Waste Management xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Economic benefits from food recovery at the retail stage: An application to Italian food chains

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ARTICLE INFO

Article history:
Received 27 September 2013
Accepted 23 February 2014
Available online xxxx

Keywords:
Food losses recovery
Waste management
Supply chain optimization
Food donation

ABSTRACT

The food supply chain is affected by losses of products near to their expiry date or damaged by improper transportation or production defects. Such products are usually poorly attractive for the consumer in the target market even if they maintain their nutritional properties. On the other hand undernourished people face every day the problem of fulfilling their nutritional needs usually relying on non-profit organizations. In this field the food recovery enabling economic benefits for donors is nowadays seen as a coherent way to manage food products unsalable in the target market for various causes and thus destined to be discarded and disposed to landfill thus representing only a cost. Despite its obvious affordability the food recovery is today not always practiced because the economic benefits that could be achieved are barely known. The paper aims at presenting a deterministic mathematical model for the optimization of the supply chain composed by retailers and potential recipients that practice the food recovery, taking into account the benefits recognized to donors and the management costs of the food recovery. The model determines the optimal time to withdraw the products from the shelves as well as the quantities to be donated to the non-profit organizations and those to be sent to the livestock market maximizing the retailer profit. The results show that the optimal conditions ensuring the affordability of the food recovery strategy including the tax reliefs and cost saving for the retailers outperforms the profit achievable in absence of such a system.

1. Introduction and literature review

Recent studies highlight that the food losses represent a significant issue affecting food supply chains. In particular the attention is focused on the economic, social and environmental impact of food losses. This is due to the awareness that a significant part of the food managed along the supply chain is wasted even if it can be still suitable for human consumption. A study conducted by Gustavsson et al. (2011), highlighted that in 2011 the per capita food loss in Europe and North-America was 280–300 kg/year, while in Sub-Saharan Africa and South/Southeast Asia it was 120–170 kg/year. Nellman et al. (2009), reported that a percentage which ranges between the 25% and the 50% of food produced is wasted through the supply chain. Beretta et al. (2013), conducted an analysis for the quantification of food losses in Switzerland by dividing them into avoidable, partially avoidable and unavoidable and calculating the percentage of losses for each type of food. They found that about the 48% of animal and agricultural food produced is lost and in particular the 13% of food loss is avoidable and nearly half of it is in perfect quality, another 13% is potentially avoidable and the 21% is not avoidable.

The need to improve food quality and reduce food waste along the supply chains is hence an emerging challenge for researchers and practitioners, who must develop and implement new concepts for planning and controlling the supply chain. New advanced technologies for food traceability, as well as innovative shelf-life based management policies are an example of the recent efforts aiming at increasing the sustainability of food supply chains.

Food losses are generally not further salable to the consumer in the target market for different reasons such as visual or quality defects, behavior consumer changes, and the reaching of the end of Shelf Life (SL), (see Kantor et al., 1997, Alexander and Smaje, 2008, Prado et al., 2010, Parfitt and Barthel, 2010, Gustavsson et al., 2011, Mena et al., 2011, Garrone et al., 2012, Barilla, 2012). On the other hand if properly recovered, such products could ameliorate the diet of undernourished people of the local country sustained by non-profit organizations. However the food recovery is not always extensively practiced due to the risk that an improper handling of the products donated can affect the firm reputation especially for products that are closer to the expiration date (see

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http://dx.doi.org/10.1016/j.wasman.2014.02.018
0956-053X/

Please cite this article in press as: Giuseppe, A., et al. Economic benefits from food recovery at the retail stage: An application to Italian food chains. Waste Management (2014), http://dx.doi.org/10.1016/j.wasman.2014.02.018

Garrone et al., 2012). In fact the main destination of food losses is today the landfill whereas the supply to livestock market as raw materials for animal feeding production, or for direct animal feeding, or for free donation to non-profit organizations could be a more effective way to manage such products under the economic environmental and social standpoint. In this context the literature does not report attempts of modeling of the economic profitability of food recovery while the importance of such practice is more and more advocated. In this paper, by following the definition done by Griffin et al. (2009), food waste is referred to the products wasted along the supply chain without distinction between edible or not, while other definitions such as the one given by Kantor et al. (1997) and Betts and Burnett (2007), refer to the food still suitable for human consumption but not sold to or consumed by people for which it had been produced. In this sense the food losses result in food which has lost its value in the target market even if it is still suitable for human (European Commission, 2010) or animal consumption. The present study focuses on a better management of food losses produced through their recovery for human consumption or recycling for animal feeding. The recovery relates to the proper withdrawal of food for direct human consumption, while the animal recycling refers to the use of the food recovered for animal feed production. The food losses in the retail sector generally comprise products close to their expiration date (or SL or sell by date), or products affected by visual or quality defects (errors during the manufacturing process, or transport or packaging mistakes), or unsold products resulting from poor forecasting, demand variability, promotions, pricing policies. For such reasons they result not attractive for the consumer in the target market, even if they still comply with safety and nutritional standards. If such food is not properly recovered for human consumption or recycled for animal feeding it represents an inefficiency in the supply chain. Such inefficiencies consist of lost sales, increased production costs, and costs related to the management and disposal of surplus products. As specified by Binyong (2007), one of the most critical aspects of food losses is that their costs are usually underestimated. In such context food losses hinder the minimization of supply chain costs and the achievement of its efficiency (Alexander and Smaje, 2008). Prado et al. (2010), state that a good management of such food represents a "differential to achieve better profit margin".

Besides mere economic implications food losses also have a strong social and environmental impact (Hall et al., 2009). From a social standpoint food losses recovery can support non-profit organizations, which are crucial for undernourished people to get sufficient food. Today an alternative use of such losses is expected to be particularly appreciated, since the economic crisis increased the number of people that cannot afford the cost of a buying sufficient food. The estimates determined by Gabe (2012), for the Congressional Research Service reveal that the poverty rate in the USA reached 15% in 2011 compared to 12.3% in 2006, while the European Commission (2011), reports that in Europe the poverty rate reached the 23% in the 2010.

The problem of food losses is linked to the characteristics of the supply chain: in responsive supply chains more food losses are expected than in efficient ones since generally the improvement of responsiveness leads to an excess of buffer capacity and inventories to face demand variability, while in an efficient supply chain the members manage their activities in order to meet predictable demand at the lowest cost (Minnich and Maier, 2006). On the other hand Mena et al. (2011), underline that even efficient supply chains can be prone to increase the potential of food loss generation, because of strategic decisions encouraging the use of cheaper transportation channels, making the products travel longer distances and requiring more handling when locking for full truckloads thus increasing risk of damage. In such context, the possibilities of an alternative employment of surplus food refer to the redistribution of such products in markets with less stringent standards related to the expiring date where they are sold at discounted prices (Thang, 2009), or in the livestock market where they can be supplied at no cost. Generally speaking the alternative use of surplus food is dependent on the type of the managed product, the stage of the supply chain in which the surplus has been generated, and its quality. For example dry food is more properly salable in the livestock market compared to liquid food while very ripe are suitable for the transformation industries. On the other hand moving from the top stages (Supplier) to the bottom stages (Distribution and Retailing) of the supply chain the quantity and variety of the food surplus switch from high quantity of a scarce variety of products to low quantity of a wide variety. On the basis of the products characteristics, selling to an alternative market can represent only a cost rather than a true source of gain. In fact, as reported by Garrone et al. (2012), usually Italian firms producing animal feeds are willing to pay a discounted price to receive dry food and cereals while they require a fee to accept fish food; however such a fee is less than the disposal cost sustained by the retailer. The effective implementation of food loss reduction strategies and policies therefore strongly depends on the possibility of recognizing a true affordability (Singer, 1979 and Kantor et al., 1997) deriving from the prevention and recovery of food loss. The ability to rely on food donation strongly depends on the possibility to highlight an economical benefit from the donation, originating from the tax relief allowed by the law and the reduction of the management costs. However food donation is a very sensitive operation with both positive and negative consequences. It can contribute to ameliorate the firm's reputation and to increment the consumer fidelity and sales, but it can have a negative impact as it can highlight the difficulty of the firm in selling the products in the target market (Prado et al., 2010).

The food waste and losses recovery problem has attracted the interest of researchers in the last thirty years (see Youngs et al., 1983, Kantor et al., 1997, Hyde et al., 2001, Al Seadi and Holm-Nielsen, 2004, Parfitt et al., 2010, Gustavsson and Stage, 2011, Garrone et al., 2012, Prado et al., 2010, Smil, 2004, Kummu et al., 2012, Kosseva, 2009, Nahman et al., 2012,). Regardless of the noticeable interest arisen about the problem, the effective sustainability of food loss reduction policies strongly depends on the evidence of the economic benefits achievable. However, this topic has barely been discussed in literature.

The present paper aims at overcoming this lack by proposing a mathematical model showing the economic advantage arising from food recovery for the operators of the supply chain and in particular for the retailers who can have additional benefits from tax reliefs. Potential benefits achievable from other parties such as non-profit organizations or livestock market are also taken into account. The model determines the optimal conditions which maximize the profit in case of the recovery and redistribution of the surplus practiced through alternative delivery channels such as the livestock and taking into account the free supply to non-profit organizations. The focus is on food loss management at the retailing stage because most of the food managed at this stage can always be considered "ready to eat" for the human consumption (Garrone et al., 2011) and thus more simply distributable to non-profit organizations. Alexander and Smaje (2008), reported that "retail food waste discarded to landfill only represents about a third of the total food waste generated in the sector", in the UK, "since on-going efficiency measures have sought to maximize the rate of re-use as far as possible", while a study conducted by Jones (2004), reported that 0.76% of the total food products offered by Commercial Food Store in the USA is wasted. The model determines the optimal profit achievable in presence of food losses recovery compared to the profit in absence of such strategy. The model takes into account the economic costs/benefits related to food donation (tax reliefs, the management costs due to operations needed for the selection and temporary storage of surplus food, cost savings consequent to delivering products to alternative channels). The outputs of the model comprise the optimal residual SL at which the products should be withdrawn from the shelves, the optimal quantities to be donated and to be recycled for animal feeding, respectively, in order to maximize the total profit. The remainder of this paper is organized as follows: Section 2 states the causes and destinations of food losses, Section 3 presents the cost/benefit involved in food recovery, Section 4 presents the mathematical model and finally Section 5 reports the conclusions.

2. Food losses in the supply chain: causes and destinations

Food losses affect all the stages of the supply chain (Lundqvist et al., 2008), with different characteristics. First of all losses arising from the first stages of the chain (i.e. production and processing) are characterized by a high quantity of few variety of raw materials or semi processed products; on the contrary those referred to the lower stages, such as the distribution and retailing, are usually composed by low quantity of big variety of products.

The channel usually chosen for the distribution of food losses depends on the stage of the supply chain in which they arise. Mena et al. (2011), that conducted a study at the interface Wholesaler-Retailer in the UK and Spain stated that the main destination of food losses is the landfill, followed by alternative destination as biogas production and composting and the donation to charity organizations and food banks. Garrone et al. (2012), that conducted a study in Italy reveal that the destination of food losses mainly consists in: (a) donation to non-profit organizations and food banks; (b) delivery at processing firms for the production of animal feeds (free or onerous supply), (c) employment as fertilizer in the farms; (d) selling in alternative markets at discounted prices; (e) recycling for animal nutrition (free or onerous supply); and (f) disposal to landfill. They reported that the delivering to non-profit organizations and food banks is a practice more common for Suppliers, Manufacturers and Wholesalers (with 10.9%, 35.3% and 35% of food recovered of their respective total food losses) rather than for the Retailers (with only 4.6% of their total food losses), the delivery at processing firms for the animal feeds and the using as fertilizer in the farms is practiced only by the Suppliers (54.7% of their total food losses), the selling at alternative market at discounted prices is practiced only by the Manufacturers (20% of their total food losses), the use of losses for animal nutrition is put in practice by Suppliers, Manufacturers and Wholesalers (28.5%, 12.5%, 10% of their respective total food losses), and finally the transferring to the landfill results the main destination of food losses for Manufacturers, Wholesalers and Retailers (32.2%, 55% and 95.4% of their respective total food losses).

The studies mentioned confirm that the food recovery is largely practiced by the Manufacturers and Wholesalers, while in the retailing stage is not a common practice. The reason of such phenomenon is generally the achievement of the sell by date of the products left on the shelves in the retailing stage which could make their recovery a critical issue, since products which are closer to their expiration date are more difficult to manage from the logistic standpoint. Such trend seems to be in contrast with the advocated "Waste Management Hierarchy", which states that the retailers should consider the following alternatives for the waste management: "Sell to consumer at reduced price", "Use in staff restaurant", "Sell to staff", "Donate to food charities for human consumption", "Donate to farms, zoo, animal sanctuaries", etc., "Dispose to landfill", as suggested in Alexander and Smaje (2008). Such hierarchy makes the use of surplus food for human consumption the favorite way to recover food followed by animal nutrition. The choice of food losses destinations is driven by mere economic considerations involving the trade-off between the cost saving due to the reduction of the disposal cost and loss profit and costs due to the recovery management for both the supply chain and the potential recipients. Actually our experience underlines that food recovery is generally associated only to organizational costs and long procedures to be put in practice while the economic benefits arising from such practice are neglected and often unknown. Such topic will be of interest of the following Section.

3. Cost/benefit of food losses recovery

Food losses management mainly represents a cost for supply chain members especially with reference to the disposal cost and the loss profit due to the lost sales. Disposal costs have generally a greater impact on the higher stages of the supply chain (Suppliers, Manufacturers and Wholesalers) where they are proportional to the quantity. At the retailing stage the disposal cost is established on the basis of the superficial extension of the retailer and is paid as a fixed cost (Garrone et al., 2012). The loss profit originating from the unsold products is proportional to the quantity of losses as in fact Manufacturers and Wholesalers tend to return unsold products to the higher stage while Retailers are less prone to practice the returns (Garrone et al., 2012). As a consequence lower stages of the supply chain are more affected by the presence of the surplus food. This is due to the characteristics of the products managed which are more recoverable in the higher stages, where the returns are mainly due to the achievement of the internal sell by date, than in the lower stages where the discard of the products is due to the achievement of the sell by date. The first condition allows an easier reallocation of products for human or animal consumption while the last involves a more complex management ensuring an immediate recovery for human or animal consumption or the discard of products. Another cost involved with the food losses is the inventory cost sustained for unsold products which is proportional to the storage time and to the quantity of products stocked. Today the only way to reduce and sometimes to avoid the food surplus is the discount of the products when they come near the end of the SL; however such policy is adopted with caution because of the opportunistic consumer behavior arising from such practice (Garrone et al., 2012).

The recovery of food losses can contribute to reduce the aforementioned costs and profit loss and in some cases it can represent a source of gain for the retailer. In fact selling products at discounted price generally allows to cover the purchase costs while supplying for animal nutrition usually does not allow to cover such costs. In such context the supply of food losses to non-profit organizations can be seen as an alternative, since it allows to achieve social and economic benefits. The recent crisis has increased the attention of the economical actors to pursuing of humanitarian purposes for the improving of undernourished people conditions, pushing the government to recognize the importance of food recovery for human consumption primarily. Several laws aiming at improving the practice of the food donation are available by the last decades: among them, the most important is that of the Bill Emerson Good Samaritan food donation act P.L. 104–210 of 1996 issued in the USA, which makes the recipient equal to the final consumer thus holding harmless the donors for further liability about the safety of food donated. Concerning the economic benefits of the donation, they are mostly related to the fiscal deductions recognized to donors. In the USA for example the tax Reform Act of 1976 (Section 170), enhanced by the US Congress on 2012 permits a deduction for inventories donations allowing the taxpayers making donation to charitable organizations to deduct the basis cost plus half of the profit that would have been recognized if the inventory had been sold at its fair market value on the date of contribution. However, the deduction may not exceed two times the taxpayer's basis in the contributed property (Quickbriefs Retail & Consumer, 2012). In the United Kingdom it has been recently proposed (2012) a bill very similar to the Good Samaritan food donation act. Such bill would have encouraged food retailers and manufacturers to donate their food surplus to homeless charities and, if food is unfit for human consumption, to make it available for livestock feed in preference over disposal. However the British Retail Consortium underlined that retailers and producers already see waste reduction as one of their corporate social responsibility objectives and that in the UK, only 6% of food waste is produced at the supply chain; the vast majority (over 50%) comes from households themselves. In Australia the Wrongs and Other Acts (Public Liability Insurance Reform) Act 2002, offers protection to food donors as long as certain pre-conditions are in place: the food is donated in good faith for a charitable or benevolent purpose, the food is donated with the intention that the receiver of the food does not have to pay for the food, the food is safe to eat when it leaves the possession or control of the donor, and the donor gives the charity any information it needs to have to ensure the ongoing safety of the food. In Italy the food donation liability is governed as well by the Good Samaritan Law (receipt by means of the Law 155/03) and the deductions recognized to donors are regulated by the Law 80 of 14/05/2005 and the Legislative Decree 460/97. The Law 80 of 14/05/2005 allows to deduct the value of the donated food in reason of the 10% of the total income declared by the donor for the period of contribution or for a maximum of 70,000€. The Legislative Decree 460/97 recognizes a deduction of 5 per 1000 of the gross salary of a worker employed for services provided to non-profit organizations for the food recovery. The same Legislative Decree establishes that the free donations of food are not subject to the sales tax (e.g. Value Added Tax for Anglophone countries). Such deductions are not equally recognized overall in the world as in fact in several countries there is a controversial discussion about the specific legislation for the food donation (Schneider, 2013).

Other benefits besides the deductions are recognizable in the reduction of disposal cost (when it is a variable one) and the storage cost. There is also a benefit which is not of economical kind but relates to the reputation of the donor engaged in humanitarian actions. This can increase the consumer fidelity and further improve the profit achieved.

Some benefits in the food recovery can be recognized also to recipients (non-profit organizations) as the reduction of the quantity of food bought for the sustaining of undernourished people and the ameliorating of the quality of diet proposed, or the use of the money saved to enhance other offers to the assisted people (Schneider, 2013).

The costs due to the food recovery mainly relate to the transport of the recovered food to the final destination (farm, processing firms or charity organizations) and the management of the food recovery which in the case of donation to charity organizations is related both to donors and recipients. Such cost can be considered proportional to the quantity recovered.

The effectiveness of the food recovery strategy is related to the proper time of withdrawing the food from shelves and send it to the alternative destination.

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

4.1. Background

Food Supply chain optimization is a well-established research field. Paksoy et al. (2012), addressed the problem of transport cost function minimization using fuzzy sets to integrate the supply chain network composed by supplier, manufacturer and warehouse managing edible vegetable oil. Mohan et al. (2013), dealt with a non-profit supply chain by analysing the tactical and operational strategies deployed by such supply chain in order to face the problem of food insecurity. They focused on the importance of the planning phase for food reclamation centers as a driver for good performance of the supply chain itself and simulated the different operations of reclamation centers taking into account the uncertainty of the process times. Chung and Erhun (2011), proposed a contract model for the supply chain coordination taking into account the age of the products in order to maximize the total profit of the coordinated chain composed by a supplier and a buyer.

Cho et al. (2011), studied the problem of sub-optimization caused by decentralized decision making over the various entities of the chain. They proposed a combined quantity discount contract based on a revenue sharing contract, to coordinate a multi-echelon supply chain facing a stochastic customer demand. Govindan et al. (2012), proposed a profit model optimization for a two echelon supply chain coordination where the inventory risk can be devised between suppliers and retailers. Wang and Lee (2012), faced the problem of perishable food waste generated from inappropriate quality control and excessive inventories and proposed a dynamic pricing approach based on identified food SL. They show that such an approach can reduce food spoilage waste and maximize food retailer's profit. Duan and Liao (2013), considered a model for the optimization of replenishment policies for a supply chain operating under two different control strategies (decentralized vs. centralized) taking into account different scenarios of market demand and the two different strategies by means of a design of experiments.

The research on supply chain models optimization shows a lack of quantitative models for the optimization of food supply chain enabling the food recovery. The present paper aims at overcoming such gap by presenting a mathematic model aiming at demonstrating that the retailers profit can be optimized by means of a food recovery strategy and such profit outperforms that in absence of such system. The model will be discussed in the sub section 4.2.

4.2. Model formulation

The proposed model addresses the supply chain optimization in the case in which the food recovery is operated by the retailing stage towards the potential recipients represented by non-profit organizations and livestock market. As discussed before, the food recovery in such stage is rarely practiced causing the true benefits achievable are scarcely considered and known. On the contrary the presence of food losses in such stage is noticeable and the "ready to eat" nature of such products can simplify the operational efforts required to the non-profit organizations for cooking of the food. A mathematical model of the supply chain studied is presented, which aims at determining the optimal time to withdraw the products from the shelves and the quantity to be shipped to each alternative destination on the basis of the already mentioned "Waste Management Hierarchy". The determination of the optimal time is based on the assumption that the residual market demand will not be satisfied. Concerning the calculation of benefits the model is referred to the Italian governmental regulations. The proposed model considers a deterministic time-dependent demand which is a common hypothesis for deteriorating products as food (see for example Sana and Chaudhuri, 2003, Alexander and Smaje, 2008, Kumar et al., 2010, Singh et al., 2011, Mishra and Sing, 2011, Saha and Chakrabarti, 2012, Singh and Pattanayak, 2012, Sharma and Chaudhary, 2013) even if several studies can be reported on stochastic demand behavior for perishable products (see for example Chiu, 1995, Aggoun et al., 2001, Halim et al., 2008, Chung et al., 2009). For the purpose of the present work, the assumption of deterministic demand is optimistic, since it involves that no safety stock is held, making the level of food losses less than in the case of stochastic demand. This means that the optimal values arisen from the deterministic model can be considered as lower bounds of the values in the stochastic case. In particular the demand faced by the retailer is supposed to be 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 best before date" or the "use by date" of the product and it is also deterministic and constant. In fact generally the products present at the retailing are discarded once one of such dates is achieved. In this case the products are considered to be fit for human consumption until the reach their SL (Nahmias, 1982). Such an assumption can be considered restrictive as several products can be considered still fit for human consumption also after the ending of their expiration date (especially those marked with "use best before"), however we do not mean to enter in such detail, therefore we prefer not to consider the donation of expired products. The model is focused on Italian regulations but despite this it can be considered as generally applicable, since the only revenue function related to Italian regulations is that of tax saving and deductions recognized to donors. Moreover even if the model relates to the retail stage it can be simply adapted to other stages of the channel as the cost/revenue functions are actually of general kind.

4.2.1. Assumptions and notation

The model formulation will be carried out under the following assumptions and notation:

- The model deals with a supply chain composed by a retailer, the livestock market and a non-profit organization,
- The product portfolio is composed by k products,
- SL_k is the SL of the kth product,
- $D_k(t)$ is the market demand of the kth product linearly decreasing with the SL_k. It is independent from the market price,
- T is the time horizon,
- Q_k is the total quantity of product k managed by the retailer during T,
- q_k is the quantity of food losses of product k generated at the retailer stage during T,
- K_k is the price of a unit of the kth product whose weight is one kg, it is the price of the product for the consumer in the target market. It is constant and independent from the SL,
- I is the tax rate,
- G is the gross salary of an employee involved in the recovery food at the retailer,
- s_k is the quantity of product k which is donated to the organization from the retailer,
- ρ_1 is the percentage of food losses which is not fit for human consumption, but still fit for animal consumption. It is considered to be constant,
- ρ_2 is the percentage of edible food losses which is yet fit for human consumption. It is considered to be constant,
- a_k is the quantity of product k purchased by the non-profit organization, corresponding to the maximum stock capacity, thus it is hypothesized that the amount of food donation does not exceed the capacity of the charity organization,
- FE_k is the food expenditure of the non–profit organization for the product k. This is consistent with our experience with Italian charity organizations which not only rely on food donations but are also prone to buy food for needing people,
- Y is the value of the food donated,
- R is the total income of the retailer during the time horizon T,
- VAT is the Value Added Tax,
- h_k is the holding cost per unit time for the kth product,
- d_c is the disposal cost of products per kg. It is an average cost including also products needing pre-treatments,
- $g_{r,k}$ is the unit management cost of food losses incurred by the retailer, due to collection, visual inspection and selection of food recovered,
- $g_{o,k}$ is the unit management cost of food losses incurred by the non-profit organization,
- The livestock market has an unlimited stock capacity,
- SL_k^* is the time to withdraw the kth product from the shelves; it is a variable which must be optimized,
- It is supposed that a product is posed on the shelf immediately after its arrival meaning that the consumed SL at the time of the exposition is null,
- $0 \leqslant w_1 \leqslant 1$ and $0 \leqslant w_2 \leqslant 1$ are two parameters representing a percentage of the K_k,
- Economies of scale due to reduction of the management costs with quantities donated are neglected. Thus the management costs for both retailers and non-profit organizations are proportional to the quantities recovered.

The boundary conditions are $D(t = 0) = D(0)_k$ *and* $D(t = SL) = 0$. Given this the demand $D_k(t)$ for a product having a lifetime SL_k is equal to:

$$D_k(t) = D(0)_k - \frac{D(0)_k * t}{SL_k} = \frac{D(0)_k}{SL_k} * (SL_k - t) \quad \forall k \tag{1}$$

where $t = 0$ represents the instant in which the product k is located into the shelf. Under the hypothesis of deterministic demand, the inventory level $Q_k(t)$ is governed by the following equation:

$$\frac{dQ_k(t)}{dt} = -D_k(t) \quad 0 \leqslant t \leqslant SL_k, \ \forall k \tag{2}$$

Eq. (2) states that the inventory depletion is due to the incoming market demand during the SL_k. It does not take into account the deterioration rate as the SL of the products considered is assumed deterministic and constant. The products are also assumed to maintain the same nutritional and safety standards within their SL. In such conditions their deterioration rate is null until the end of their SL is reached, when they are considered completely deteriorated and consequently discarded. Integrating Eq. (2) we obtain:

$$Q_k(t) = -D(0)_k t + \frac{D(0)_k}{SL_k}\frac{t^2}{2} + c \tag{3}$$

Subject to the conditions:

$$Q_k(0) = Q_k \tag{4}$$

and

$$Q_k(SL_k) = 0 \tag{5}$$

Solving (3) by using (4) and (5) we obtain:

$$Q_k = \frac{D(0)_k * SL_k}{2} \quad \forall k \tag{6}$$

Thus the total quantity of product k managed by the retailer during the time horizon T is:

$$Q_k' = \frac{T}{SL_k} * Q_k = \frac{T * D(0)_k}{2} \quad \forall k \tag{7}$$

The quantity q_k can be determined as the difference of the quantity Q_k' and the quantity of products sold until SL_k^*:

$$q_k = Q'_k - \left[\frac{T}{SL_k} * \int_{t=0}^{SL_k^*} D_k(t)dt\right]$$
$$= Q'_k - \left\{\frac{T}{SL_k} * \left[D(0)_k * SL_k^* * \left[1 - \frac{SL_k^*}{2SL_k}\right]\right]\right\} \quad \forall k \tag{8}$$

We further distinguish two cases, the first case deals with the supply chain profit in the case of food recovery while the second with the supply chain profit in absence of such system.

4.2.2. The model in presence of food recovery

The Function Π_s representing the Total Profit of the system can be expressed as:

$$\Pi_s = (\Pi_r + \Pi_o) \tag{9}$$

where Π_r is the total profit of the retailer and Π_o is the total profit of the non-profit organization.

$$\Pi_r = R_r - C_r \tag{10}$$

where R_r andC_r are the Total Revenue and the Total Cost of the retailer.

Following the "Waste Management Hierarchy" the Total Revenue R_r of the retailer is calculated as the sum R_{r1} due to products sold between $t = 0$ and $t = SL_k^*$, R_{r2} being the revenue due to benefits recognized to donors from the Italian governmental regulations, R_{r3} equal to the revenue deriving from the quantity of surplus food not supplied to non-profit organizations and, if possible, sold at the livestock market as animal feeding, and the R_{r4} equal to the storage cost saving for the food recovered.

The Total Revenue R_{r1} due to the products sold is expressed as:

$$R_{r1} = \sum_{k=1}^{q}\left\{K_k * \left[\frac{T}{SL_k} * \left(\int_{t=0}^{SL_k^*} D_k(t)dt\right)\right]\right\}$$
$$= \sum_{k=1}^{q}\left\{K_k * \left\{\frac{T}{SL_k} * \frac{D(0)_k}{SL_k}\left[SL_k SL_k^* - \frac{SL_k^{*2}}{2}\right]\right\}\right\} \tag{11}$$

The revenue R_{r2} due to the deduction recognized to donors is:

$$R_{r2} = 0.005 * G + Y * I + \sum_{k=1}^{q} C_k * s_k * VAT \tag{12}$$

where

- the quantity $0.005 * G$ is the deduction recognized to donors from the Legislative Decree 460/97;
- based upon the Law of the 14/05/2005 the quantity donated $Y * I$ can be entirely deducted until reaching 70,000€, as follows:

$$Y = \sum_{k=1}^{q} k_k * s_k \quad \text{if } Y \leqslant 0.1 * R < 70,000€ \tag{13}$$
$$Y = 70,000€ \quad \text{otherwise} \tag{14}$$

Thus the quantity $Y_i * I$ is the total tax saving recognized to the donor.

- $\sum_{k=1}^{q} C_k * s_k * VAT$ relates to the Legislative Decree 460/97 which recognizes that the food donated is not subject to the VAT. The Legislative Decree prescribes that the tax saving for the donor is calculated on the basis of the unit purchasing cost C_k of the quantity donated s_k. It is assumed that C_k is a fraction of the price K_k:

$$C_k = K_k * w_1 \tag{15}$$

- the quantity donated s_k of the product k is equal to:

$$s_k = q_k * \rho_1 * \rho_2 \quad \text{if } q_k * \rho_1 * \rho_2 < a_k \quad \forall k \tag{16}$$
$$s_k = a_k \quad \text{if } q_k * \rho_1 * \rho_2 \geqslant a_k \quad \forall k \tag{17}$$

Eq. (12) says that the total deduction recognized can be considered as additional revenue for the donor.

The revenue R_{r3} due to the products sold at the livestock market is:

$$R_{r3} = \sum_{k=1}^{q} pz_k * (\rho_1 * q_k - s_k) * y_k \tag{18}$$

where

- pz_k is the price of a unit of product k at the livestock market equal to a fraction of the price K_k:

$$pz_k = K_k * w_2 \tag{19}$$

- y_k is an integer binary parameter equal to 1 if the product k can be sold at the livestock market and 0 otherwise.

The revenue R_{r4} due to the storage cost saved due to food recovery of the kth product withdrawn from the shelves can be calculated by starting from Eq. (3) and determining the inventory holding cost between SL_k^* and SL_k:

$$R_{r4} = \sum_{k=1}^{q}\left\{h_k * \frac{T}{SL_k} * \int_{SL_k^*}^{SL_k} Q_k(t)dt\right\}$$
$$= \sum_{k=1}^{q}\left\{h_k * \frac{T}{SL_k} * \left[\frac{D(0)_k * SL_k^2}{3} - \frac{D(0)_k * SL_k^{*2}}{2} * \left(1 - \frac{SL_k^*}{3SL_k}\right)\right]\right\} \tag{20}$$

The Total Revenue of the retailer can thus be expressed as:

$$R_r = R_{r1} + R_{r2} + R_{r3} + R_{r4} \tag{21}$$

The Total Cost C_r for the retailer is determined as the sum of the cost C_{r1} due to the disposal of not edible surplus food, C_{r2} due to the loss profit of products withdrawn from the shelves at SL_k^*, the cost C_{r3} related to the food surplus management in the store (mainly due to recovery operations and temporary storage of products) and the holding cost C_{r4} of the products stored.

The Total Disposal cost C_{r1} is equal to:

$$C_{r1} = \sum_{k=1}^{q}\{d_c * [(1 - \rho_1) * q_k] + d_c * [(\rho_1 * q_k - s_k) * (1 - y_k)]\} \tag{22}$$

Eq. (22) says that the quantity of surplus food disposed is equal to the food unfit for human or animal consumption plus the food which is fit for animal consumption but not requested by the livestock market.

The cost C_{r2} of the Total Loss Profit for products withdrawn from the shelves at SL_k^* corresponding to the value of the lost market demand can be expressed as:

$$C_{r2} = \sum_{k=1}^{q}\left\{K_k * \frac{T}{SL_k} * \int_{SL_k^*}^{SL_k} D_k(t)dt\right\}$$
$$= \sum_{k=1}^{q}\left\{K_k * \frac{T}{SL_k} * \left[\frac{D(0)_k * SL_k}{2} - D(0)_k * SL_k^* * \left(1 - \frac{SL_k^*}{2SL_k}\right)\right]\right\} \tag{23}$$

The Total Cost C_{r3} of food surplus management is:

$$C_{r3} = \sum_{k=1}^{q} g_{r,k} * s_k \tag{24}$$

The Total Inventory Holding Cost C_{r4} between $t = 0$ and SL_k^* is:

$$C_{r4} = \sum_{k=1}^{q}\left\{h_k * \frac{T}{SL_k} * \int_{0}^{SL_k^*} Q_k(t)dt\right\}$$
$$= \sum_{k=1}^{q}\left\{h_k * \frac{T}{SL_k} * \left[\frac{D(0)_k * SL_k^{*2}}{2} * \left(1 - \frac{SL_k^*}{3SL_k}\right)\right]\right\} \tag{25}$$

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The Total Cost for the ith retailer is:

$$C_r = C_{r1} + C_{r2} + C_{r3} + C_{r4} \tag{26}$$

The Total Profit of the non-profit organization is:

$$\Pi_o = -R_o - C_o \tag{27}$$

where R_o and C_o are the revenue and the cost of the non-profit organization collaborating the food recovery. The revenue relates to the possible cost saving due to food received while the cost is related to the management of the food received into the organization.

$$R_o = -\sum_{k=1}^{q}(FE_k - s_k * K_k) \tag{28}$$

where

$$FE_k = K_k * a_k \quad \forall k \tag{29}$$

Eq. (28) says that R_o corresponds to the difference between the food expenditure usually sustained by the organization and the value of the quantity of product received by means of the food donation. Such value is null if the food donated equals the food expenditure and negative if the food donated is less than the food expenditure. In this case R_o corresponds to the residual cost sustained by the organization for food purchasing. Such position is consistent with our experience with Italian charity organizations which usually buy additional food with the savings or use the money to enhance other offers to their clients. Similar experiences are reported in the literature like for example that mentioned by Schneider (2013), related to food recovery in Germany.

$$C_o = \sum_{k=1}^{q}(g_{o,k} * s_k) \tag{30}$$

The profit function of the system is subject to the constraint:

$$0 \leqslant SL_k^* \leqslant SL_k \tag{31}$$

4.2.3. The model in absence of food recovery

In the case in which the supply chain does not rely on food recovery the total profit of the supply chain is determined as follows:

$$\widehat{\Pi}_s = \widehat{\Pi}_r \tag{32}$$

where $\widehat{\Pi}_r$ has the same meaning of Eq. (10).

In such case the Total Profit corresponds to the total profit of the retailer. Such quantity is constant and independent from SL_k.

The Total Revenue R_{rr} of the retailer is determined as:

$$\widehat{R_r} = \sum_{k=1}^{q}\left\{K_k * \left[\frac{T}{SL_k} * \left(\int_{t=0}^{SL_k} D_k(t)dt\right)\right]\right\} = \sum_{k=1}^{q} K_k * Q'_k \tag{33}$$

The Total Cost C_r corresponds to the Total Inventory Holding Cost between $t = 0$ and SL_k determined as:

$$\widehat{C_r} = \sum_{k=1}^{q}\left\{h_k * \frac{T}{SL_k} * \int_0^{SL_k} Q_k(t)dt\right\} = \sum_{k=1}^{q}\left\{h_k * \frac{T}{SL_k} * \left[\frac{D(0)_k * SL_k^2}{3}\right]\right\} \tag{34}$$

The total profit of the non-profit organizations is negative and equal to the sum of food expenditure as in Eq. (29).

4.2.4. Profit function analysis

For the purpose of the present study it is assumed that the retailer optimizes its profit function (10) by determining the optimal time to withdraw the products from the shelves and the quantities to sell or donate to the alternative destinations. The possible cost saving of the non-profit organization (28) and the profit function of the system (9) are consequently determined. The profit function of the retailer has been studied taking into account that the quantity donated and the deductions can alternatively be depending from the SL_k^* or be constant on the basis of Eqs. (13) and (14) and that the tax saving can be also dependent on s_k or constant as in Eqs. (16) and (17). The first derivative of Eq. (10) is:

$$\frac{d\Pi_r}{dSL_k^*} = -2h_k * SL_k^* * \left(\frac{2SL_k - SL_k^*}{2(SL_k - SL_k^*)}\right) + \varepsilon = 0 \tag{35}$$

$$h_k * SL_k^{*2} - SL_k^*(2h_kSL_k + \varepsilon) + SL_k\varepsilon = 0 \tag{36}$$

$$SL_k - SL_k^* \neq 0 \quad SL_k \neq SL_k^* \tag{37}$$

and

$$SL_k^* < SL_k \tag{38}$$

It can be easily proven that $\Delta = 4h_k^2SL_k^2 + \varepsilon^2 > 0$ meaning that there exist two real and distinct roots which must be compared with position (38).

First case: Eqs. (13) and (16) are verified.

In such case

$$\varepsilon = 2K_k - K_k * w_1 * \rho_1 * \rho_2 * VAT - K_k * w_2 * \rho_1 * (1-\rho_2) * y_k + d_c * (1-\rho_1) + d_c * \rho_1 * [(1-\rho_2) * (1-y_k)] + g_k * \rho_1 * \rho_2 \tag{39}$$

Second case: Eqs. (13) and (17) are verified.

In such case

$$\varepsilon = 2K_k - K_k * w_1 * \rho_1 * \rho_2 * VAT - K_k * w_2 * \rho_1 * (1-\rho_2) * y_k + d_c * (1-\rho_1) + d_c * \rho_1 * [(1-\rho_2) * (1-y_k)] + g_k * \rho_1 * \rho_2 \tag{40}$$

Third case: Eqs. (14) and (16) are verified.

In such case

$$\varepsilon = 2K_k - K_k * \rho_1 * \rho_2 * I - K_k * w_2 * \rho_1 * y_k + d_c * (1-\rho_1) + d_c * \rho_1 * (1-y_k) \tag{41}$$

Fourth case: Eqs. (14) and (17) are verified

In such case

$$\varepsilon = 2K_k - K_k * w_2 * \rho_1 * y_k + d_c * (1-\rho_1) + d_c * \rho_1 * (1-y_k) \tag{42}$$

In all cases the solutions are:

$$SL_k^* = \frac{2h_kSL_k + \varepsilon \pm \sqrt{4h_k^2SL_k^2 + \varepsilon^2}}{2h_k} \tag{43}$$

Being $\Delta > 0$ and $2h_k > 0$, $\frac{d\Pi_i}{dSL_k^*} > 0$ for $SL_k^* < \frac{2h_kSL_k+\varepsilon-\sqrt{4h_k^2SL_k^2+\varepsilon^2}}{2h_k}$ or $SL_k^* > \frac{2h_kSL_k+\varepsilon+\sqrt{4h_k^2SL_k^2+\varepsilon^2}}{2h_k}$ and $\frac{d\Pi_r}{dSL_k^*} < 0$ for $\frac{2h_kSL_k+\varepsilon-\sqrt{4h_k^2SL_k^2+\varepsilon^2}}{2h_k} < SL_k^* < \frac{2h_kSL_k+\varepsilon+\sqrt{4h_k^2SL_k^2+\varepsilon^2}}{2h_k}$. This means that the negative root corresponds to a relative maximum while the positive root to a relative minimum which cannot be accepted as it violates (38).

The two profit functions (10) and (32) have been further analysed in order to show the conditions making profitable the food recovery for the retailer to respect to the case in absence of such system. For such purpose the following position has been considered:

$$\Pi_r \geqslant \widehat{\Pi}_r \tag{44}$$

Being the profit in absence of food recovery a constant quantity, the optimality conditions of (44) are the same of the retailer profit function (10).

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4.2.5. The numerical application

In this section a numerical case illustrating the model discussed in the sub-Sections 4.2.1, 4.2.2, 4.2.3, and 4.2.4is presented. The case study has been performed by considering a supply chain with 1 retailer, 1 non-profit organization, a livestock market and a product portfolio of 10 products. The products sample considered is: 1. Frozen, 2. Dairy products 3. Canned meat, 4. Canned fruits, 5. Canned tomato sauce, 6. Canned vegetables, 7. Cold cuts (enveloped), 8. Bread for toasting, 9. Biscuits, and 10. Pasta. The products are expressed in unit whose weight is 1 kg. The input parameters are: $T = 360$ days, $\rho_1 = 0.94$, $\rho_2 = 0.90$, (deduced by Alexander and Smaje (2008), $I = 58\%$, (current fiscal burden as found in Cattani and Carrarese (2011), $VAT = 21\%$ (current value of the VAT in Italy), $h_k = 0.02$ €/unit * *unit time*, $g_{r,k} = g_{o,k} = 0.01$€/unit, $dc = 0.15$€/kg, $G = 25{,}000$€, $Y = 70{,}000$€. The SL_k and the selling prices K_k are reported in Table 1. The $D_k(0)$ is the same for all products and equal to 100 units, $w_1 = 0.6$, $w_2 = 0.3$. The annual value of R for the retailer is 1,500,000€ and the annual food expenditure of the non-profit organization is 14,675€ while the request a_k of products of the non-profit organization is also reported in Table 1 as well as the values of y_k. The livestock market demand is considered unlimited. All the value considered are consistent with actual current value in Italian market.

The quantity Q_k' has been determined by starting from Eq. (7) meaning that the quantity stored by the retailer is equivalent to the market demand. Such assumption is actually optimistic since usually the retailers tend to store a higher quantity of food to face the demand variability and for image reasons (full shelves) or in dependence of strategic decisions. The results consisting in the retailer profit, the non-profit organization cost saving and the system profit in the two cases of food recovery and absence of such system have been obtained by means of the Microsoft Excel Solver Tool and are summarized in Tables 2.

Table 2 shows that the profit is higher in presence of food recovery than in absence of such option. Such results are confirmed even for the profit of the single actor (retailer and non-profit organization). In particular the non-profit organization can achieve a cost saving in the food expenditure due to the quantity donated.

Table 3 reports the SL_k^* values corresponding to the time to realize the alternative management of the surplus food in the case of food recovery, the total food losses, the quantity donated, that sold at the livestock market and that disposed to landfill. The results reported in such table show that the 44.13% of food losses is donated to the non-profit organization, the 28.69% is sold at the livestock market and the 27.18% is disposed through the usual channel, namely the landfill.

The profit function of the retailer in the two cases of the food recovery and no food recovery adoption for the product 4 is illustrated in Fig. 1.

Fig. 1. Representation of the profit function for both recovery and no recovery strategy.

Table 1
Input data.

Product	SL_k (Days)	K_k (€/unit)	a_k (unit)	y_k
1	80	8	0	1
2	60	16	200	0
3	50	10	200	0
4	55	3	450	1
5	65	2	0	1
6	75	5	350	0
7	45	35	150	1
8	60	4	150	0
9	75	5	0	1
10	55	1.5	350	0

Table 2
Total Profit of the system and that of the single actors.

	Retailer Profit	Non-profit Organization Profit	System Profit
Food recovery	1,500,914	−8407	1,492,507
No food recovery	1,462,200	−14,675	1,476,675

Table 3
Output of the profit model.

Product	SL_k^* (*Days*)	Food losses (units)	Quantity donated (units)	Quantity sold at the livestock market (units)	Quantity disposed to landfill (units)
1	70	281	0	264	17
2	56	80	68	0	12
3	46	115	97	0	18
4	43	856	450	355	51
5	43	2062	0	1938	124
6	63	461	350	0	111
7	45	0	0	0	0
8	51	405	150	0	255
9	62	540	0	508	32
10	37	1928	350	0	1578

Such figure confirms that the optimal time SL_k^* allows to maximize the profit function of the retailer also compared to the case in absence of food recovery. It also shows how each profit/cost function influences the final result. In particular, if a variation of the market price for animal feed (which is subject to the supply and demand of feed grain) occurs, the related revenue function R_{i3} would become more or less steep, and the influence on the optimal SL_k^* value can be obtained. For example, in the case presented, if the price for animal feed drops significantly, and the corresponding revenue becomes negligible, the corresponding SL_k value increases of 0.3%. This is a consequence of the fact that the non-edible part of the food recovered is generally small, and the corresponding profit curve is flat near to the optimum value.

4.2.6. The sensitivity analysis

In this section a sensitivity analysis is proposed to investigate the impact of the variation of the monetary input factors on the optimal solution. In particular a full experimental plan having four factors varying on two levels consisting of 16 configurations has been considered as shown in Table 4. The variation of the input factors by moving from the low level to the high level is of 10%. The input data are referred to the product 4 of the sample considered in the Section 4.2.5.

For each configuration of the experimental plan the optimal SL_k^* and the Π_r in presence of food recovery have been determined through the model proposed in the Section 4.2.2. They represent the response variables of the experimental plan. The results of the experimental plan are illustrated in Table 5.

Table 5 shows that the SL_k^* does not change substantially as the input factors move from their low level to their high level thus confirming the robustness of the solution found through the model proposed. In fact, the percentual difference between maximum and minimum values (respectively configuration 6 and 3 of the experimental plan) is only of 2,7%. The same Table shows the overall impact of the variation of the input factors on the Π_r. In this case the impact is more significant as the percentual difference between maximum and minimum values (respectively configuration 6 and 7 of the experimental plan) is of 10.5%.

Thus the Factorial analysis and the ANOVA analysis have been conducted to investigate the impact of the single input factors on the optimal values of the response variables. Results are shown in Tables 6–9.

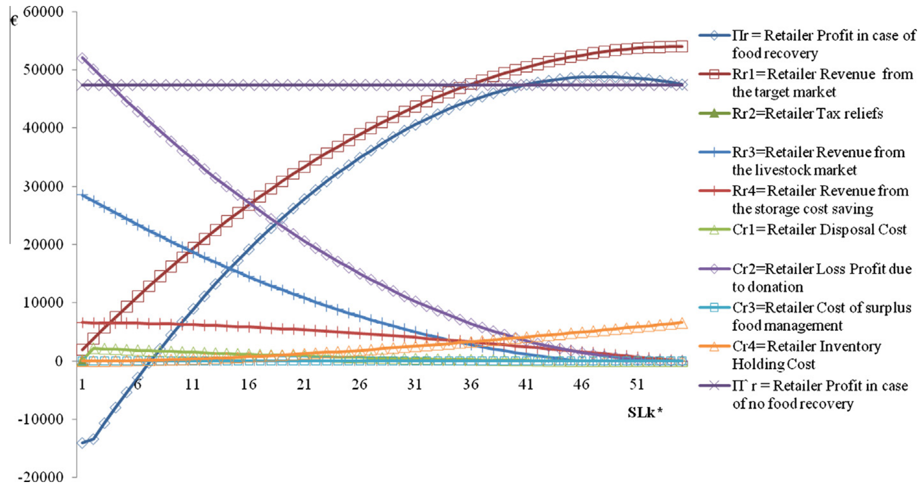

Fig. 1. Representation of the profit function for both recovery and no recovery strategy.

Table 4
Input factors of the experimental plan.

	Low level	High level
k_k	3	3.3
h_k	0.01	0.011
d_c	0.15	0.165
$g_{r,k}$	0.01	0.011

Results reported in Tables 6 and 8 show that the factors mainly influencing the SL_K^* and the Π_r are the market price and the holding cost. The former contributes to increase both the SL_K^* and the Π_r while the latter contributes to decrease such optimal values. This means that the food recovery is encouraged by low prices and high holding costs. The disposal and the management cost do not have any impact on the response variables SL_K^* and Π_r. The ANOVA analysis shown in Tables 7 and 9 underlines that the main factors are responsible for the overall variance of the response variables. This means that the two way interactions between the main factors can be neglected.

A comparison of the numerical results of the model presented with other mathematical models could have highlighted the significance of the results obtained and provide further suggestions. However the literature analysis has not allowed to find quantitative models addressing the topic of supply chain optimization based on food recovery. This is actually a limitation of the present study which could be overcome as the research in such field will progress in the following years.

Table 5
Results of the experimental plan: optimal SL_k^* and Π_r for each of the 16 configurations.

Configuration	k_k	h_k	d_c	$g_{r,k}$	SL_k^*	Π_r
1	3	0.01	0.15	0.01	47.819814	48824.821
2	3.3	0.01	0.15	0.01	48.45092	54109.429
3	3	0.011	0.15	0.01	47.129439	48434.072
4	3.3	0.011	0.15	0.01	47.817171	53695.339
5	3	0.01	0.165	0.01	47.821321	48824.545
6	3.3	0.01	0.165	0.01	48.452178	54109.199
7	3	0.011	0.165	0.01	47.131081	48433.74
8	3.3	0.011	0.165	0.01	47.818542	53695.063
9	3	0.01	0.15	0.011	47.82123	48824.562
10	3.3	0.01	0.15	0.011	48.452102	54109.213
11	3	0.011	0.15	0.011	47.130983	48433.76
12	3.3	0.011	0.15	0.011	47.81846	53695.08
13	3	0.01	0.165	0.011	47.822737	48824.286
14	3.3	0.01	0.165	0.011	48.453359	54108.983
15	3	0.011	0.165	0.011	47.132624	48433.428
16	3.3	0.011	0.165	0.011	47.819831	53694.804

Table 6
Factorial analysis on the optimal SL_k^*.

Factorial analysis SL_k^*			
Term	Effect	Coef	P
Constant		47.8057	0
k_k	0.6592	0.3296	0
h_k	−0.6619	−0.331	0
d_c	0.0014	0.0007	0.869
$g_{r,k}$	0.0014	0.0007	0.877

Table 7
ANOVA analysis on the optimal SL_k^*.

ANOVA analysis SL_k^*			
Source	DF	Seq SS	P
Main effects	4	3.49068	0
Residual error	11	0.0032	
Total	15	3.49389	

Table 8
Factorial Analysis on the optimal retailer profit.

Factorial analysis optimal retailer profit			
Term	Effect	Coef	P
Constant		51265.6	0
k_k	5273	2636.5	0
h_k	−402.5	−201.2	0
d_c	−0.3	−0.1	0.938
$g_{r,k}$	−0.3	−0.1	0.942

Table 9
ANOVA Analysis on the optimal Retailer Profit.

ANOVA analysis optimal retailer profit			
Source	4	111,865,485	0
Main effects	11	544	
Residual error	15	111,866,030	
Total	4	111,865,485	0

Finally the applicability of the presented model strongly relies on the use of an automated warehouse management system in which information about the use by date or best before date is available as well as the information about the optimal SL_k^*.

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However the optimization of such a system by means of manual inspection of shelves is scarcely practicable. In such context new pervasive and non-invasive technologies such as the Radio Frequency Identification (RFID) allowing the fast localization of the product that have to be withdrawn can be seen as enabling the proposed model.

5. Conclusions

This study deals with the topic of food recovery, which is nowadays a critical treat to the sustainability of agrifood chains. The problem has been faced from an economic standpoint by formalizing a mathematical model for the optimization of the retailer profit function including tax reliefs recognized to donors. The model has been carried out by considering a deterministic market demand linearly decreasing with the SL of the products. The practical relevance of the methodology proposed falls in the field of decision making for the supply chain actors. In fact the model allows to determine the optimum residual SL when products should be withdrawn from the target market and redirected towards alternative uses and destinations (non-profit organizations, livestock market, etc.) and the quantity of products to be redirected in order to maximize the retailer profits and the economic benefits. Its applicability mainly concerns the retail stage even if it can also be simply extended to the other stages of the supply chain as the cost/revenue functions are generally common to all the supply chain stages. The model also takes into account the loss of profit due to the early withdrawal of products. However such loss could be avoided by optimizing the time of arrival of products on the basis of SL_k^*. The results show that the food recovery strategy allows the retailer to achieve a greater profit respect to the case in absence of such strategy. The sensitivity analysis carried out through an experimental plan underlines that the optimal solutions (SL_K^* and Π_r) are robust for a variation of the input factors of the 10%. Although the model proposed focuses on the Italy country it is of general applicability as in fact the only revenue function specifically related to Italian regulations is the revenue due to tax saving and deductions recognized to donors, which can be simply adapted to the regulation of other countries. In this sense the model proposed is generally applicable. However, the model does not take into account the effects of the uncertainty factors on the optimality conditions. In such context further studies could address the stochastic behavior of the market demand and the SL. This should make the optimal time for the products withdrawal also a stochastic variable which however should increase the entity of food losses due to the safety stock. Moreover, the study of policies making attractive for the retailers to donate food losses should also be investigated by determining the optimal policy of incentives and penalty schemes for the achievement of a common benefit (supply chain coordination), leading to better results as compared to policy of fiscal donations.

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Please cite this article in press as: Giuseppe, A., et al. Economic benefits from food recovery at the retail stage: An application to Italian food chains. Waste Management (2014), http://dx.doi.org/10.1016/j.wasman.2014.02.018