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Effectiveness of the food recovery at the retailing stage under shelf life uncertainty: An application to Italian food chains

Cinzia Muriana *

Corso Calatafimi, 429, 90129 Palermo, Italy

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ABSTRACT

Food losses represent a significant issue affecting food supply chains. The possibility of recovering such products can be seen as an effective way to reduce such a phenomenon, improve supply chain performances and ameliorate the conditions of undernourished people.

The topic has been already investigated by a previous paper enforcing the hypothesis of deterministic and constant Shelf Life (SL) of products. However, such a model cannot be properly extended to products affected by uncertainties of the SL as it does not take into account the deterioration costs and loss of profits due to the overcoming of the SL within the cycle time. Thus the present paper presents an extension of the previous one under stochastic conditions of the food quality. Differently from the previous publication, this work represents a general model applicable to all supply chains, especially to those managing fresh products characterized by uncertain SL such as fruits and vegetables. The deterioration costs and loss of profits are included in the model and the optimal time at which to withdraw the products from the shelves as well as the quantities to be shipped at each alternative destination have been determined. A comparison of the proposed model with that reported in the previous publication has been carried out in order to underline the impact of the SL variability on the optimality conditions. The results show that the food recovery strategy in the presence of uncertainty of the food quality is rewarding, even if the optimal profit is lower than that of the deterministic case.

1. Introduction

The food supply chain is affected by losses of products close to their expiration date or damaged by improper transportation or manufacturing defects. Such products are usually poorly attractive for the consumer of the target market for different reasons, such as visual or quality defects, consumer behaviour changes, and the reaching of the end of Shelf Life (SL). However, they still maintain their nutritional properties (European Commission, 2010), making conceivable the recovery for human consumption or the recycling for animal feeding. On the other hand undernourished people are constantly dealing with their nutritional needs usually relying on non-profit organizations. Thus, if properly recovered, the food losses could ameliorate the diet of undernourished people of the local country sustained by non-profit organizations and improve the supply chain efficiency. In this field the food recovery, enabling economic benefits for donors, is nowadays seen as a coherent way to manage the food not further saleable in the target market and destined to be disposed of in landfill, where it represents only a cost. For reference about the deductions recognized to donors see for example Bill Emerson Good Samaritan food donation act P. L. 104-210 of 1996 and tax Reform Act of 1976 for the USA, the Wrongs & Other Acts (Public Liability Insurance Reform) Act 2002 for Australia, the Law 80 of 14/05/2005 and the Legislative Decree 460/97 for Italy.

However the food recovery is not always extensively practiced due to the risk of the firm's reputation damaging in the case of the improper handling of the food (see Garrone et al., 2012).

In such context the paper builds on a previous publication (see Aiello et al., 2014) addressing the economic affordability of food recovery along the supply chain. In that paper a deterministic mathematic model for the optimization of the supply chain composed of retailers and potential recipients practicing the food recovery has been presented, taking into account the benefits recognized to donors and the management costs of the food recovery. In that case the hypothesis of constant and deterministic SL has been enforced. The model determined the optimal time at which to withdraw the products from the shelves as well as the quantities which are to be donated to non-profit organizations and those to be sent to the livestock market maximizing the retailer profit. The main results showed that the food recovery strategy

* Tel.: +39 091424094, cell: +39 3290128446.
E-mail address: cinzia.muriana@unipa.it

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allows optimizing the retailer profit thanks to tax relief recognized to donors and cost savings for the early withdrawal of products from the shelves.

However, the model previously discussed can be suitably applied only to canned products whose SL can be considered deterministic and constant (namely open dating products). Such a hypothesis is not further valid for products which do not report the "sell by date" or "use by date". The products whose lifetime cannot be determined in advance while in stock are known as random lifetime products. A typical example is fresh produce, such as fruits, vegetables, meat and poultry whose time of spoilage is uncertain and as a result the lifetime is assumed to be a random variable (Goyal and Giri, 2001). The SL of such products can be rather considered dependent on the producing (e.g., harvesting, for fruits and vegetables) and storage conditions. Moreover, even the deterioration process plays a fundamental role, ceteris paribus, determining the decreasing of the product quality during the postharvest phases. Such a condition has been extensively investigated by several authors attempting at determining the Economic Order Quantity (EOQ) minimizing the total cost considering the deterioration cost and the salvage value of partially deteriorated products remaining on hand at the end of the cycle time (for reference about the perishable inventory theory see Nahmias, 1982; Raafat, 1991; Bakker et al., 2012).

SL assessment and monitoring field have attracted noticeable interest since the early 1990s. The main focus has been on the application of the well known Arrhenius law by means of mathematic models aiming at determining the remaining quality of products at certain stages of the supply chain given their time–temperature history (see for example Giannakourou and Taoukis, 2003). Afterwards SL picking rules such as the First Expiry First Out (FEFO) have been studied (see for example Taoukis et al., 1998) and some applications of such policies for the warehouse management systems have been proposed, with the aim of optimizing the mean quality of products managed (see for example Aiello et al., 2011).

On the other hand, the food recovery is a topic of recent interest; for reference about causes, destinations and management policies of the food losses see Aiello et al. (2014), Garrone et al., 2014, Papargyropoulou et al., 2014.

In this field the impact of the uncertainty of the SL on the profit optimization for supply chains practicing the food recovery towards non-profit organizations does not result investigated until now. In the case of stochastic SL the main issue that is to be considered is the possibility that the products stocked overcome the SL within the cycle time. This implies the presence of deteriorated units on hand, leading to loss of profits and disposal and deterioration costs. In such case the hypothesis of deterministic and constant SL enforced in Aiello et al. (2014), can result of hard applicability, as it does not include the impact of the deterioration process in terms of deterioration and disposal costs and loss of profits. In Aiello et al. (2014), it has been taken into account only the loss of profit due to the early withdrawal of products for the purpose of the recovery. To overcome this gap the paper reviews the model presented in Aiello et al. (2014) by relaxing the assumption of constant and deterministic SL and proposing a more general stochastic model. The aim is to present a model which can be easily applied not only to supply chains managing canned products but also to those managing fresh products. In this context the introduction of the uncertainty of the SL allows to extend the previous model which can be considered in all respects a specific case of the present one. The present work aims at determining the optimal time at which to withdraw the products from the shelves allowing optimizing the total profit. A comparison with the deterministic model proposed in Aiello et al. (2014) is then proposed to highlight the implications of the present model on the variables under study. In order to verify the impact of the stochastic SL on the optimality conditions, a simulation model has been specifically designed and the economic profit model has been correspondingly solved. The model refers to fresh products usually managed at the retailing stage, but it can easily be applied to the higher stages of the supply chain by substituting the SL with the internal SL usually defined in contractual agreements between manufacturers and wholesalers. The internal SL represents the time-window available for an actor for the delivery of products allowing to guarantee the residual SL fixed by the buyer (for a definition, see Garrone et al., 2012). The focus is on food losses management at the retailing stage because of their "ready to eat" suitability for the human consumption (Garrone et al., 2011), which makes them simply distributable to non-profit organizations. Moreover the food losses at this stage represent a considerable issue. In fact Rutten et al. (2013) estimated that in the 2006 the per capita food waste/losses at the wholesaler/retail stage in Europe was of 9 kg, corresponding to the 3.6% of the total food produced. Of such quantities the 10% was fruits and vegetables and the 9% was fish and seafood. Buzby and Hyman (2012) reported that in the 2008 the per capita food losses in the USA were of 64 kg, the 16.71% of which was grain products, the 16.09% vegetables and the 21.87% dairy products.

The paper is organized as follows: Section 2 reports the model proposed, Section 3 states with a brief introduction on simulation tools, Section 4 reports the numerical application, Section 5 deals with the sensitivity analysis and finally Section 6 underlines the main conclusions of the work.

2. Supply chain optimization: the proposed model and the case study

2.1. Model formulation

The model addresses a supply chain composed by a retailer, a non-profit organization and a livestock market towards which the food recovery is practiced. The main assumptions of the model are that the SL of products follows a known random distribution and that the retailer does not know the actual value of the SL of products; thus, it will purchase the amount of products sellable within the mean SL taking into account the market demand. This implies that the average quality of products is known and the standard deviation is under control, based on the contractual agreement between wholesaler and retailer. The actual SL value will be known once the products will be received by the retailer, when visual inspections will take place. Similarly, only the visual inspection will drive the consumer's choice, that will be more willing to buy a greater amount of fresher products and less prone with respect to less fresh ones.

This means that the consumers are considered able to discern the quality of products.

The mathematical model proposed determines the optimal time at which to withdraw the products from the shelves and the quantity to be shipped to each alternative destination on the basis of the "Waste Management Hierarchy" (Alexander and Smaje, 2008). The determination of the optimal time is based on the assumption that the residual market demand will not be satisfied. As regards to the benefits the model refers to the Italian governmental regulations. As in the previous model the market demand has been considered deterministic and SL-dependent (see for example Bai and Kendall, 2008; Avinadav and Arponen, 2009; Yan, 2012; Avinadav et al., 2013; Piramuthu and Zhou, 2013). The SL can be defined as the time until a perishable product becomes unacceptable to consumers under given storage conditions (Singh and Cadwallader, 2004). In the present paper, it is assumed that it corresponds to the "use by date" of the product. Consequently the products are