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Inventory and credit decisions for time-varying deteriorating items with up-stream and down-stream trade credit financing by discounted cash flow analysis

Sheng-Chih Chen[a,b], Jinn-Tsair Teng[c,*]

[a] Master's Program of Digital Content and Technologies, College of Communication, National ChengChi University, Taipei 11605, Taiwan, ROC
[b] Graduate Institute of Development Studies, National ChengChi University, Taipei 11605, Taiwan, ROC
[c] Department of Marketing and Management Sciences, The William Paterson University of New Jersey, Wayne, NJ 07470-2103, USA

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ABSTRACT

In today's competitive markets, most firms in United Kingdom and United States offer their products on trade credit to stimulate sales and reduce inventory. Trade credit is calculated based on time value of money on the purchase cost (i.e., discounted cash flow analysis). Recently, many researchers use discounted cash flow analysis only on the purchase cost but not on the revenue (which is significantly larger than the purchase cost) and the other costs. For a sound and rigorous analysis, we should use discounted cash flow analysis on revenue and costs. In addition, expiration date for a deteriorating item (e.g., bread, milk, and meat) is an important factor in consumer's purchase decision. However, little attention has been paid to the effect of expiration date. Hence, in this paper, we establish a supplier–retailer–customer supply chain model in which: (a) the retailer receives an up-stream trade credit from the supplier while grants a down-stream trade credit to customers, (b) the deterioration rate is non-decreasing over time and near 100 percent particularly close to its expiration date, and (c) discounted cash flow analysis is adopted for calculating all relevant factors: revenue and costs. The proposed model is an extension of more than 20 previous papers. We then demonstrate that the retailer's optimal credit period and cycle time not only exist but also are unique. Thus, the search of the optimal solution reduces to a local one. Finally, we run several numerical examples to illustrate the problem and gain managerial insights.

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1. Introduction

In today's competitive markets, most companies grant buyers varied credit terms to stimulate sales and reduce inventory. "Estimates suggest that more than 80 percent of business-to-business transactions in the United Kingdom are made on credit, while about 80 percent of United States firms offer their products on trade credit" as shown in Tirole (2006). The presence of trade credit reduces the buyer's inventory holding cost, and hence affects the buyer's economic order quantity (EOQ). Goyal (1985) established the retailer's optimal EOQ when the supplier offers a permissible delay in payments. Later, Aggarwal and Jaggi (1995) generalized the EOQ model from non-deteriorating items to deteriorating items. Jamal, Sarker, and Wang (1997) further extended the EOQ model to allow for shortages. Thereafter, Teng (2002) amended the model by using selling price to calculate the revenue instead of unit cost, and obtained an easy analytical closed-form solution. Afterwards, Huang (2003) extended the trade credit problem to both up-stream and down-stream trade credit financing. Then Liao (2008) further generalized Huang's model to an economic production quantity (EPQ) model for deteriorating items. Subsequently, Teng (2009) established optimal ordering policies for a retailer to deal with bad credit customers as well as good credit customers. After, Teng, Krommyda, Skouri, and Lou (2011) obtained the optimal ordering policy for stock-dependent demand under progressive payment scheme. Further, Teng, Min, and Pan (2012) extended the demand from constant to non-decreasing pattern. Ouyang and Chang (2013) then built up an EPQ model with imperfect production process and complete backlogging. Lately, Ouyang, Yang, Chan, and Cárdenas-Barrón (2013) considered two-level trade credit link to order quantity. Recently, Chen, Cárdenas-Barrón, and Teng (2014a, 2014c), discussed the retailer's optimal EOQ/EPQ when the up-stream trade credit is link to order quantity or when the down-stream trade credit is only a fraction of the purchase amount. Currently, Sarkar, Gupta, Chaudhuri, and Goyal (2014) established an integrated inventory model with lead time, defective units, and delay in payments. Likewise, Liao, Huang, and Ting (2014) derived optimal

* Corresponding author. Tel.: +1 973 7202651; fax: +1 973 7202809.
E-mail address: tengj@wpunj.edu, tengjt@gmail.com (J.-T. Teng).

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strategy for deteriorating items with capacity constraints under two-level trade credit. In all articles described above, the EOQ/EPQ models with trade credit financing were studied only from the perspective of the buyer. From the seller's perspective to determine the optimal credit period has been received relatively little attention until now. Teng and Lou (2012) first established the seller's optimal credit period and cycle time in a supply chain with up-stream and down-stream trade credits. Currently, Chern, Pan, Teng, Chan, and Chen (2013, 2014) discussed Stackelberg and Nash solutions in a vendor–buyer supply chain model with trade credit financing. Lately, Seifert, Seifert, and Protopappa-Sieke (2013) organized a review of trade credit literature and provided a detailed agenda for future research.

Many products such as vegetables, fruits, volatile liquids, blood banks, fashion merchandises and high-tech products deteriorate continuously due to evaporation, spoilage, obsolescence, etc. In the literature, Ghare and Schrader (1963) built an EOQ model with an exponentially decaying inventory. A decade later, Covert and Philip (1973) extended the constant exponential deterioration rate to a two-parameter Weibull distribution. Later, Dave and Patel (1981) studied an EOQ model for deteriorating items with linearly increasing demand. Sachan (1984) further generalized the EOQ model to allow for shortages. Thereafter, Hariga (1996) established EOQ models for deteriorating items with log-concave time-varying demand. Teng, Chern, Yang, and Wang (1999) then generalized EOQ models with shortages and fluctuating demand. Teng, Chang, Dye, and Hung (2002) further extended the model to allow for partial backlogging. Skouri, Konstantaras, Papachristos, and Ganas (2009) established inventory EOQ models with ramp-type demand rate and Weibull deterioration rate. In a subsequent paper, Skouri, Konstantaras, Papachristos, Teng (2011) further generalized the model for deteriorating items with ramp-type demand and permissible delay in payments. Recently, Dye (2013) studied the effect of technology investment on deteriorating items. Although deteriorating items cannot be sold after expiration dates, none of the above mentioned papers took the expiration date into consideration until recently such as in Chen and Teng (2014), Sarkar (2012), Wang, Teng, and Lou (2014), and Wu, Ouyang, Cárdenas-Barrón, Goyal (2014).

The trade credit, either the cost to the seller or the benefit to the buyer, is calculated based on time value of money on the purchase cost (i.e., discounted cash flow analysis or net present value method). Recently, many researchers use discounted cash flow analysis only on the purchase cost while not on the revenue which is significantly larger than the purchase cost. For a sound and rigorous analysis, one should use a discounted cash flow analysis on all relevant revenue and costs. Consequently, in this paper, we propose an EOQ model in a supplier–retailer–customer supply chain in which: (a) the supplier offers the retailer an up-stream trade credit of S years meanwhile the retailer grants a down-stream trade credit of R years to the customer, (b) trade credit not only increases sales and revenue but also opportunity cost and default risk, (c) deteriorating rate is closed to 100 percent especially near to its expiration date, and (d) the retailer determines both credit period and cycle time to maximize his/her present value of the annual total profit. In fact, the proposed inventory model forms a general framework that includes numerous previous models as special cases such as Goyal (1985), Teng (2002), Huang (2003), Teng and Goyal (2007), Teng and Lou (2012), Lou and Wang (2013), Wang et al. (2014), Wu et al. (2014), and others. We then discuss the retailer's objective functions under different possible alternatives. By applying existing theorems in concave functions, we prove that there exists a unique global optimal solution to the retailer's credit period and replenishment time. Finally, we run several numerical examples to illustrate the problem and provide some managerial insights.

The rest of the paper is designed as follows. To establish a general framework, we assume in Section 2 that (i) the deterioration rate is non-decreasing with time and close to 100 percent near its expiration date, and (ii) both the demand and the default risk are log-concave with credit period. Then we derive mathematical expressions of the retailer's present value of the annual total profit function under each alternative case in Section 3. In Section 4, we demonstrate that both the optimal credit period and cycle time exist uniquely which simplifies the search for the optimal solution to a local one. In Section 5, we show that several previous inventory models are special cases of our proposed model including those non-deteriorating items. Numerical examples are presented to illustrate the model and obtain managerial insights in Section 6. Finally, in Section 7, we provide the conclusions and the future research.

2. Notation and assumptions

The following notation and assumptions are used in the entire paper.

2.1. Notation

For simplicity, we define the symbols for parameters, decision variables, functions, and optimal values accordingly.

Parameters

c	purchasing cost per unit in dollars.
h	holding cost per unit per year in dollars excluding interest charge.
m	expiration time in years, which starts at the order received and ends at product expiration date.
o	ordering cost per order in dollars.
p	selling price per unit in dollars.
r	annual compound interest paid per dollar per year.
S	up-stream credit period in years by the supplier.
t	time in years.
I_c	interest charged per dollar per year.
I_e	interest earned per dollar per year.

Decision variables

R	down-stream credit period in years by the retailer.
T	replenishment cycle time in years.

Functions

$\theta(t)$	deterioration rate at time t, which is a non-decreasing function in t.
$D(R)$	demand rate, which is increasing in R.
$I(t)$	inventory level at time t.
$PTP(R, T)$	present value of annual total profit, which is a function of R and T.

Optimal values

R^*	optimal down-stream credit period in years.
T^*	optimal replenishment cycle time in years.
PTP^*	optimal present value of annual total profit in dollars.

We then propose some necessary assumptions to build up the mathematical model.

2.2. Assumptions

1. In a supplier–retailer–customer supply chain system, the retailer buys deteriorating items from his/her supplier, and then sells them to his/her customers. Since near 80 percent of UK and US companies offer their products on trade credit, we may assume without loss of generality (WLOG) that the supplier grants an up-stream credit period of S years to the retailer while the retailer in turn provides a down-stream credit period of R years to his/her customers.
2. Trade credit attracts new buyers who consider it a type of price reduction. Hence, we may assume that the demand rate $D(R)$ given

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