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Sustainable trade credit and replenishment decisions with credit-linked demand under carbon emission constraints

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ABSTRACT

In this paper, we consider issues of sustainability in the context of joint trade credit and inventory management in which the demand depends on the length of the credit period offered by the retailer to its customers. We quantify the impacts of the credit period and environmental regulations on the inventory model. Starting with some mild assumptions, we first analyze the model with generalized demand and default risk rates under the Carbon Cap-and-Trade policy, and then we make some extensions to the model with the Carbon Offset policy. We further analytically examine the effects of carbon emission parameters on the retailer's trade credit and replenishment strategies. Finally, a couple of numerical examples and sensitivity analysis are given to illustrate the features of the proposed model, which is followed by concluding remarks.

1. Introduction

Trade credit is a common phenomenon in the current business environment. In today's competitive business environment, many businesses have no pricing power. To avoid lasting price competition, businesses use credit as part of the pricing strategy and provide credit terms to their customers to gain a competitive edge. We can observe that businesses often provide credit terms to allow their customers to make purchases today and pay for them at a later date without any additional charges. Since trade credit can reduce the customer's inventory holding cost, lengthening the credit period may create reputation among potential customers and consequently gain increased market share. In recent years, a large amount of attention has been devoted to the models for inventory replenishment policies involving trade credit policy. The analysis of the effect of trade credit policy on the economic order quantity (EOQ) model began with Goyal (1985), who studied an EOQ model under the condition of permissible delay in payments. Since the deterioration of inventory items is a common phenomenon in daily life because of poor storage and preservation quality, Aggarwal and Jaggi (1995) and Hwang and Shinn (1997) extended the model of Goyal (1985) to consider the deterministic inventory model with a constant deterioration rate. Later on, Jamal, Sarker, and Wang (1997) extended Aggarwal and Jaggi's model (1995) to allow for shortages. Since Jamal et al. (1997) did not provide a procedure to find the global minimum, Hsieh, Dye, and Ouyang (2008) complemented the shortcomings of Jamal et al. (1997) and showed that the optimal solution for each case not only exists but is unique under specific circumstances. Chang and Dye (2001) then extended this issue to the inventory model with time-varying deterioration rate and time-dependent partial backlogging. In addition, Teng (2002) amended Goyal's (1985) model by considering the difference between unit price and unit cost, and found that it makes economic sense for the retailer to order less quantity to take advantage of the payment delay more frequently. Huang (2003) developed an EOQ model in which a supplier offers a retailer the permissible delay period M, and the retailer in turn provides the trade credit period N (with $N \leq M$) to its customers. Chang, Ouyang, and Teng (2003) presented an inventory model for the items with constant demand and deterioration rates under supplier credits linked to ordering quantity. Chang and Dye (2005) investigated the effects of time-varying demand and deterioration rates in the inventory model when the credit period depends on the retailer's ordering quantity. Recently, to accommodate more practical features of the real inventory systems, there are also many research efforts that consider trade credit in deteriorating inventory models. Sana and Chaudhuri (2008), Tsao and Sheen (2008), Tsao (2010), Geetha and Uthayakumar (2010), Ho (2011), Sarkar (2012), Chen, Teng, and Skouri (2013), Lou and Wang (2013), Tsao (2013), Chern, Chan, Teng, and Goyal (2014), and Chen and Teng (2014) are such studies.

However, the above-mentioned papers mainly take the buyer's perspective of finding the optimal ordering policies under a given credit period, but little is known about how to determine the optimal length of the credit period for the retailer. For agreement with the practical inventory situation, Jaggi, Goyal, and Goel (2008)

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established an inventory model to analyze the impact of credit-linked demand on retailer's replenishment behavior. Although sales can be stimulated by trade credit, longer credit period ties up the business capital in receivables, and this affects cash flow directly and increases the probability of a customer default. Therefore, trade credit management needs to balance the trade-off between increased sales and default risk of granting credit. Recently, Teng and Lou (2012) incorporated the credit-linked demand and default risk to establish an EOQ model for the retailer in a supply chain with up-stream and down-stream trade credits. Meanwhile, Lou and Wang (2012) extended the classical EOQ model by introducing the credit-linked demand and default risks. Based on the results of Teng and Lou (2012) and Lou and Wang (2012), numerous research works, such as Wu and Chan (2014), Wang, Teng, and Lou (2014), Wu, Ouyang, Cárdenas-Barrón, and Goyal (2014) and Teng, Lou, and Wang (2013), constructed and analyzed inventory models for deteriorating items with expiration dates under different environmental scenarios and focused on how to determine the optimal credit period for the retailer. Chern, Pan, Teng, Chan, and Chen (2013) and Chern et al. (2014) discussed the vendor–buyer inventory-production models with trade credit risk in a supply chain. However, the rates of demand and default risk in the above-mentioned studies are all assumed to be specific functions of the credit period.

In recent years, the greenhouse effect and global warming have gained much attention due to stronger and more frequent extreme weather events. To slow down the greenhouse effect and global warming, the so-called Kyoto Protocol was signed in 1997 as a result of the United Nations Framework Convention on Climate Change (UNFCCC). The purpose of the Kyoto Protocol was to reduce greenhouse gas emissions from industrial countries to 5.2 percent below levels in 1990 between 2008 and 2012. The protocol also introduced three flexible mechanisms—International Emissions Trading, Joint Implementation, and the Clean Development Mechanism. One of the most effective market-based mechanisms in Kyoto Protocol is Emissions Trading (also known as Cap-and-Trade) which has been broadly adopted by the United Nations system. This mechanism puts a mandatory limit on emissions to all the firms, and allows firms to buy or sell rights to emit carbon dioxide within the cap. To meet targets for the carbon emissions reduction set by the Kyoto Protocol, many countries or regions have made either voluntary or regulatory efforts to reduce their carbon emissions, e.g. the World Bank's BioCarbon Fund, the EU Emissions Trading System, the US Chicago Climate Exchange and the Midwestern Regional Greenhouse Gas Reduction Accord etc. Since carbon is the basic element in fossil energy, cutting carbon equals to cost savings and operational efficiency. Recently, the impact of carbon emissions on operations management has drawn more academic attention. Benjaafar, Li, and Daskin (2010) first presented a series of model formulations that illustrate how carbon emission considerations can be incorporated into operational decision-making with regard to procurement, production and inventory managements. Bonney and Jaber (2011) examined some possible environmental consequences of common inventory activities and suggested that all functions within the product life cycle should be looked at from an environmental point of view. They also provided a simplified inventory model with some environmental costs to illustrate how the business could determine inventory parameters in an environmental context. Arslan and Turkay (2010), Hua, Cheng, and Wang (2011), Bouchery, Ghaffari, Jemai, and Dallery (2012) and Chen, Benjaafar, and Elomri (2013) considered single product replenishment problems with carbon emission considerations and analytically examined the impacts of carbon regulatory mechanisms on ordering decisions. Meanwhile, Song and Leng (2012) investigated the classical newsvendor problem under various carbon emissions policies. Hua, Qiao, and Jian (2011) extended the same issue to the price-sensitive demand under the Carbon Cap-and-Trade policy. Since transportation is a main source of carbon emission, Absi, Dauzère-Pérès, Kedad-Sidhoum, Penz, and Rapine (2013) analyzed multi-sourcing lot-sizing problem with various carbon emission constraints: Periodic, Cumulative, Rolling and Global carbon emission constraints. They also showed that the first case is solvable in polynomial time, while the three others are NP-hard. Zhang and Xu (2013) extended the multi-item newsvendor problem to the multi-item production-planning problem with finite capacity under the Carbon Cap-and-Trade policy. Bozorgi, Pazour, and Nazzal (2014) examined an inventory model for cold items in which the emission and costs associated with transportation are represented in the non-linear objective function. They also analyzed the trade-off between the cost function and emission function, and observed that the emission function is more sensitive to deviation from optimality than the cost function. For a detailed survey on the literature of inventory models considering carbon emissions, we refer the readers to Benjaafar et al. (2010) and the references therein for more details on the subject. However, the above mentioned papers do not take into account the effect of the deterioration on the inventory model, which plays an important role in settling a replenishment strategy.

Customers prefer longer credit periods as lengthening payment period will stimulate sales growth. However, this ties up with retailer's capital and will increase the risk of default. Furthermore, a higher demand leads to greater carbon emissions. Sustainable development is the main policy of economic development nowadays. In order to achieve the sustainable development, many countries are implementing environmental regulations to restrict the carbon emissions for public or private sectors. Since the environmental regulations will impact business decisions at any time, the joint trade credit and inventory replenishment strategies for a deteriorating product need to take into account the effect of environmental issues. The inventory system for deteriorating items with trade credit policy has been an object of study for a long time, but little is known about the effects of trade credit risk and environmental issues. In this paper, to obtain robust and general results, we extend previous knowledge of inventory control and trade credit policy by incorporating environmental considerations and exploring the impacts on the retailer's inventory replenishment and trade credit strategies. The objective of this study is to determine the following joint decisions: (1) how long the credit period should be made and (2) inventory replenishment policy. We contribute to two streams of literature: (1) the inventory model with credit risk, and (2) the inventory model subject to environmental considerations. While the first stream of literature always assumes the demand and default risk rates to be specific functions of credit period, the second stream of literature typically ignores the deterioration of product.

The remainder of this paper is organized as follows. In Section 2, we first present the deteriorating inventory model with trade credit policy under the Carbon Cap-and-Trade policy with generalized demand and default risk rates, and then rigorously analyze the effects of carbon emission parameters on the retailer's inventory replenishment and trade credit strategies. Using the obtained theoretical results, we make further extensions to the deteriorating inventory model under the Carbon Offset policy. In Section 3, a couple of numerical examples and sensitivity analysis are given to illustrate the features of the proposed model. Finally, the conclusions and suggestions for future research are given in Section 4. All the proofs are delegated to Appendix A.

2. The model

This paper studies the following optimal inventory replenishment model under various carbon emissions policies. A single product is considered sold and backorders are allowed. In addition, the goods under consideration are perishable. Let the inventory cycle represent the time interval between two consecutive orders, we assume that the demand in each inventory cycle is known with certainty and