Int. J. Production Economics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Joint pricing and inventory control for fresh produce and foods with quality and physical quantity deteriorating simultaneously

Yiyan Qin [a,*], Jianjun Wang [b], Caimin Wei [c]

[a] College of Business, Guangxi University for Nationalities, Nanning 530006, PR China
[b] Faculty of Management and Economics, Dalian University of Technology, Dalian 116023, PR China
[c] Department of Mathematics, Shantou University, Shantou 515063, PR China

ARTICLE INFO

Article history:
Received 13 November 2012
Accepted 4 January 2014

Keywords:
Quality and physical quantity deterioration
Inventory
Pricing
Time varying deterioration

ABSTRACT

A great number of models have been proposed to investigate the deterioration inventory. However, most of models assume that a fixed physical quantity of items deteriorates over time, the quality of items does not decay before their expiration dates. In practice, the quality and physical quantity of many products, including fresh produce and foods, often deteriorate over time. The quality of an item usually plays an important role in influencing the demand for products. In this paper, we consider the pricing and lot-sizing problem for products with quality and physical quantity deteriorating simultaneously. The deterioration rate of quality and physical quantity is taken to be time proportional. The demand rate is assumed to be deterministic and dependent on the quality of an item, the selling price per unit and the on-display stock level. The theory for finding the optimal solution of problem is discussed and numerical examples are used to illustrate the model and the solution procedure. Finally, sensitivity analysis of the optimal solution with respect to price sensitive parameter and values of different deterioration functions is carried out.

1. Introduction

Due to advance in postharvest science and technological innovation in produce handling, agricultural produce grown in diverse climates that are continents apart can be purchased in top quality condition elsewhere in the world, and with the rising influence of multinational firms in the globalization of fresh produce supply chain, and increasing epidemiological evidence which positively link high consumption of fruits and vegetables with a reduced incidence of cardiovascular and other chronic diseases. The market for fresh produce has continued to expand during the past decade (Florkowski et al., 2009). On the other hand, fresh produce can easily spoil or deteriorate, which often results in product loss. Kantor et al. (1997) estimated the U.S. total retail, foodservice, and consumer food losses in 1995 to be 23% of fruits and 25% of vegetables. Fresh fruits and vegetables accounted for nearly 20% of consumer and foodservice losses. In the European grocery sector, products that are not purchased before their sell-by-date are estimated to cause costs running into billions of dollars each year (Karkkainen, 2003). Thus, how to design an inventory system for fresh produce and foods to decrease cost and meet customer requirements is a current managerial concern as well as an important research issue.

Fresh produce is a living entity. Even after harvest, fresh produce continues its metabolic activity and undergoes further biochemical and physiological changes. These changes are influenced by biological factors (respiration rate, ethylene production and action, rates of compositional changes, mechanical injuries, physiological disorders, and pathological breakdown) and environmental factors (temperature, relative humidity, air velocity, atmospheric composition, and sanitation procedures). The rate of biological deterioration depends on environmental factors. For example, transpiration or water loss is a main cause of deterioration because it results not only in direct quantitative losses (loss of salable weight), but also in losses in appearance (wilting and shriveling), textural quality (softening flaccidity limpness, loss of crispness and juiciness), and nutritional quality. Although all five environmental factors are important, temperature has the most profound affect on the deterioration rate of fresh produce placed in storage. For each increase of 10 °*C* (18 °*F*) above optimum, the rate of deterioration increases by two to threefold.

The biochemical and physiological changes lead to the qualitative and quantitative deterioration in fresh produce. Quality is defined by the International Organization for standardization (ISO) as the totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs. This means quality is a term defined by the consumer, buyer, grader, or any other client based on a number of subjective and objective measurements of the food product. These may include measures of sensory,

* Corresponding author. Tel.: +86 771 3261390.
E-mail address: qinyiyan2002@sina.com.cn (Y. Qin).

0925-5273/$ - see front matter © 2014 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.ijpe.2014.01.005

nutrition, safety, wholesomeness, or any other attribute or characteristic of the product. In some cases, quality degradation leads to a discarded product whereas in others it reduces consumer acceptability. In order to improve quality management in fresh produce, it is necessary to develop mathematical models to predict the quality deterioration of fresh produce. Most approaches used in quality prediction models are based on the fact that there is usually the most rapidly changing criterion for a given product (Achour, 2006).

Traditionally, the most common method for food quality prediction during their thermal processing and storage is the kinetic model which has been described in terms of zero; first; or higher order kinetics (Labuza, 1985). However, the theory has been frequently challenged in the last years. The most studied alternative model is the Weill-Log logistic (Well) model, which is built on the notion that degradation or inactivation curve is the cumulative form of the temporal distribution of events that resulted in destruction of the affected molecules, requiring no specific mechanism (Corrdini and Peleg, 2004a). The Weill-Log logistic model has been demonstrated to be applicable of describing microbial growth, microbial inactivation, nutrients, pigments and enzymes degradation under nonisothermal conditions (Corradini and Peleg, 2006; Yu et al., 2011; Derossi et al., 2010; etc). The Weill-logistic model assumes that the instantaneous deterioration rate function is a two-parameter Weibull distribution.

$$\chi(t) = \alpha\beta t^{\beta-1}$$

where α and β are temperature-dependent coefficients. $\alpha > 0$, $\beta > 0$, t is the time of deterioration.

Recent developments of tracking and monitoring technologies such as Radio Frequency Identification Devices (FRID) and Time Temperature Indicator (TTI) provide great opportunities for effective management of fresh produce. While these technologies are more widely adopted, it enables to automatically capture product information regarding product identity and related data (e.g. temperature, humidity, and the time period during which products have been exposed to the temperature in the supply chain process) in real time. Such transparency generates the possibility that, as products pass through a supply chain, the shelf life can be dynamically predicted based on the environmental conditions during storage and transportation as well as the varied time required for these operations. In this paper, we formulate a fresh produce and foods inventory model to decide the pricing and lot-sizing policy assuming that the quality and physical quantity deteriorate simultaneously over time.

2. Literature review

Perishable inventory has been intensively studied and a large number of models have been proposed in the literature for the various situations that exist. A model with exponentially decaying inventory was initially proposed by Ghare and Shrader (1963). Covert and Philip (1973) formulated model with variable deteriorating rate of two-parameter Weibull distribution. Further, Philip (1974) generalized this model by taking three-parameter Weibull distribution. After that many researchers such as Goyal (1987), Raafat et al. (1991), Wee (1993), and others developed models on deteriorating items. A detailed review of deteriorating inventory literature was given by Goyal and Giri (2001).

In many real-life situations, for certain types of consumer goods (e.g., fruits, vegetables, and donuts), it is usually observed that a large pile of goods on shelf in a supermarket will lead the customer to buy more and then generate higher demand. The consumption rate may go up or down with the on-hand stock level. Mandal and Phaujdar (1989) developed an economic production quantity model for deteriorating items with constant production rate and linearly stock-dependent demand. Urban and Baker (1997) generalized the economic order quantity model (or *EQQ*) in which the demand is a multivariate function of price, time, and level inventory. Recently, Datta and Paul (2001) analyzed a multi-period *EQQ* model with stock-dependent and price-sensitive demand rate. Yang et al. (2010) formulated an inventory lot-size model under inflation for deteriorating items with stock-dependent consumption rate when shortages are partial backlogging. Other papers related to this area are Teng and Chang (2005), Ray and Chaudhuri (1997), and others.

Customers are usually sensitive to quality changes of fresh produce and foods. Considering supermarket customers, they will prefer to buy newly replenished goods instead of expiring ones. When price is the same, they will prefer the newer ones. Hardie et al. (1993) developed the notion of reference quality and empirically demonstrated that differences between observed and reference quality can significantly affect purchase probabilities. Bai and Kendall (2008) formulated an inventory model for fresh produce, where demand rate is assumed to be dependent on the displayed inventory and the freshness of an item, but the deterioration of freshness is not connected with the deterioration characteristics of fresh produce. Wang and Li (2012) presented a dynamic pricing model to evaluate the quality of perishable foods.

Price is one of the key factors which influence the demand of any type of product. Recently, significant researches combine pricing and inventory control for perishable products. Wee (1997) developed a replenishment policy for deteriorating items with price dependent demand and Weibull distribution deterioration. Abad (2003) studied the optimal pricing and lot-sizing policies under conditions of perishability and partial backordering. Mukhopadyay et al. (2004) discussed pricing and lot-sizing problem for a product with a time proportional and two-parameter Weibull distribution deterioration rate respectively. There are several interesting papers on joint pricing and replenishment policy for a deteriorating item such as Chang et al. (2006), Dye (2007), Hsieh and Dye (2010), Sana (2010), Sana (2011) and so forth. Wu et al. (2006) advocated the phenomenon that the deterioration of items does not occur for particular period of time and analyzed inventory model for non-instantaneous deteriorating items and price-sensitive demand. Papers related to this area are Maihami and Kamalabadi (2012), Ouyang et al. (2006), Geetha and Uthayakumar (2010), Shah et al. (2013), etc.

In all above cited papers, the amount of inventory of items is only measured by physical quantity or by quality solely. However, it is not appropriate for fresh produce and foods, because its quality and physical quantity usually decay simultaneously during storage or on shelf life. Furthermore, the demand for fresh produce is affected not only by its inventory level (physical quantity) but also by its quality. Therefore, the proposed study considers the inventory model for fresh produce and foods to allow for: (1) the quality and physical quantity of products deteriorate simultaneously, (2) the deterioration rate of quality and physical quantity is taken to be time proportional, and (3) the demand rate is the function of selling price, quality and physical quantity of the products. Such considerations make the study advantageous and provide a general framework that includes numerous previous studies such as in Wee (1997) and Mukhopadyay et al. (2004) as special cases. To foster additional managerial insights, we perform sensitivity analyses and illustrate our results with a simulation study.

The rest of the paper is organized as follows: In Section 3, the assumption and notations which are used throughout the article are presented. Mathematical model to maximize the total profit is formulated in Section 4. Solution methodology comprising some