chanda and Kumar (2017) formulated the EOQ model for the technology products under the trade credits while considering dynamic pricing and advertising. Chanda and Kumar (2019) developed a similar model under trade credits for dynamic market potential. Nagpal and Chanda (2020a) suggested that the inventory of technology generations cannot be optimized unless the interaction effect between the multiple generations is considered. Nagpal and Chanda (2020b) developed a single-period inventory replenishment model for multi-generational technology products. However, the single-period inventory model is not very practical in today's scenario. Nagpal and Chanda (2021a) worked on linking the warehousing space limitations to the inventory decisions for technology generations. Nagpal and Chanda (2021b) developed the inventory model for multi-generation products with price-sensitive demand.

2.1 Assumptions Behind the Model

This model has been made for the products whose demand follows the innovation diffusion theory. Although the demand is varying with time across the product life cycle, it is deterministic. The trade credit also influences the demand. Since the product has multiple technological generations, the newer generations cannibalize the older generations with time. Thus, the assumptions can be stated as follows:

- The diffusion of the products is governed by the lifecycle dynamics of the technology products.
- The credit period is offered by the retailer to the customer and it tends to increase the market potential of the product since the customers who do not have the funds at the time of the purchase can also purchase the product on credit.
- The demand for the products is deterministic.
- The backlogging of orders are not allowed. This means that the consumer demand at any instant has to be met instantaneously, failing which there will be loss of sales to the extent of difference between the demand and the available supply.
- The customers of the existing generation do not repeat their purchase transaction on the launch of the newer product generation.
- There is a cannibalization effect on the demand of the first generation product post the launch of the second generation product.
- The second-generation product is a significantly enhanced version of the earlier generation product with better functionality, form, or features.

2.2 Notations Used

The notations used in the model are summarized in Table 1.

3. DEMAND MODEL

Now, let us consider the patterns of the credit-linked demand that have been considered by the earlier studies, as mentioned in Table 2.

The above models of credit-linked demand have not been applied to the technology generations. Since the Demand Model $D(m) = K \exp(\alpha m)$ has been the most popular one among the ones mentioned above, we shall integrate the same model with the Norton and Bass Model (1987) in this research for the technology generations.

The demand for technology products is influence by the diffusion of innovations and follows the Norton and Bass Model (1987) which can be captured as:

$$f_1(t) = p_1 + q_1 F_1(t) \quad (1)$$

In the presence of a credit period, the fraction of adopters at time t gets multiplied by a factor of $\exp(\alpha PD_1)$, where α is a constant. Therefore, we can say that:

$$f_1(t) = \mu_1(t) \exp(\alpha PD_1) \quad (2)$$

$$F_1(t) = \left[\int \mu_1(t) dt \right] \exp(\alpha PD_1) \quad (3)$$

Table 1. Description of the notations used in the model

Notation	Assumption
τ	time instant at which the second-generation product is introduced in the market
$\mu_i(t)$	demand rate of i th generation product at time t in absence of credit period
$f_i(t)$	fraction of the normal market potential of the i th generation product that adopts it at the time $(t + \Delta t)$ in the absence of the credit period
$F_i(t)$	cumulative fraction of the normal market potential of the i th generation product that has adopted it till time instant t in the presence of credit period offer
p_i	the innovation coefficient of the i th generation product
q_i	the imitation coefficient of the i th generation product
$\lambda_1(t)$	demand rate of the first generation product at time t in single generation scenario
$\lambda_1'(t)$	demand of the first generation product at time t when $t > \tau$
$\lambda_2(t)$	demand rate of the second generation product at time t
$CD_1(t)$	cumulative demand of the first generation product before the launch of the second generation till time t
$CD_2(t)$	cumulative demand of the second generation product before the launch of the second generation till time t
$CD_1'(t)$	cumulative demand of the first generation product post the launch of the second generation till time t
PD_i	credit term offered by the retailer to the customer of the i th generation product
M_i	market potential of the i th generation product in the absence of trade credits
I_r	% opportunity cost of credit offered to the customer by the retailer
H_i	the inventory holding cost as % of the basic purchase cost for the i th generation product
C_i	basic purchase cost per unit for the i th generation product
pr_i	selling price per unit for the i th generation product
η	the sequence of the planning time bucket
Rev_i	total turnover for the i th generation product

continued on following page

Table 1. Continued

Notation	Assumption
Rev'	total turnover in a planning time bucket post the launch of the second generation product
BC_i	total basic purchase cost for the i th generation product
BC'	total basic purchase cost in a planning time bucket post the launch of the second generation product
TCM_i	contribution margin for the i th generation product
TCM'	total contribution margin in a planning time bucket post the launch of the second generation product
A_i	fixed product-specific ordering cost of the i th generation product irrespective of the order volumes
A	fixed generic ordering cost
OC_i	total ordering cost specific to the i th generation product
OC	total generic ordering cost which is not specific to the products being ordered
HC_i	total inventory holding cost for the i th generation product
HC'	total inventory holding cost in a planning time bucket post the launch of the second generation product
IC_i	interest cost on the credit offered for the i th generation product
z	a binary variable which equals 1 for joint replenishment and 0 for disjoint replenishment
RC_i	replenishment cost (including inventory ordering, inventory carrying, and interest on credit) for the i th generation product
RC'	total replenishment cost (including inventory ordering, inventory carrying, and interest on credit) in a planning time bucket post the launch of the second generation product
TP_i	total profit for the i th generation product
TP'	total profit in a planning time bucket post the launch of the second generation product
$\xi_{i\eta}$	quantity of the i th generation product ordered in each lot in the time bucket η
$\xi_{i\eta'}$	quantity of the i th generation product ordered in each lot in the time bucket η' post the launch of the second generation product
ε	length of the time bucket for which the inventory norms are fixed

Table 2. Demand patterns considered by the existing studies on credit-linked demand

Demand Pattern	Studies
$D(m) = K \exp(\alpha \cdot m)$ where m is the credit period, K and α are constants >0	Chern et al. (2013), Chern et al. (2014), Wang et al. (2014), Wu et al. (2017), Su et al. (2007), Chung (2012)
$D(N, p) = D_0 N^\alpha p^\beta$ where N is the credit period, p is the selling price; D_0 , α and β are constants >0	Ho et al. (2011)
$D(s, N) = \alpha(s) - [\alpha(s) - \beta(s)] \exp(-rN)$ where $\alpha(s)$ is the maximum demand at the selling price of s , N is the credit period, p is the selling price; $0 \leq r < 1$ is the rate of demand saturation	Thangam and Uthayakumar (2009), Jaggi et al. (2008)
$D(t) = D_0 \exp(b_1 N (M - N) t)$ where N is the credit offered by retailer to the customer, and M is the credit period offered to the retailer by the supplier, b_1 is a constant	Banu and Mondal (2016)

Substituting equations (2) and (3) in equation (1), we get:

$$\mu_1(t) \exp(\alpha \cdot PD_1) = p_1 + q_1 \exp(\alpha \cdot PD_1) \int \mu_1(t) dt \quad (4)$$

On solving the above-mentioned differential equation, we get:

$$\mu_1(t) = \frac{b_1^2 \exp(-b_1 t)}{\left[\{p_1 / \exp(\alpha \cdot PD_1)\} \{1 + a_1 \cdot \exp(-b_1 t)\}^2 \right]} \quad (5)$$

where:

$$b_1 = p_1 / \exp(\alpha \cdot PD_1) + q_1 \quad (6)$$

and:

$$a_1 = q_1 \exp(\alpha \cdot PD_1) / p_1$$

So:

$$f_1(t) = \frac{b_1^2 \exp(-b_1 t) [\exp(\alpha.PD_1)]^2}{\left[p_1 \left\{ 1 + a_1 \cdot \exp(-b_1 t) \right\}^2 \right]} \quad (7)$$

$$F_1(t) = \frac{[1 - \exp(-b_1 t)] \exp(\alpha.PD_1)}{[1 + a_1 \cdot \exp(-b_1 t)]} \quad (8)$$

$$f_2(t) = \frac{b_2^2 \exp(-b_2(t - \tau)) [\exp(\alpha.PD_2)]^2}{\left[p_2 \left\{ 1 + a_2 \cdot \exp(-b_2(t - \tau)) \right\}^2 \right]} \quad (9)$$

$$F_2(t) = \frac{[1 - \exp(-b_2(t - \tau))] \exp(\alpha.PD_2)}{[1 + a_2 \cdot \exp(-b_2(t - \tau))]} \quad (10)$$

where:

$$b_2 = p_2 / \exp(\alpha.PD_2) + q_2$$

and:

$$a_2 = q_2 \exp(\alpha.PD_2) / p_2$$

If the first generation product is launched at time $t = 0$, and the second generation gets introduced at time $t = \tau$, the demand for the products of the two generations can be written as proposed by Nagpal and Chanda (2020b):

$$\lambda_1(t) = M_1 f_1(t) \quad \text{for } t \leq \tau \quad (11)$$

$$\lambda_1'(t) = M_1 f_1(t) - M_1 f_1(t) F_2(t - \tau) \quad \text{for } t \geq \tau \quad (12)$$

$$\lambda_2(t) = M_2 f_2(t) + M_1 f_1(t) F_2(t - \tau) \quad \text{for } t \geq \tau \quad (13)$$

The above equations show that a few of the potential adopters of the first generation technology product will adopt the second generation product instead of the earlier generation product.

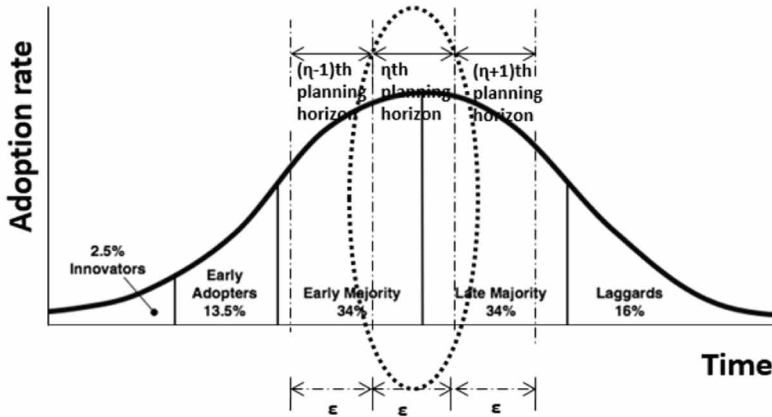
4. INVENTORY MODEL

The business decisions related to the procurement of inventories are tactical. For a particular bucket of time, the retailers decide their EOQ and then, review it at regular periodic intervals, with the life cycle dynamics of the product changing in each of these time buckets. Thus, the retailers try to determine their inventory replenishment strategies based on the stage of the life cycle of the product. If the length of each of those time buckets is ε , and there is ξ_η amount of order quantity in the η time bucket, we have to determine the value of ξ_η for which the total profit is maximum in the time bucket η .

4.1 Inventory Model in Case of Single Generation Existing in the Market

The time at which the time bucket η starts is given by $(\eta-1)\varepsilon$, and the time at which it ends is $(\eta)\varepsilon$ as shown in Figure 1.

Figure 1. Time buckets into which product life cycle is divided in the single generation case



Since the EOQ in this time bucket is ξ_η , the number of orders to be placed in this period is given by:

$$j = \left\lceil \frac{1}{\xi_\eta} \right\rceil \left[CD_1(\eta \cdot \varepsilon) - CD_1((\eta - 1) \cdot \varepsilon) \right] \quad (14)$$

The time of the start of the k th ordering cycle is given by:

$$t_{k,\eta,\xi_\eta} = \left(\eta - 1 + (k - 1) / j \right) \varepsilon \quad (15)$$

The time of the end of the k th ordering cycle is given by:

$$t_{(k+1),\eta,\xi_\eta} = (\eta - 1 + k / j) \varepsilon \quad (16)$$

The holding costs of inventory in the k th ordering cycle in the time bucket η are given by:

$$I_1 C_1 \int_{t_{k,\eta,\xi_\eta}}^{t_{(k+1),\eta,\xi_\eta}} I_1(t) dt = I_1 C_1 \int_{t_{k,\eta,\xi_\eta}}^{t_{(k+1),\eta,\xi_\eta}} \int_t^{t_{(k+1),\eta,\xi_\eta}} \lambda_1(t) dt dt \quad (17)$$

Net interest costs on the credit period in k th replenishment cycle of the η time bucket are given as:

$$I_r \cdot C_1 \cdot PD \cdot \int_{t_{k,\eta,\xi_\eta}}^{t_{(k+1),\eta,\xi_\eta}} \lambda_1(t) dt \quad (18)$$

The replenishment costs for the η time bucket are given as:

$$RC_1 = j(A + A_1) + I_1 C_1 \sum_{k=1}^{k=j} \int_{t_{k,\eta,\xi_\eta}}^{t_{(k+1),\eta,\xi_\eta}} \int_t^{t_{(k+1),\eta,\xi_\eta}} \lambda_1(t) dt dt + I_r \cdot C_1 \cdot PD \cdot \sum_{k=1}^{k=j} \int_{t_{k,\eta,\xi_\eta}}^{t_{(k+1),\eta,\xi_\eta}} \lambda_1(t) dt \quad (19)$$

The revenue is given by:

$$Rev_1 = pr_1 \cdot \sum_{k=1}^{k=j} \int_{t_{k,\eta,\xi_\eta}}^{t_{(k+1),\eta,\xi_\eta}} \lambda_1(t) \cdot dt \quad (20)$$

$$BC_1 = C_1 \cdot \sum_{k=1}^{k=j} \int_{t_{k,\eta,\xi_\eta}}^{t_{(k+1),\eta,\xi_\eta}} \lambda_1(t) \cdot dt \quad (21)$$

$$TCM_1 = Rev_1 - BC_1 \quad (22)$$

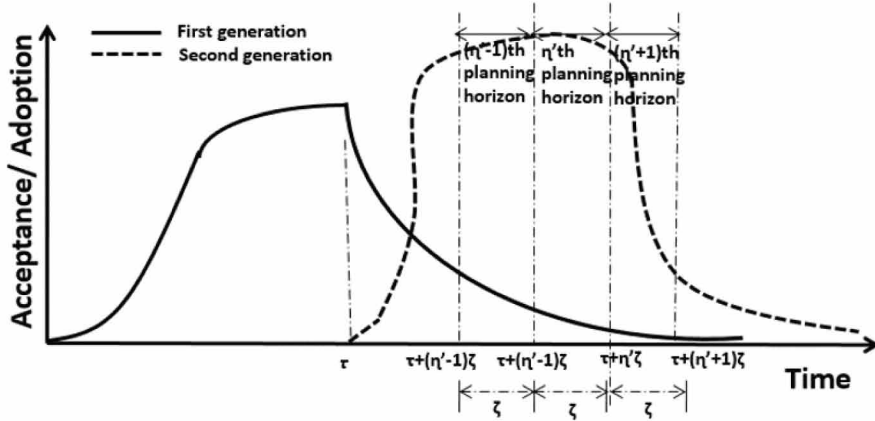
$$TP_1 = TCM_1 - RC_1 \quad (23)$$

4.2 Inventory Model for the Two Generations Scenario

Let us say that planning horizon η' begins at time $t = \tau + (\eta' - 1)(\varepsilon)$ and ends at time $t = \tau + (\eta')(\varepsilon)$.

The time at which the time bucket η starts is given by $(\eta'-1)\varepsilon$, and the time at which it ends is $(\eta)\varepsilon$ as shown in Figure 2.

Figure 2. Time buckets into which product life cycle is divided after the launch of the second generation product



If $\xi_{1\eta}'$ and $\xi_{2\eta}$ be the order quantities of the products of the first generation and the second generation respectively, the number of orders to be placed for the products are:

$$j_1' = \left[CD_1'(\tau + (\eta)(\varepsilon)) - CD_1'(\tau + (\eta-1)(\varepsilon)) \right] / \xi_{1\eta}' \quad (24)$$

$$j_2 = \left[CD_2(\tau + (\eta)(\varepsilon)) - CD_2(\tau + (\eta-1)(\varepsilon)) \right] / \xi_{2\eta} \quad (25)$$

The k th replenishment cycle for the first generation starts at the time:

$$t_{(k-1), \xi_{1\eta}'} = \tau + (\eta - 1 + (k - 1) / j_1') \varepsilon$$

and ends at the time:

$$t_{k, \xi_{1\eta}'} = \tau + (\eta - 1 + k / j_1') \varepsilon$$

Similarly, the k th replenishment cycle for the second generation starts at the time:

$$t_{(k-1), \xi_{2\eta}} = \tau + (\eta - 1 + (k - 1) / j_2) \varepsilon$$

and ends at the time:

$$t_{k,\xi_{2\eta}} = \tau + \left(\eta - 1 + k / j_2 \right) \varepsilon$$

In the case of consolidated logistics for both the generations of products, the clubbed quantity to be transported in the k th replenishment cycle is $t_{(k-1),\xi_{\eta 1}'} = t_{(k-1),\xi_{\eta 2}}$; and $t_{k,\xi_{\eta 1}'} = t_{k,\xi_{\eta 2}}$.

Similar to the way we worked out the economics in the single generation case, the economics of the two generations situation can be captured as below:

$$\begin{aligned} RC' &= RC_1 + RC_2 = j_1' (A_1 + A) + j_2 (A_2 + A) - z \cdot (A) \\ &+ H_1 C_1 \sum_{k=1}^{k=j_1'} \int_{t=t_{(k-1),\xi_{\eta 1}'}}^{t=t_{k,\xi_{\eta 1}'}} \lambda_1'(t) dt + H_2 C_2 \sum_{k=1}^{k=j_2} \int_{t=t_{(k-1),\xi_{\eta 2}}}^{t=t_{k,\xi_{\eta 2}}} \lambda_2(t) dt \\ &+ I_r \cdot C_1 \cdot PD_1 \cdot \sum_{k=1}^{k=j_1'} \int_{t=t_{k,\eta,\xi_{\eta 1}'}}^{t=t_{k,\xi_{\eta 1}'}} \lambda_1'(t) dt + I_r \cdot C_1 \cdot PD \cdot \sum_{k=1}^{k=j_1'} \int_{t=t_{k,\eta,\xi_{\eta 1}'}}^{t=t_{k,\xi_{\eta 1}'}} \lambda_1'(t) dt \end{aligned} \quad (26)$$

where:

$$z = 1 \text{ if } j_1' = j_2, \text{ and } 0 \text{ otherwise}$$

$$Rev' = Rev_1 + Rev_2 = pr_1 \cdot \sum_{k=1}^{k=j_1'} \int_{t=t_{k,\eta,\xi_{\eta 1}'}}^{t=t_{(k+1),\eta,\xi_{\eta 1}'}} \lambda_1'(t) \cdot dt + pr_2 \cdot \sum_{k=1}^{k=j_2} \int_{t=t_{k,\eta,\xi_{\eta 2}}}^{t=t_{(k+1),\eta,\xi_{\eta 2}}} \lambda_2(t) \cdot dt \quad (27)$$

$$BC' = BC_1 + BC_2 = C_1 \cdot \sum_{k=1}^{k=j_1'} \int_{t=t_{k,\eta,\xi_{\eta 1}'}}^{t=t_{(k+1),\eta,\xi_{\eta 1}'}} \lambda_1'(t) \cdot dt + C_2 \cdot \sum_{k=1}^{k=j_2} \int_{t=t_{k,\eta,\xi_{\eta 2}}}^{t=t_{(k+1),\eta,\xi_{\eta 2}}} \lambda_2(t) \cdot dt \quad (28)$$

$$TP' = Rev' - BC' - RC' \quad (29)$$

The optimization problem is:

$$\text{Max } TP' = Rev' - BC' - RC'$$

subject to the constraints:

$$j_1' = j_2$$

$$j_1' \text{ and } j_2 \text{ are positive integers.}$$

Theorem 1: With the increase in the trade credits, the holding costs tend to fall given other factors constant.

Proof: See below:

$$\frac{\partial(HC_1)}{\partial(PD_1)} = \left[\frac{\partial(HC_1)}{\partial(\lambda_1(t))} \right] \left[\frac{\partial(\lambda_1(t))}{\partial(f_1(t))} \right] \left[\frac{\partial(f_1(t))}{\partial(PD_1)} \right]$$

All the three terms in the expression above are positive.

We know that holding costs tend to fall with the increase in demand rate due to lesser time spent

by the inventories in the system. Hence, $\left[\frac{\partial(HC_1)}{\partial(\lambda_1(t))} \right]$ is negative:

$$\left[\frac{\partial(\lambda_1(t))}{\partial(f_1(t))} \right] = M_1 > 0$$

$$\begin{aligned} \frac{\partial(f_1(t))}{\partial(PD_1)} &= \frac{2\alpha b_1^2 \exp(-b_1 t) [\exp(\alpha \cdot PD_1)]^2}{\left[p_1 \{1 + a_1 \cdot \exp(-b_1 t)\}^2 \right]} \\ &- \frac{2b_1 p_1 \alpha \exp(-b_1 t) \exp(\alpha \cdot PD_1)}{\left[p_1 \{1 + a_1 \cdot \exp(-b_1 t)\}^2 \right]} + \frac{b_1^2 t \cdot \alpha \cdot \exp(-b_1 t) \exp(\alpha \cdot PD_1) p_1}{\left[p_1 \{1 + a_1 \cdot \exp(-b_1 t)\}^2 \right]} \end{aligned}$$

$$\begin{aligned} \frac{\partial(f_1(t))}{\partial(PD_1)} &= \alpha \cdot \exp(-b_1 t) \exp(\alpha \cdot PD_1) \\ &/ \left[p_1 \{1 + a_1 \cdot \exp(-b_1 t)\}^2 \right] \left[2b_1^2 \exp(\alpha \cdot PD_1) - 2b_1 p_1 + b_1^2 t \cdot p_1 \right] \end{aligned}$$

Since $b_1 \exp(\alpha \cdot PD_1) > p_1$, we can conclude that $\frac{\partial(f_1(t))}{\partial(PD_1)}$ is always positive.

Figure 3 illustrates the influence of the credit period on the adoption rate for any product.

Figure 4 shows the influence of the credit period on the cumulative adoption rate of any product.

So:

$$\frac{\partial(HC_1)}{\partial(PD_1)} < 0$$

Theorem 2: With the increase in trade credits, the total contribution margin tends to increase.

Proof: See below:

Figure 3. Influence of credit period PD_1 on the adoption rate $f_1(t)$

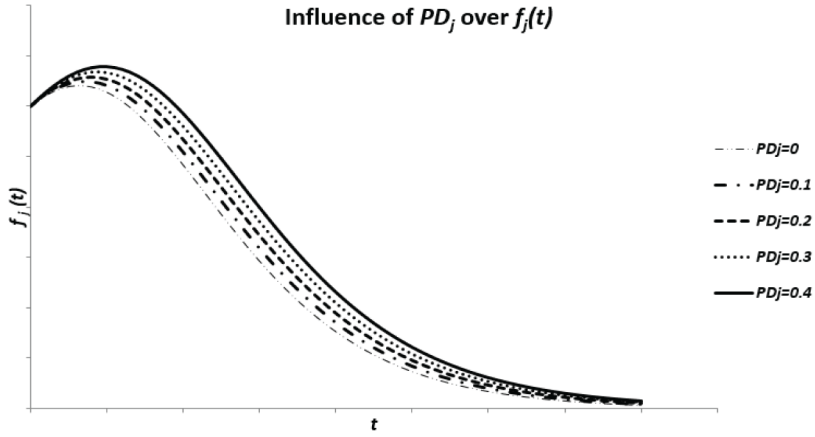
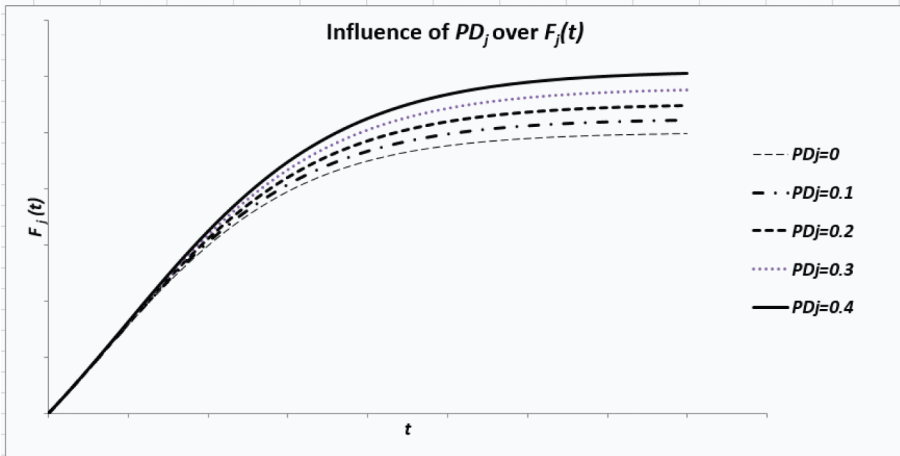


Figure 4. Influence of credit period PD_1 on the cumulative adoption rate $F_1(t)$



$$\frac{\partial(TCM_1)}{\partial(PD_1)} = \left[\frac{\partial(TCM)}{\partial(\lambda_1)} \right] \left[\frac{\partial(\lambda_1(t))}{\partial(f_1(t))} \right] \left[\frac{\partial(f_1(t))}{\partial(PD_1)} \right]$$

$$\left[\frac{\partial(TCM_1)}{\partial(\lambda_1)} \right] = pr_1 - C_1 > 0$$

Since the later two terms in the expression above have already been proven to be positive:

$$\left[\frac{\partial (TCM_1)}{\partial (\lambda_1)} \right] > 0$$

Theorem 3: Offering the higher trade credits on the newer generation product expedites the phase-out timing of the first generation product.

Proof: The higher trade credits on the second generation product lead to an increase in its demand rate, at the expense of cannibalization of the earlier generation product. The lower demand rate of the first-generation product, thus caused, results in the replenishment costs from being recovered from the contribution margin, thus making the first-generation product a loss proposition:

$$\frac{\partial (\lambda_1)}{\partial (PD_2)} = \left[\frac{\partial (\lambda_1(t))}{\partial (f_2(t))} \right] \left[\frac{\partial (f_2(t))}{\partial (PD_2)} \right] = -M_1 \left[\frac{\partial (f_2(t))}{\partial (PD_2)} \right]$$

$$\frac{\partial (f_2(t))}{\partial (PD_2)} = \frac{2\alpha b_2^2 \exp(-b_2(t-\tau)) [\exp(\alpha \cdot PD_2)]^2}{\left[p_1 \left\{ 1 + a_1 \cdot \exp(-b_1(t-\tau)) \right\}^2 \right]} > 0$$

Thus, we can say that:

$$\frac{\partial (\lambda_1)}{\partial (PD_2)} < 0$$

Figure 5 sums up the phenomenon explained above.

Figure 5. Influence of the credit period of second product generation on the demand of the first generation product

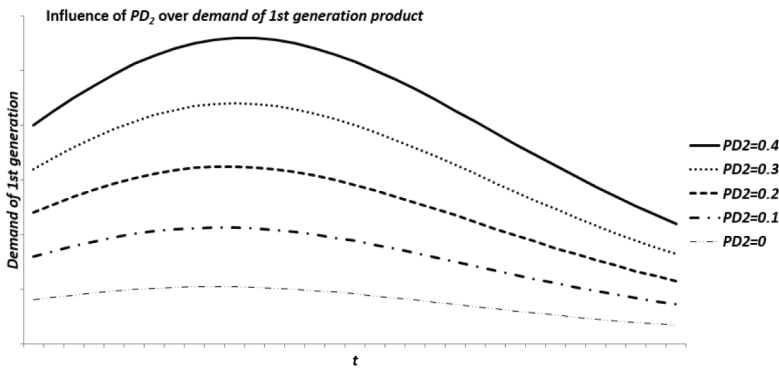
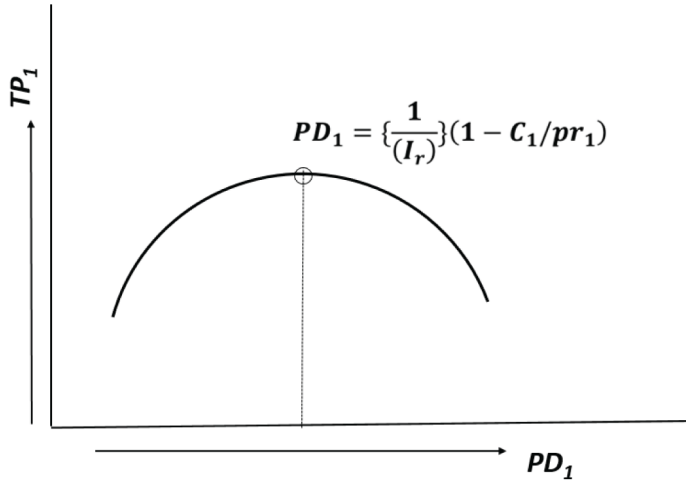


Figure 6. Influence of the credit period on the total profit of a product



Theorem 4: The total profit curve as a function of the credit terms is convex to the origin.

Proof: As the credit term increases, the contribution margin of the product increases due to a rise in the demand, while the credit costs also increase. It makes sense to increase the credit terms till the point where the increase in contribution margin is more than the rise in credit costs. Let D be the demand in the absence of the credit period, and ΔD be the rise in demand with a credit period PD_1 , then:

$$(\Delta D)(pr_1 - C_1) > (\Delta D)pr_1 \cdot \left(\frac{1}{I_r}\right)(PD_1)$$

$$PD_1 = \left\{ \frac{1}{\left(\frac{1}{I_r}\right)} \right\} \left(1 - C_1 / pr_1\right)$$

From the above expression, it is evident that the higher contribution margin results in a higher optimal credit period, and vice versa. Also, the higher interest rates lead to lower optimal credit periods. Figure 6 illustrates this phenomenon.

Figure 7 shows how the iso- C_i / pr_i lines on the two-dimensional graph of the credit terms and the interest rates at the point of optimal credit period for a product.

Figure 8 shows the iso-interest-rate lines on the graph of the credit period and the cost-price ratio at the point of optimal credit period for a product.

Theorem 5: In times of recessionary business cycles, the optimal credit terms are higher than in times of economic growth.

Proof: In times of recession, the number of investment opportunities falls, leading to a drop in the opportunity cost of capital for the investors and therefore, a drop in the interest rates. As clear from the expression, the lower interest rates lead to a higher optimal credit period. Figure 9 shows how the optimal trade credit terms change with the business cycles.

Figure 7. Iso-Cost-Price-Ratio lines plotted on the credit terms and interest rates

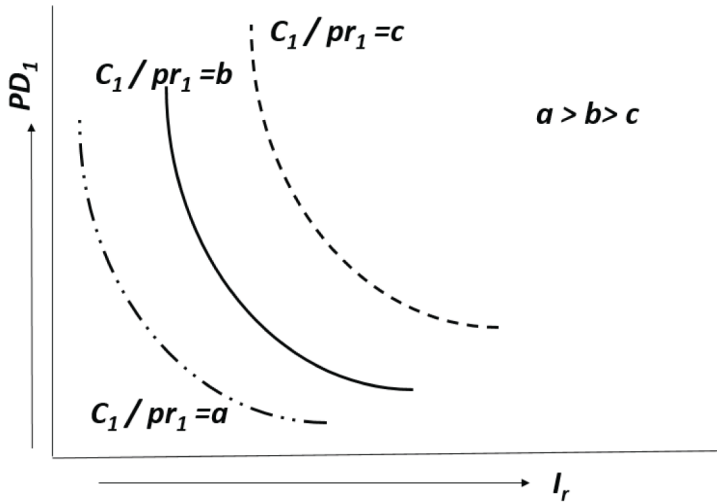
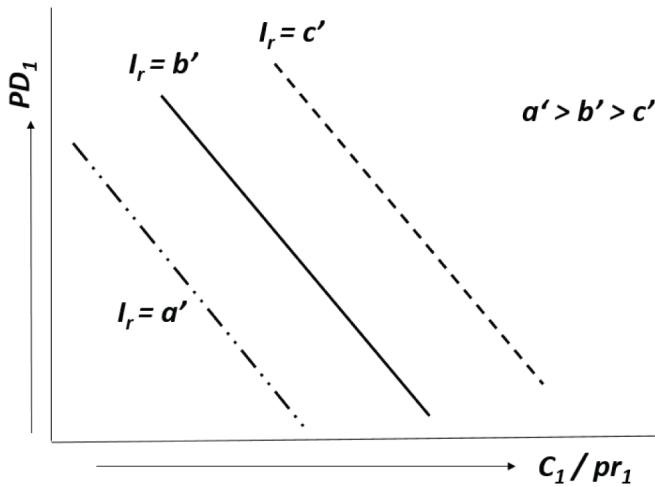


Figure 8. Iso-Interest rate lines plotted on the credit terms and cost-price-ratio

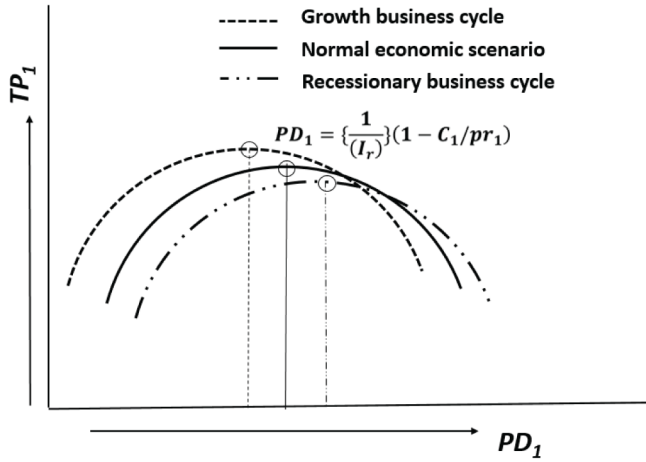


Theorem 6: For the fast-moving popular products with lower per-unit contribution margins, the retailers should offer negative or lesser credit periods, while for the slow-moving and higher per-unit contribution margin products, it makes sense to offer a higher credit period.

Proof: The credit period has three effects on the profit margin:

1. The increase in contribution margin due to higher volumes, as explained below;
2. The reduction in inventory carrying costs due to faster movement of inventories caused by higher demand rate; and

Figure 9. Influence of business cycles on the optimal credit terms



The higher credit costs, as explained below:

$$\frac{\partial(\lambda_1)}{\partial(PD_1)} = M_1 \frac{\partial(f_1)}{\partial(PD_1)} > 0$$

as proved above in Theorem 1:

$$\frac{\partial(TCM_1)}{\partial(PD_1)} = (pr_1 - C_1) \cdot \frac{\partial\left(\sum_{k=1}^{k=j} \int_{t=t_{k,\eta,\xi_\eta}}^{t=t_{(k+1),\eta,\xi_\eta}} \lambda_1(t) dt\right)}{\partial(PD_1)} > 0$$

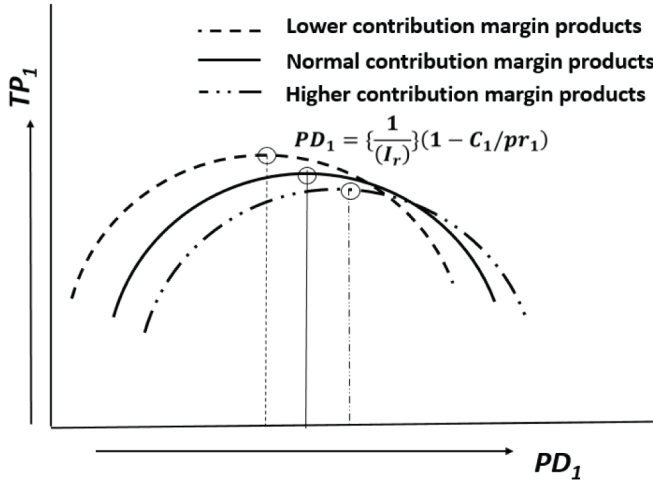
since it is cumulative of a positive function:

$$\frac{\partial(RC_1)}{\partial(PD_1)} = I_r \cdot C_1 \cdot \sum_{k=1}^{k=j} \int_{t=t_{k,\eta,\xi_\eta}}^{t=t_{(k+1),\eta,\xi_\eta}} \lambda_1(t) dt > 0$$

While the first two have a positive influence on the profit, the third effect has a negative influence on the profit. For the mass market technology products that enjoy smaller contribution margins per unit, and faster inventory turnover rates, the positive effect on the retailer's profit will be lesser than the negative effect on credit costs. Therefore, it makes sense for the retailers to offer a lesser credit period (or sometimes, a negative credit period, i.e. insisting on advance collection from customers) on the popular technology products. While in the case of the technology products with higher contribution margin per unit and slower inventory turnover rates, the positive effect of the first two influences is

higher than the negative effect of the third influence, making it an attractive proposition to offer a higher credit period. Figure 10 shows how the optimal trade credit terms change with the contribution margin of the product under consideration.

Figure 10. Influence of the contribution margin on optimal credit terms



Special Case 1: When the credit period is two-sided, i.e. from supplier to retailer PD_{sr} and from retailer to customer PD_{rc} , the demand for the products increases with PD_{rc} as long as

$$PD_{sr} < \left(\frac{1}{2}\right) PD_{rc}, \text{ Also, there shall be no influence on demand when } PD_{sr} = PD_{rc} \text{ or } PD_{sr} = 0$$

Proof: As proposed by Banu and Mondal (2016), the demand in such a case is proportional to $\exp(b_1 PD_{sr} (PD_{rc} - PD_{sr}))$:

$$\frac{\partial \left(\exp(b_1 PD_{sr} (PD_{rc} - PD_{sr})) \right)}{\partial (PD_{sr})} = \left[b_1 \cdot \exp(b_1 PD_{sr} (PD_{rc} - PD_{sr})) \right] (PD_{rc} - 2 \cdot PD_{sr})$$

This is positive $PD_{rc} - 2 \cdot PD_{sr} > 0$. Therefore, the demand for the product rises with the increase in $2 \cdot PD_{sr}$ till the point where $PD_{sr} < \left(\frac{1}{2}\right) PD_{rc}$.

Also, the expression $\exp(b_1 PD_{sr} (PD_{rc} - PD_{sr}))$ reaches the value of 1 when $PD_{sr} = PD_{rc}$ or $PD_{sr} = 0$, and therefore, loses its multiplier effect on the demand.

Special Case 2: Under the capital constraints of credit, it is better to offer credits on the newer generation product rather than the earlier generation product.

Proof: This is a special case of constraints on credit capital. Let us consider that SL_i be the service level of the i th generation product, D_i be the demand of the i th generation product during the credit cycle and $TVPPU_i$ be the total variable profit per unit for the i th generation product. The problem becomes approximately a linear program with the following formulation:

$$\text{Max. } Z = SL_1 \cdot D_1 \cdot TVPPU_1 + SL_2 \cdot D_2 \cdot TVPPU_2$$

subject to the constraints:

$$SL_1 \cdot D_1 + SL_2 \cdot D_2 - CC \leq 0$$

$$z \leq M \cdot SL_1$$

$$z \leq 1$$

$$SL_1 \text{ and } SL_2 \geq 0 \text{ and } \leq 1$$

M is a very large number

The newer generation products have higher contribution margins as compared to the older generation products on account of price skimming for the advanced features.

Therefore, $TVPPU_1 < TVPPU_2$.

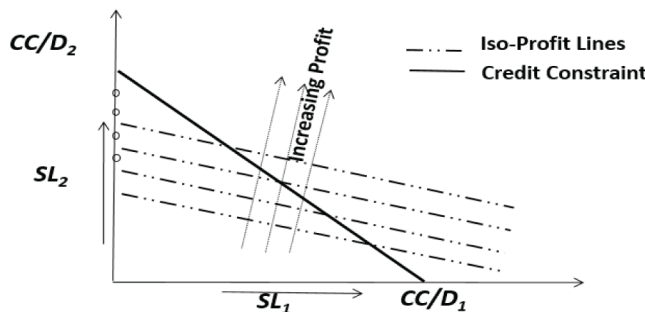
Since these are technology products, within a very short span of the launch of the next generation, significant cannibalization happens, making $D_1 < D_2$.

Hence, $TVPPU_1 \cdot D_1 < TVPPU_2 \cdot D_2$. Therefore, it makes sense to increase the SL_2 at the expense of SL_1 . This is illustrated in Figure 11.

5. NUMERICAL ILLUSTRATION

Let us use the following values of the parameters to illustrate the model proposed above:

Figure 11. The service level determination for Profit Maximization in a capital-constrained supply chain



$$H_1 = .15, H_2 = .15, p_1 = .05, q_1 = .25, p_2 = .06, q_2 = .4, I_r = .18,$$

$$pr_1 = 3500, pr_2 = 4500, C_1 = 1500, C_2 = 1700, PD_1 = .25$$

$$PD_2 = .25, \alpha = .15, \tau = 0.5, \varepsilon = 0.5, M_1 = 100000,$$

$$M_2 = 200000, A = .05, A_1 = .25, A_2 = .06, A = .4$$

With the help of the proposed model, we get the results as tabulated in Table 3. The number of replenishments at the optimal EOQ in the first two planning time buckets have been delivered. The optimal EOQ refers to the lot size that delivers the highest profit. Since the technology products can have very short product life cycles in the light of changing consumer preferences and ever-up-gradation of technologies and business models, we can observe how the share of the first generation product reaches minuscule levels over a short period.

Table 3. Optimal number of replenishments corresponding to the pooled logistics scenario

η	Number of orders	1st Generation Product					OC	2nd Generation Product					TP	TP%
		Rev ₁	BC ₁	OC ₁	HC ₁	IC ₁		Rev ₂	BC ₂	OC ₂	HC ₂	IC ₂		
1st	1	1,106	474	4.0	14.1	55.4	20.0	6,705	2,533	4.0	106.0	335.5	4,285	54.9%
	2	1,106	474	8.0	8.0	55.4	40.0	6,705	2,533	8.0	49.9	335.5	4,339	55.6%
	3	1,106	474	12.0	5.5	55.4	60.0	6,705	2,533	12.0	32.6	335.5	4,351	55.7%
	4	1,106	474	16.0	4.2	55.4	80.0	6,705	2,533	16.0	24.4	335.5	4,353	55.7%
2nd	1	90	39	4.0	0.7	55.4	20.0	5,286	1,997	4.0	61.2	335.5	2,880	53.6%
	2	90	39	8.0	0.5	55.4	40.0	5,286	1,997	8.0	34.2	335.5	2,899	53.9%
	3	90	39	12.0	0.4	55.4	60.0	5,286	1,997	12.0	23.4	335.5	2,902	54.0%
	4	90	39	16.0	0.3	55.4	80.0	5,286	1,997	16.0	17.9	335.5	2,899	53.9%

We also try to check the cross elasticity of demand of any generation product with the credit terms of the other generation. On changing the credit terms of the second generation, the demand of the first generation increases, and vice versa.

Table 4 shows the influence of the credit terms of the products on the demand for each other. It can be seen that the cumulative adoption of a product is dependent upon the credit term of that product as well as the substitutable products. The increase (or decrease) in the credit terms of the substitutable generation product leads to a fall (or rise) in the demand for a product.

Table 5 shows that an increment in the credit terms benefits the retailer up to a certain threshold limit, post which it starts creating a dent in their profits. This has been computed for the normal values of contribution margin since the optimal credit period tends to be very large for higher contribution margin products and very small for low contribution margin products.

Figure 12 shows not only that the total profit, when plotted on the credit period, is concave to the origin, but also shows that the optimal credit period for the second generation product is higher than that for the first generation product, as we had discussed in the Special Case 2.

Table 4. Influence on the adoption of the first-generation product by changing the relative credit terms with the second generation product

Cumulative Number of Adopters (Mn)						
t	PD ₁ =PD ₂ =.25		PD ₁ =0, PD ₂ =.5		PD ₁ =.5, PD ₂ =0	
	1st Gen	2nd Gen	1st Gen	2nd Gen	1st Gen	2nd Gen
0.5	0.04	0.00	0.04	0.00	0.36	0.00
1	0.04	0.15	0.04	0.15	0.04	0.15
1.5	0.08	0.23	0.09	0.21	0.07	0.25
2	0.10	0.23	0.12	0.22	0.09	0.26
2.5	0.11	0.24	0.13	0.22	0.10	0.26

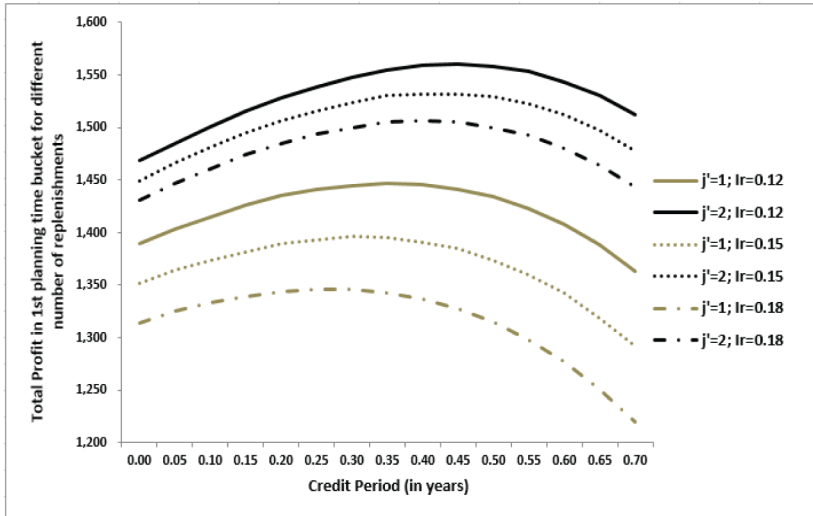
Table 5. The behavior of total profit (in Mn INR) for different values of credit period (assuming the same for both the generation products)

PD ₁ =PD ₂	I _r =0.12		I _r =0.15		I _r =0.18	
	j'=1; I _r =0.12	j'=2; I _r =0.12	j'=1; I _r =0.15	j'=2; I _r =0.15	j'=1; I _r =0.18	j'=2; I _r =0.18
0.00	1,390	1,468	1,352	1,449	1,314	1,431
0.05	1,403	1,485	1,364	1,466	1,325	1,447
0.10	1,415	1,501	1,374	1,481	1,333	1,461
0.15	1,426	1,516	1,382	1,495	1,339	1,474
0.20	1,435	1,528	1,389	1,506	1,344	1,485
0.25	1,441	1,539	1,393	1,516	1,346	1,494
0.30	1,445	1,548	1,396	1,524	1,346	1,500
0.35	1,447	1,554	1,395	1,530	1,343	1,505
0.40	1,446	1,559	1,391	1,532	1,337	1,506
0.45	1,441	1,560	1,385	1,532	1,328	1,505
0.50	1,434	1,558	1,374	1,529	1,315	1,500
0.55	1,423	1,553	1,360	1,522	1,298	1,493
0.60	1,408	1,543	1,342	1,512	1,277	1,480
0.65	1,388	1,530	1,319	1,497	1,251	1,464
0.70	1,363	1,512	1,292	1,478	1,220	1,443

6. MANAGERIAL IMPLICATIONS

This research study can guide the industry practitioners in appreciating the cannibalization among the different generations of the technology products. It can also guide them in determining the optimal credit terms in business. The optimal credit terms would be the one at which the total profit is maximized. With the increase in credit period, the overall value proposition to the buyer improves leading to the increase in the sales volumes rise. As a result, the contribution margin increases, and the holding costs fall. But this happens at the expense of a rise in credit costs. Thus, there is an optimal credit term till which the positive effect of the credit period on contribution margin and holding costs

Figure 12. Optimal values of credit period for the maximum profit in the first time bucket with one replenishment cycle and two replenishment cycles



outweighs its negative effect on the credit costs. It makes business sense to offer incremental credit as long as the rise in credit costs is outweighed by the rise in the contribution margin and fall in holding costs.

This paper also helps the managers understand the interplay between the credit periods and the demand rates of multiple-generation substitutable products. Another important implication for the managers is that the credit period offers become more beneficial in times of recessionary business cycles as compared to the growing business cycles. Also, the credit terms provide more value for the low-volume high-margin products, in contrast to the high-volume low-margin products. The inventory practitioners in the supply chains of digital products can make sound business decisions related to the inventory replenishment frequency, economic order lot size, and credit terms. The differential service levels can be explored in a capital-constrained supply chain, and generally, it is better to achieve a higher service level for the later generation product at the expense of that for the earlier generation product.

It also came out that the higher credit period offered on any product has a negative influence on the demand of the substitutable products. This is because the higher amount of trade credit on any product incentivizes the buyer to purchase the product more, leading to an increase in the demand of the product and cannibalization of the demand of the substitutable products. Thus, the demand for substitutable products falls. It is also important to note that in the case of multi-echelon supply chains, the credit periods offered by the intermediate echelons benefit the total profit only till a certain point.

7. CONCLUSION AND FUTURE DIRECTIONS

This research study is the first multi-period inventory optimization model developed for the multi-generation technology products under credit offer and credit dependent demand. It has also illustrated the model numerically and established a few insights in the form of theorems.

There are a few areas of possible extension for this research in the future. First, the interest rate can be very volatile and uncertain in the economy, which can be best described using fuzzy logic. Second, backlogging of sales is possible when the customer is ready to wait and when the postponement of product delivery increases the total profit of the supply chain. So, we need to also build the models

for a scenario where backlogging is allowed. Third, we often observe that the existing adopters of the earlier generation product purchase the newer generation product and repeat their transaction. This phenomenon of repeat purchase needs to be considered to make the model more practical. It is a common practice that the credit terms which are agreed mutually between the two entities are not adhered to, which makes it relevant to consider the deviation from agreed credit terms in practice. Fourth, the demand can be stochastic by nature, which needs to be considered using suitable probability distributions, and also the safety stocks.

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Gaurav Nagpal (PhD) is an Assistant Professor in the Management Department at Birla Institute of Technology and Science Pilani. He received his Ph.D. from BITS Pilani and is a full-time MBA from IIFT Delhi. He feels humbled to have been a 99.83 percentile scorer in the GATE exam in the year 2004. He has also done EPMBD (one-year executive program in managing business decisions) from IIM Calcutta and is CSCP qualified from APICS. He has fourteen years of experience of which twelve years is into the industry. His last industry assignment was with the grocery e-commerce firm "Grofers" as Associate Director- Business Planning when he decided to make an academic career and joined BITS Pilani. He has teaching and research interests in Data Analytics, Operations and Supply Chain Management, Operations Research, and Business Statistics. He has been instrumental in the launch of MBA- Business Analytics for working professionals at BITS Pilani. He is also the Practice School Lead for management-domain industry projects at BITS Pilani. He has published 7 research articles and 3 book chapters in peer-reviewed international journals and books.

Udayan Chanda (PhD) is currently working as Associate Professor in Department of Management, Birla Institute of Technology & Science (BITS) Pilani. Earlier he was associated with Industrial Statistics Lab., Department of Information & Industrial Engineering Yonsei University as Post Doctoral Fellow and Department of Operational Research, University of Delhi as Assistant Professor (Ad-hoc). He received his Ph.D. degree in Marketing Models and Optimization (Operational Research) from University of Delhi, Delhi. He has published numerous papers in the area of Marketing Models, Optimization, Software Reliability and Inventory Management in international journals and conference proceedings. His current research interests include Marketing Models, Inventory Modeling, Software Reliability Growth Modeling, and Dynamic Optimization Techniques.

Himanshu Seth (PhD) is Assistant Professor at Woxsen University, Hyderabad. His area of research is related to working capital management and trade credit analysis.

Namita Ruparel (PhD) is Assistant Professor at Woxsen University in India. She has published 10 peer-reviewed research articles, 2 book chapters and presented her work at 11 national and international conferences. She has earned her Ph.D. from BITS Pilani and M. Sc. in Applied Psychology and Bachelor of Arts in Psychology from St. Francis College.